INMATEH – AGRICULTURAL ENGINEERING

MAY - AUGUST
Editorial

The National Institute of Research Development for Machines and Installations designed to Agriculture and Food Industry - INMA Bucharest has the oldest and most prestigious research activity in the field of agricultural machinery and mechanizing technologies in Romania.

Short History

- In 1927, the first research Center for Agricultural Machinery in Agricultural Research Institute of Romania - ICAR (Establishing Law was published in O.D. no. 97/05.05.1927) was established;
- In 1930, was founded The Testing Department of Agricultural Machinery and Tools by transforming Agricultural Research Centre of ICAR; that founded the science of methodologies and experimental techniques in the field (Decision no. 2000/1950 of ICAR Manager - GHEORGHE IONESCU ŞIȘEȘTI);
- In 1952, was established the Research Institute for Mechanization and Electrification of Agriculture - ICMA Băneasa, by transforming the Department of Agricultural Machines and Tools Testing;
- In 1979, the Research Institute of Scientific and Technological Engineering for Agricultural Machinery and Tools - ICSITMUA was founded - subordinated to Ministry of Machine Building Industry - MICM, by unifying ICMA subordinated to ICPMA and ICPMA subordinated to MICM;
- In 1996 the National Institute of Research Development for Machines and Installations designed to Agriculture and Food Industry - INMA was founded - according to G.D. no. 1308/25.11.1996, by reorganizing ICSITMUA, G.D. no. 1308/1996 coordinated by the Ministry of Education and Research G.D. no. 825/2004;
- In 2008 INMA has been accredited to carry out research and developing activities financed from public funds under G.D. no. 551/2007, Decision of the National Authority for Scientific Research - ANCS no. 9634/2008.

As a result of widening the spectrum of communication, dissemination and implementation of scientific research results, in 2000 was founded the institute magazine, issued under the name of SCIENTIFIC PAPERS (INMATEH), ISSN 1583 – 1019.

Starting with volume 30, no. 1/2010, the magazine changed its name to INMATEH – Agricultural Engineering, appearing both in print format (ISSN 2068-4215), and online (ISSN online: 2068-2239). The magazine is bilingual, being published in Romanian and English, with a rhythm of three issues/year: January–April, May–August, September–December and is recognized by CNCSIS – with B category. Published articles are from the field of AGRICULTURAL ENGINEERING: technologies and technical equipment for agriculture and food industry, ecological agriculture, renewable energy, machinery testing, environment, transport in agriculture etc. and are evaluated by specialists inside the country and abroad, in mentioned domains.

Technical level and performance processors, technology and machinery for agriculture and food industry increasing, according to national requirements and European and international regulations, as well as exploitation of renewable resources in terms of efficiency, life, health and environment protection represent essential elements for the magazine INMATEH – Agricultural Engineering.

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Abstract: This study comprises two structural analyses applications, having as subject the same structure, very common for agricultural machinery designed to tillage, namely a beam, [5], [7]. The two applications are made in well known CAD programs, each including its own structural analysis module: SolidWorks and Autodesk Inventor. The study aims to demonstrate the easiness with which the analysis is performed in either of the two programs, but especially, the way in which the results of the two analyses converge. The converged results are able to show, that the use of one or other of the programs is irrelevant, of course, in terms of the analysis modules, that both programs have. In this study it compares the performances in terms of linear static analysis (check the resistance) and the modal analysis (analysis in frequencies or calculating of a number of structure natural frequencies). It can be said that, the results obtained without doing an additional study of convergence and stability on meshing are satisfactory, possibly good enough in the case of the maximum equivalent stress in the structure.

Keywords: structural analysis, agricultural machinery, comparative solutions

INTRODUCTION

The geometric model is a tridimensional one made in CAD SolidWorks program and it was exported in Autodesk Inventor for analysis, for training. The beam thickness is set to 10 mm, the outer diameter of small holes situated at the top of the plate is 5 mm and the large hole has a diameter of 10 mm. Those three holes situated at the top of the shank forms a catching system of the beam on the portant structure of soil working machine. One of the holes with smaller diameter is pierced on the half of the beam thickness (5 mm), namely from the back of the beam.

The general calculus of resistance is mainly aimed to determine the equivalent stress field (structure is built entirely of metal) in the structure. It is noted, the extreme values and their locations, for possible consolidation, or in case of small requests in relation to the resistance capacity of the material, the shape optimization for weight reduction [1], [2], [3].

It is also important the determination, within the same resistance classic calculation of the relative displacement field (vector field with three components by the three axes). The resultant relative displacement is called strain in engineering language (not to be confused with specific strain, tensorial field calculated in linear theory as the gradient of the relative displacement).

Rezumat: Acest studiu cuprinde doua aplicatii de analiza structurala, avand ca subiect aceeasi structura destiinta de la utilitata la masinile agricole destinate lucrariilor solului, o bara, [5], [7]. Cele doua aplicatii sunt efectuate in programe CAD foarte cunoscute, fiecare incluzand modulul sau de analiza structurala: SolidWorks si Autodesk Inventor. Studiul urmareste sa demonstreze usorinta cu care analiza se efectueaza in oricare dintre cele doua programe, dar, mai ales, masura in care rezultatele celor doua analize converg. Rezultatele convergente sunt in masura sa arate ca utilizarea unuia sau altuia dintre programe este indiferenta, bineteles in ceea ce priveste modulele de analiza pe care le poseda ambele programe. In acest studiu performantele se compara in termenii analizei statice liniere (verificarea la rezistenta) si anlizei modale (analiza in frecvente sau calculul unui numar de frecvente proprii ale structurii). Se poate afirma ca rezultatele obtinute, fara a face un studiu suplimentar de convergenta si stabilitate pe discretizare, sunt satisfacatoare, eventual suficient de bune in cazul tensiunii echivalente maxime in structura.

Cuvinte cheie: analiza structurala, masini agricole, solutii comparative

INTRODUCERE

Modelul geometric este unul tridimensional, a fost creat in programul CAD SolidWorks si a fost exportat in Autodesk Inventor pentru analiza in scopul instruirii. Grosimea baresei este valoarea 10 mm, diametrul exterior al gaurilor mici de la partea superioara a placii este de 5 mm iar gaura mare este diametrul de 10 mm. Cele trei gauri de la partea superioara formeeaza un sistem de prindere al baresei la structura portanta a masinii de lucrat solul. Una dintre gaurile de diametru mai mic este despunsa pe jumate in grosimea baresei (5 mm), anume cea din partea dorsala a baresei.

Calculul general de rezistenta are ca obiectiv principal determinarea campului de tensiune echivalenta (structura este construita integral din metal) in structura. Se urmareasc valorile extreme si locatiile acestora, pentru eventuala lor consolidare, sau in cazul unei solicitari mici in raport cu capacitatea de rezistenta a materialelui, optimezarea de forma pentru reducerea masei [1], [2], [3].

De asemenea este importante determinarea, in cadrul aceluiasi calcul clasic de rezistenta, a campului de deplasare relativa (camp vectorial cu trei componente dupa cele trei axe de coordonate). Deplasarea relativa rezultanta se numeste in limbaj ingineresc deformatie (a nu se confunda cu deformatia specifica, camp tensorial calculat in teoria liniera ca gradientul deplasarii relative).
MATERIALS AND METHODS

Structural model

The structural model of a working body, ensemble or subassembly has five main components:
- geometry of the structure;
- bearing or border conditions or conditions related to the external environment;
- loading or tasks;
- material or materials used to build the structure;
- meshing.

This was made on the basis of hypothetical conditions.

For this study, the structural model defined above by meshing of its main components is the same for both computer programs used. The beam structure geometry is represented in Fig.1, where, also appear the main geometric characteristics of the structure. The images are taken from both programs by means of which the problem was addressed.

Fig. 1 - The structure geometry with the main features /

The material characteristics from which the beam is built can be extracted from the analysis report of any of programs and are given in Table 1.

Table 1

<table>
<thead>
<tr>
<th>The material properties used (carbon steel)</th>
</tr>
</thead>
<tbody>
<tr>
<td>The reference model</td>
</tr>
<tr>
<td>Name</td>
</tr>
<tr>
<td>Model type</td>
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<tr>
<td>Default breaking criterion</td>
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<tr>
<td>Breaking limit</td>
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<td>Breaking strength</td>
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<tr>
<td>Mass density</td>
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<tr>
<td>Elastic modulus</td>
</tr>
<tr>
<td>Poisson's ratio</td>
</tr>
<tr>
<td>Thermal expansion coefficient</td>
</tr>
</tbody>
</table>
The chosen material (Plain Carbon Steel) is part of the materials library of SolidWorks program. For Autodesk Inventor program this material was introduced by the operator in the database.

**Bearing**

Bearing the structure or border conditions (or in the language of some software manufacturers that include modules of finite element method, linking conditions with external environment) are naturally required in the areas where the beam is mounted on the bearing structure - cylindrical surfaces of the three holes grouped at the top of the structure. The way in which the bearing is made is called mounting of the geometry in both programs we worked and is materialized in canceling translations of all meshing nodes located on the beam surfaces fixing holes on the bearing structure. In Fig.2 are given the representations of the bearing areas of the structure in both solving alternatives (the one that uses the SolidWorks program and the other that uses Autodesk Inventor).

**Loading**

Loading the structure or applying tasks can be done in various ways. In this paper are addressed issues of continue bodies mechanics, The loads may be the nature of forces, some pressures, moments or gravitational, possibly even all being able to participate to the complex loads.

In this example, the action of the soil on the soil working bodies found in the soil is shaped by a pressure to the intensity of $10^6$ Pa, that was applied to all surfaces marked in fig.3 by arrows or / and by hatching.

**Incarcarea**

Incarcarea structurii sau aplicarea sarcinilor se poate face in diverse moduri. In aceasta lucrare fiind abordate probleme de mecanica corpurilor continue, incarcările pot fi de natura unor forțe, a unor presiuni, momente sau gravitationala, eventual chiar toate putând participa la solicitările complexe. Pentru acest exemplu, actiunea solului asupra organelor de lucru aflate in sol s-a modetat printr-o presiune cu intensitatea de $10^6$ Pa, aplicată pe toate suprafețele marcate in fig.3 prin ageti sau/si prin hasurare.
Obviously, in order to model the soil – working body interaction can also be used other models extremely complicated in terms of bearing and loading. Some alternative models are obtained very simply by reversing the loading areas with those of bearing or changing loads from pressures in forces. The complex models, often hybrid are obtained taking in consideration the soil and a part or all the bearing structure.

Meshing

Meshing in the two types of programs is graphically represented in Fig. 4 and the main characteristics in each of the variants are given below.

Meshing of the structure in both variants corresponds meshing on the two programs, automatically set to the established resolution by the software producers and their main characteristics appear in Table 2. These meshing can be refined or simplified, in order to obtain a more precise result or in a less time. A convergence analysis to refine the meshing networks is given in Table 5.

Discretizarea

Discretizarea, in cele doua variante de programe este reprezentata grafic in Fig. 4 iar caracteristicile principale in fiecare dintre variante este tabelata mai jos.

RESULTS

The main results of the linear elastic structural analysis are: the values of the relative displacement vector, the values of specific deformation tensor and the Cauchy’s stress tensor in each node of the meshing network.

With these values are calculated: the resultant relative displacement, the resultant specific deformation or its equivalent and the Von Mises equivalent stress [1], [2], [3], [4], [6]], terms in which is estimated the way how the structure meets the demands imposed. In this article, for economic reasons, at the static analysis we have discussed only the last three characteristics of the solution.

The main results of the analysis in frequency (or modal analysis, [6]) consist of the first n frequencies of own spectrum, the n number being set by the user and the deformed shapes of the structure being set when it vibrates on the selected frequencies of own spectrum.

The relative displacement

The relative displacement resulted is an important parameter of structures deformation. For agricultural machinery designed for tillage, a too high value of relative displacement can lead to a poor quality of agricultural works. The arrow of the sowing machines bearing structure should be limited, so not to alter the distances between seeded rows, for example.

Evident, pentru modelarea interacțiunii sol – organ de lucru, se pot folosi și alte modele extrem de complicate în ceea ce privește rezemarea și încarcarea.

Unele modele alternative se obtin foarte simplu, inversand zonele de încarcare cu cele de rezemare sau schimbând încarcările din presiuni în forte. Modele complexe, de cele mai multe ori hibride, se obtin considerând si solul si o parte sau toata structura portante.

Meshing of the structure in both variants corresponds meshing on the two programs, automatically set for both programs used SolidWorks (right) and Autodesk Inventor

![Fig.4 - The intersection of the structure meshing network with its border for each of the two programs used SolidWorks (right) and Autodesk Inventor](image)

Discretizările structurii, in ambele variante corespund punctele discretizărilor pe care cele doua programe sunt setate automat la rezolutia stabilita de producatorii programelor si caracteristicile lor principale apar in Tabelul 2. Aceste discretizari se pot rafina sau se pot simplifica in vederea obtinerii unui rezultat mai exact sau in timp mai scurt. O analiza de convergenta la rafinarea retelelor de discretizare este data in Tabelul 5.

Table 2

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<thead>
<tr>
<th>Characteristic</th>
<th>SolidWorks</th>
<th>Autodesk Inventor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of nodes</td>
<td>12314</td>
<td>3027</td>
</tr>
<tr>
<td>Number of elements</td>
<td>7527</td>
<td>1665</td>
</tr>
</tbody>
</table>

REZULTATE

Principalul rezultate ale analizei structurale liniar elastice sunt: valorile vectorului deplasare relativa, valorile tensorului deformatie specifica si ale tensorului tensiune Cauchy, in fiecare nod al retelei de discretizare.

Cu aceste valori, se poate discuta deplasarea relativa rezultanta, deformatia specifica rezultanta sau echivalenta si tensiunea echivalenta (Von Mises, [1], [2], [3], [4], [6]), termeni in care se apreciaza masura in care structura face fata solicitarilor aplicate. Pentru acest articol, din motive de economie, la analiza statica s-au luat in discutie numai ultimele trei caracteristici ale solutiei.

Principalul rezultate ale analizei in frecvente (sau analiza modala, [6]) constau in primele n frecvente ale spectrului propriu, numarul n fiind setat de utilizator, si formele deformate ale structurii atunci cand aceasta vibreaza pe frecventele selectate ale spectrului propriu.

Deplasarea relativa

Deplasarea relativa rezultanta este un parametru important al deformarii structurilor. Pentru masiniile agricole destinate lucrarii solului, o valoare prea mare a acesteia putând conducă la calitatea necorespunzătoare a lucrărilor agricole. Sageata structurii portante a masiniilor agricole de semenat trebuie sa fie limitata pentru a nu altera distantele dintre randurile semanate, de exemplu.
In fig. 5 are given by comparison the states of the resultant relative displacement on the beam border, states provided by the two finite element analysis programs used. It is noted, the coincidence of the maximum values and the concordance of the distribution of the values of resultant relative displacement field.

**The Von Mises equivalent stress**

The Von Mises equivalent stress [1], [2], [3], [4], [6] is the measure of the stress in metal structures and is used for comparing with the yield strength, towards which, in order to functioning in elastic range, it must be smaller.

In fig.6 are represented the equivalent stress fields on the beam border, fields resulted by using structural analysis programs, mentioned above. Although, as distribution in the structure, the two fields are similar, qualitatively, the maximum value indicated by the Autodesk Inventor program is by 26.48% higher than the maximum value indicated by SolidWorks program.

Since the difference is significant, a convergence study has been made, which results are given in Table 5, but this study raises new questions. These questions are not related to the training of the engineer, but can be setup details of the very complex numerical analysis.

In fig.5 sunt date comparativ starile de deplasare relativa rezultanta pe frontieră barsei, stari furnizate de cele două programe de analiza cu elemente finite folosite. Se observă coïncidența valorilor maxime și concordanța distribuției valorilor campului de deplasare relativa rezultanta.

**Tensiunea echivalentă (Von Mises)**

Tensiunea echivalentă (Von Mises), [1], [2], [3], [4], [6], este masura tensiunii în structurile metalice care se folosește pentru compararea cu tensiunea limita de curgere, fata de care, în scopul functionării în domeniul elastic, trebuie să fie mai mica.
The resultant specific deformation

The tensor of specific deformation is the gradient of the relative displacement in relation to spatial variables and its components and are used to calculate the components of Cauchy stress tensor, when the structure works in elastic linear field.

Deformation specifica rezultanta

Tensorul deformatiei specifice este gradientul deplasarii relative in raport cu variabilele spatiale, iar componentele acestuia se folosesc pentru calculul componentelor tensorului tensiunilor Cauchy atunci cand structura lucreaza in domeniul elastic liniar.

Using the components of the specific deformation tensor is calculated the equivalent specific or total deformation, which is a measure of the specific deformation in metallic structures. The distribution of the equivalent specific deformation on the structure border for both solutions is given in fig.7. As the equivalent stress, the specific deformation for the given solution using Autodesk Inventor program is approximately 28% higher.

The safety factor

The safety factor is calculated relatively to the yield strength stress and varies on the structure border in the two variants of solving, according to maps in fig.8.

Between the minimum values of the safety factor in the two variants of solving is transmitted approximately the same difference, as between the maximum values of the equivalent specific deformation and the equivalent stress.

For SolidWorks solution, the minimum safety factor is 19 and for the Autodesk Inventor solution, the minimum value of the safety factor is 15. Therefore, a difference of about 27%, comparable to that resulted from the maximum values of the specific deformation fields and the equivalent stress.

Si intre valorile minime ale factorului de siguranta in cele doua variante de rezolvare, se transmite aproximativ aceeasi diferenta ca intre valorile maxime ale deformatiei specifice echivalente si tensiunii echivalente.

For the solution SolidWorks factorul de siguranta minim este 19 iar pentru solutia Autodesk Inventor valoarea minima a factorului de siguranta este 15. Prin urmare, exista o diferență de aproximativ 27%, comparabilă cu cea rezultată din valorile maxime ale campurilor de...
stress in the structure, exists. Transmission of the error is completely natural, considering that works with the same material and the calculation relation is extremely simple for the safety factor.

**Modal analysis**

The modal analysis, [6], determines the own frequencies (first few) and own vibration modes of the structures. Knowledge of these features help to avoid some resonant regimes in determining by visualization of some causes of vibration, or some malfunction of equipment, defects due to variation on a characteristic frequency of one of the components.

In fig.9…13 are presented the deformation forms of the beam, when it vibrates in its own first five modes.

---

**Analyza modala**

Analyza modala, [6], determina frecventele proprii (primele cateva) si modurile proprii de vibratie ale structurilor. Cunoasterea acestor caracteristici ajuta la evitarea in lucru a unor regimuri rezonante, in determinarea prin vizualizare a unor cauze de vibratie, sau a unor defecte de functionare a unor instalatii, defecte datorate variatiei pe o frecventa proprie a uneia dintre componente.

In fig.9…13 sunt desenate formele de deformatie ale barsei atunci cand aceasta vibreaza in primele cinci moduri proprii.

---

**The first own frequency (fundamental)**

![SolidWorks, \(f_1=534.41\) Hz](image1)

![Autodesk Inventor, \(f_1=535.35\) Hz](image2)

**Fig.9** - The deformed shape of the structure at vibration in its first own mode

**A second own frequency**

![SolidWorks, \(f_2=1024.50\) Hz](image3)

![Autodesk Inventor, \(f_2=1026.06\) Hz](image4)

**Fig.10** - The deformed shape of the structure at vibration in the second own mode
A third own frequency

SolidWorks, $f_3 = 1929.3$Hz

Autodesk Inventor, $f_3 = 1934.43$Hz

Fig.11 - The deformed shape of the structure at vibration in the third own mode

A fourth own frequency

SolidWorks, $f_4 = 3853.80$Hz

Autodesk Inventor, $f_4 = 3858.07$Hz

Fig.12 - The deformed shape of the structure at vibration in the fourth own mode

A fifth own frequency

SolidWorks, $f_5 = 5506.20$ Hz

Autodesk Inventor, $f_5 = 5488.49$ Hz

Fig.13 - The deformed shape of the structure at vibration in the fifth own mode

**Comparative synthesis**

An efficient comparison of the results of the two structural analysis programs for the same structure under stress conditions in the same way can be done using Table 3 and Table 4.

**Sinteza comparativa**

O comparatie eficienta a rezultatelor celor doua programe de analiza structurala pentru o aceeasi structura solicitata in acelasi mod, se poate face folosind tabelul 3 si tabelul 4.
### Table 3

<table>
<thead>
<tr>
<th>Number of nodes</th>
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<th>Maximum equivalent stress [MPa]</th>
<th>Maximum resultant relative displacement [mm]</th>
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<tbody>
<tr>
<td>1459</td>
<td>760</td>
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<td>1664</td>
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<td>1713</td>
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<td>1058</td>
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<tr>
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<td>1144</td>
<td>13.79</td>
<td>0.02277</td>
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<td>3027</td>
<td>1665</td>
<td>14.09</td>
<td>0.02278</td>
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<tr>
<td>4223</td>
<td>2420</td>
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<tr>
<td>6939</td>
<td>4075</td>
<td>15.16</td>
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<td>12971</td>
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<tr>
<td>778348</td>
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### Table 4

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<th>Maximum resultant relative displacement [mm]</th>
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<tr>
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<td>79171</td>
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<td>0.02281</td>
</tr>
</tbody>
</table>

### Table 5

<table>
<thead>
<tr>
<th>Term</th>
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<th>Autodesk Inventor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structure weight [kg]</td>
<td>0.215963</td>
<td>0.215963</td>
</tr>
<tr>
<td>Maximum resultant relative displacement [mm]</td>
<td>0.022760</td>
<td>0.0227788</td>
</tr>
<tr>
<td>Maximum equivalent stress [MPa]</td>
<td>11.14</td>
<td>14.095</td>
</tr>
<tr>
<td>Minimum safety factor</td>
<td>19.80</td>
<td>15.00</td>
</tr>
<tr>
<td>Fundamental natural frequency [Hz]</td>
<td>534.41</td>
<td>535.35</td>
</tr>
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</table>

### CONCLUSIONS

The structural analysis solutions of the beam for linear static analysis and modal analysis are partially satisfactory. If the modal analysis is more than satisfactory, the static analysis gives results only in terms of resultant relative displacement, but not satisfying enough, regarding the specific deformation and equivalent stress, namely, exactly in the most interesting part, from engineering point of view. These issues remain an open question to be studied at a deeper level, possibly contacting software manufacturers.

COSMOS/M structural analysis program, that is integrated in the current CAD SolidWorks program can give results (for a large number of types of finite elements with which it is working) both in nodes and on the elements.

The module of numerical solutions that solves the problem of finite element method in COSMOS program, evaluates stresses on each element of the module at a specific location within each element, in a point of the element (called Gaussian points or quadrature points). These points form the numerical basis of numerical integration schemes used in the finite elements codes. The number of selected points in this basis depends on the type and the quality of each element type.

The string of stresses obtained in the Gaussian points network inside each element are extrapolated in the nodes of each element.

### CONCLUZII

Solutiile analizei structurale ale barsei la analiza static si analiza modala sunt parțial satisfacătoare. Daca analiza modala este mai mult decat satisfăcătoare, analiza statica da rezultate convergente numai in termenii deplasarii relative rezultante, dar nu suficient de satisfăcătoare in privinta deformatiei specifice si tensiunii echivalente, adica exact in partea cea mai interesanta din punct de vedere ingineresc. Aceste aspecte raman un problema deschis care trebuie cercetata la un nivel mai profund, eventual contactand si producătorii programelor.

Programul de analiza structurala COSMOS/M care este integrat in actualul program CAD SolidWorks, poate da rezultatele (pentru o mare parte dintre tipurile de elemente finite cu care lucreaza) atat in noduri cat si pe elemente.

Modulul de solutii numerice care rezolva problema de metoda elementelor finite in programul COSMOS, evalueaza tensiunile pentru fiecare element al modelului la o locatie specifica in interiorul fiecarui element – intr-un punct al elementului (numite puncte Gaussiene sau puncte de cuadratura). Aceste puncte formeaza o baza numerica a schemelor de integrare numerică folosite in codurile elementelor finite. Numarul de puncte selectate in aceasta baza de pe tip si calitatea fiecarui tip de element.

Sirul tensiunii obtinute in retea Gaussiana de puncte in interiorul fiecarui element sunt extrapolate in nodurile fiecarui element.
The nodal stress or stress in a some node is the average of all points from the Gaussian network, included in elements that have in one of the peaks the considered node.

The elemental stress or the stress in an element is the stress exactly calculated in the Gaussian points network (one and only one such point exists in each element). It is found that, the elemental values of the stress are the mean values of the nodal values from all element nodes. Most of the time, between the two types of stress values are differences, sometimes quite large, at least in some areas, usually in the most stressed.

The big difference between the nodal values and the elements shows that, the meshing should be refined to achieve the appropriate closeness or convergence.

REFERENCES
[7]. Ştefan A. & collective (1972) - Dictionary of agricultural mechanics, Publisher CERES, Bucharest;
STUDIES REGARDING A PNEUMATIC EQUIPMENT FOR SOWING SMALL SEEDS IN CUPS

STUDII PRIVIND REALIZAREA UNUI ECHIPAMENT PNEUMATIC PENTRU SEMĂNÄTUL SEMINȚELOR MICI ÎN ALVEOLE


1 University of Craiova, Faculty of Agriculture / Romania; 2 University of Agricultural Sciences and Veterinary Medicine Bucharest / Romania; 3 INMA Bucharest / Romania

Tel: 0762142949; E-mail: iom_saracin@yahoo.com

Abstract: The paper presents theoretical studies and laboratory experiments regarding pneumatic equipment for sowing small seeds in cups, highlighting the advantages of this type of equipment with superior parameters obtained from the considered crops.

Keywords: seeds, distributor, ditch, cups, sowing

INTRODUCTION

Utilization the equipment proposed for sowing small seeds in seedbeds decreases the volume of manual force required to do the work, decreases the amount of seed per surface unit, eliminates the execution of works thus reducing costs for obtaining seedlings. [3], [4].

It is also ensured the sowing depth and emerging uniformity of plants. To achieve the equipment plastic products or existing components of some installations and equipment that can be reused, are used.

Studies and experimental tests relating to the production index, consumption standard, the emerging degree and the plants percentage obtained will be continued. Based on the rules relating to the influencing factors for achieving optimal density can be established by species, the crop nature, the crop schemes implicitly expressing the productivity. [1], [2].

MATERIALS AND METHODS

Studies aim to achieve an equipment that can be used to set up small specific seed crops respectively forestry, flower, vegetable species and develop in the mechanization laboratories of the Faculty of Horticulture and Agriculture from Craiova. [6, 7]

Therefore, some of the methods used for sowing manually or mechanized the small seeds, existing in the country and abroad, were studied. (fig.1). [8]

Rezumat: În lucrare se prezintă studiile teoretice și experimentale din laborator privind realizarea unui echipament pneumatic pentru semănatul semințelor mici în alveole, evidențând avantajele acestui tip de echipament prin parametrii superiori obținuți la culturile luate în calcul.

Cuvinte cheie: semințe, distribuitor, rigolă, alveolă, semănat

INTRODUCERE

Folosirea echipamentului propus pentru semănătul semințelor mici în răsadnițe scade volumul de forță manuală necesar pentru realizarea lucrării, scade cantitatea de semințe pe unitatea de suprafață, elimină efectuarea unor lucrări reducând astfel cheltuielile pentru obținerea răsadurilor. [3], [4].

De asemenea este asigurată adâncimea de semănat și uniformitatea de răsărire a plantelor. Pentru realizarea echipamentului se folosesc mase plastice sau elemente componente ale unor instalări și aparate existente care pot fi refolosite.

Studiile și încercările experimentale referitoare la indicii de producție, norme de consum, gradul de răsărire și procentul de plante obținut vor continua. Pe baza regulilor referitoare la factorii de influență pentru realizarea unei densități optime se pot stabili pe specii, pe natură de cultură, implicit de producție care exprimă în final productivitatea. [1], [2].

MATERIALE ŞI METODE

Studiile efectuate în vederea realizării unui echipament care să poată fi folosit la înființarea culturilor specifice din semințe mici respectiv specii silvice, florițe, leguminoase au început și s-a desfășoară în laboratoarele de mecanizare ale Facultății de Horticultură și Agricultură din Craiova. [6, 7]

În acest scop au fost studiate o parte din metodele folosite pentru semănătul semințelor mici, manuale sau mecanizate existente în țară și și în strânsâtate. (fig.1). [8]
Also have been studied some characteristics of the seeds belonging to forestry, flower and vegetable species. [2]

Totodată au fost studiate și unele caracteristici ale semințelor din speciile silvice, floricole și legumicole. [2]

Fig. 2 – Tabacco seeds covered by treating substances

Fig. 3 – Nude small and very small seeds

Fig. 4 - Small seeds of vegetable species

Documented and studies consideration was given to the following:
- Direct sowing in cups;
- Consecutive sowing in several cups at the same time;
- Possibilities for sowing depth adjustment; [5]
- Automation possibilities for sowing small seeds in cups. [9], [10]

Based on the rules relating to the influencing factors for achieving optimal density, the production indexes, expressing the final productivity may be established on species, the crops nature on culture scheme.

Research and testing relating to the production indices at the consumption norms, will continue. [6], [7]

Following the results obtained recently through research, the consumption norms of the seeds sown in seedbeds should be set in relation to the average index of soil emergence, determined by laboratory germination, with plants maintenance index and the percentage of capable plants obtained. Sowing rate can be calculated as it follows:

a) Sowing rate in number of seeds per linear meter of the ditch channel, with the relation (1):

\[
\frac{n}{100} = \frac{i}{100} \times \frac{100}{A} \times \frac{100}{R} = \frac{i}{100} \times \frac{1,000,000}{R \times M \times A} \text{ seeds/meter,}
\]

or / sau:

Documentarea și studiile au luat în considerație și următoarele:
- Semănatul direct în alveole;
- Semănatul consecutiv în mai multe alveole în același timp;
- Posibilitățile de reglare a adâncimii de semănat; [5]
- Posibilitățile de automatizare a semănatului a semințelor mici în alveole. [9], [10]

Pe baza regulilor referitoare la factorii de influență în realizarea unor densități optime, se pot stabili pe specii, pe natură de culturi pe scheme de cultură, indicii de producție care exprimă în final productivitatea .

Cercetările și experimentările referitoare la indicii de producție, la normele de consum, vor continua. [6], [7]

Ca urmare a rezultatelor obținute în ultimul timp, prin cercetare, normele de consum de semințe la semănăturile în răsadnițe trebuie să se stabilească în raport cu indicele mediu de răsărire în sol, cu germinarea determinată în laborator, cu indice de menținere a plantelor precum și procentul de plante apte obținute .

Norma de semănat se poate calcula astfel:

a) Norma de semănat în număr de semințe la metru liniar de răsărită, după relația (1):
\[ n = \frac{I}{L} \times \frac{1.000.000}{R \times M \times A} \text{ [seeds/m]}, \quad (1) \]

where:
\( n \) = consumption rate (sowing rate) in seeds number and seeds number to be sown per meter [pcs/m];
\( i \) = index of production per ditch meter [pcs/m];
\( R \) = index (percentage) of emerging;
\( G \) = technical germination or potency germination indicated in the analysis report [%];
\( M \) = index (percentage) of plant maintenance;
\( A \) = percentage of plants capable for planting.

b) **Sowing rate in grams of seeds per meter**, with the relation (2):

\[ q = n \times \frac{G_{1000}}{1000} \times \frac{100}{P} = n \times \frac{G_{1000}}{10 \times P} \text{ [g/m]} \]

or / sau

\[ q = \frac{I}{L} \times \frac{1.000.000}{R \times M \times A} \times \frac{G_{1000}}{10 \times P} = 1 \times \frac{1.000.000 \times G_{1000}}{R \times M \times A \times P} \text{ [g/m]} \quad (2) \]

where:
\( q \) = consumption rate (sowing rate), in grams of seeds or quantity of seeds in grams to be sown at linear meter;
\( G_{1000} \) = weight of 1000 seeds, indicated in the analysis report, stating the average number of seeds per kilogram – NK;
\( P \) = seeds purity [%], indicated in analysis reports.

\[ n = \text{norma de consum (norma de semănăt) în număr de semințe sau numărul de semințe ce trebuie semănăt la metru [buc/m];} \]
\( i = \text{indicele de producție la metru de rigolă [buc/m];} \]
\( R = \text{indicele (procent) de răsărire;} \]
\( G = \text{germinația tehnică sau potența germinativă indicată în buletinul de analiză [%];} \]
\( M = \text{indicele (procent) de menținere al plantelor;} \]
\( A = \text{procentul de plante apte de plantat.} \]

b) **Norma de semănăt în grame de semințe la metru**, după relația (2):

\[ q = n \times \frac{G_{1000}}{1000} \times \frac{100}{P} = n \times \frac{G_{1000}}{10 \times P} \text{ [g/m]} \]

or / sau

\[ q = \frac{I}{L} \times \frac{1.000.000}{R \times M \times A} \times \frac{G_{1000}}{10 \times P} = 1 \times \frac{1.000.000 \times G_{1000}}{R \times M \times A \times P} \text{ [g/m]} \]

\[ q = \text{norma de consum (norma de semănăt), în grame de semințe sau cantitatea de semințe în grame ce trebuie semănăt la metrul liniar;} \]
\( G_{1000} = \text{greutatea a 1000 de semințe, indicată în buletinele de analiză, ce menționează și numărul mediu de semințe la kilogram – NK;} \]
\( P = \text{puritatea semințelor [%], indicată în buletinele de analiză.} \]
RESULTS

The results obtained in laboratory regarding the uniformity of distribution of turnip, eggplant and tabacco seeds are shown in fig. 7, 8 and 9:

From the fig.7 it can be observed that the uniformity of seed distribution decreases with the outer diameter of the cone. This happens probably because the surface between the hole and the exterior of the cone allows setting more seeds on it during the aspiration.

Fig.7 - Uniformity of distribution for turnip small grains average diameter of 1 mm and suction hole diameter of 0.5 mm

REZULTATE

Rezultatele obținute în laborator privind uniformitatea de distribuire pentru semințele de guli, vinete, respectiv tutun sunt prezentate în fig. 7, 8 și 9:

Din fig.7 se observă că uniformitatea de distribuire a semințelor scade odată cu creșterea diametrului exterior al conului. Probabil că suprafața rezultată între orificiu și exteriorul conului permite așezarea mai multor semințe pe el în timpul aspirației.

From the fig.8 it can be observed that the uniformity of seed distribution decreases with the outer diameter of the cone. This happens probably because the surface between the hole and the exterior of the cone allows setting more seeds conditioned by width during the aspiration.

Fig.8 - Uniformity of distribution for small seeds of eggplants with average diameter of 1 mm and suction hole diameter of 0.5 mm

Din fig.8 se observă că uniformitatea de distribuire a semințelor scade odată cu creșterea diametrului exterior al conului. Probabil că suprafața rezultată între orificiu și exteriorul conului permite așezarea mai multor semințe condiționate de lățime în timpul aspirației.
From the fig.9 it can be observed that the uniformity of seed distribution decreases with the outer diameter of the cone. This happens probably because the seeds outer diameter grows by pelleting and the surface between the cone and the hole does not allow setting more seeds during the aspiration.

**CONCLUSIONS**

For performing the production indexes the following technical indications related to compulsory minimum works to perform are imposed, such as:

- When preparing the seeds: verification of seeds quality, establishing the sowing norms, setting the sowing method, preparation of seeds according to each variety;
- When sowing the seeds: soil temperature, at the moment of sowing should be between +9ºC ... +15ºC;
- When covering the seeds: seeds covering with the humus-sand mixture prepared, slightly compressing the humus after soil covering;
- Equipment can be used in narrower spaces, being easily to handle and use;
- Driving the vacuum generator can be done electrically or thermically;
- Depression in installation does not require greater values, because of the seeds small mass;
- Nozzles holes should represent 0.5-0.6 out of the smallest size of seed;
- Nozzle peak should not allow placing more than one seed on the nozzle hole;
- Seeds aspired within the sucking tube can be collected in lower cover, recovered and considered as inappropriate;
- By using this equipment, the productivity is increased, the space of establishing the seedlings is reduced, the seeds norm is diminished;
- The germinating, rising and development space of plants is assured;
- Equipment can be automated and built by minimum costs.

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THE DETERMINATION OF THE RESISTANT FORCES FOR DEEP LOOSENING OF SOIL MACHINES WITH ACTIVE ORGANS

DETERMINAREA FORTELOR REZISTENTE LA MASINILE DE AFÂNARE ADÂNCĂ A SOLULUI CU BRĂZDARE ACTIVE

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Abstract: This paper presents the calculation of the resistant forces that occur during the deep loosening works in a machine with active organs driven by the quadrilateral mechanism from the tractor PTO. By using the relations for calculating the resistance forces presented in the paper we determined the momentum necessary to drive the plowshares and compare it with the determined experimental values

Keywords: deep loosening of soil machines, resistant forces, soil.

INTRODUCTION

Destruction of soil structure and compaction of the arable layer in depth reduces the water storage capacity, prevents soil aeration and spoils the aerohidric balance. In our country the area occupied by soils that require deep loosening works represent approximately 19.8% of the total agricultural area [1].

Removing these shortcomings and increasing the efficiency of land works requires the application of complex improvement measures, where the deep soil loosening is very important.

The deep loosening soil machines with active organs have plowshares which are operated by a quadrilateral mechanism of the tractor PTO, cutting and loosening the soil [4].

Resisting forces acting on the main bodies of deep soil loosening machines driven by a quadrilateral mechanism are shown in figure 1.

- the resistant force to the displacement of the connecting rod (\(F_{RH}\));
- the resistant forces due to the breaking and accelerating of the soil by the plowshare found in oscillation(\(Q\));
- the drag force (\(F_{R}\)).

Fig. 1 - The resisting forces acting on deep soil loosening machine organs

Rezumat: Lucrarea prezinta calculul forţelor rezistente ce apar în timpul lucrărilor de afânare adâncă a solului la masinile cu organele de lucru acţionate de un mecanism patrulater de la priza de putere a tractorului. Utilizând relaţiile de calcul al forţelor rezistente prezentate în lucrare se determina forţa de tracţiune şi momentul necesar acţionării brăzdarului şi se compară cu valorile determinate experimental.

Cuvinte cheie: maşina de afânarea adâncă a solului, forţe rezistente,sol.

INTRODUCERE

Distrugerea structurii solului în stratul arabil șii compactarea lui în profunzime duce la reducerea capacităţii de acumulare a apei, la împiedicarea aerării solului și stricarea echilibrului aerohidric. Suprafaţa ocupată în ţara noastră de solurile care necesită lucrări de afânare adâncă este de circa trei milioane hectare, respectiv 19,8% din totalul suprafeţei agricole [1].

Înlăturarea acestor neajunsuri şi sporirea eficienţei lucrărilor de îmbunătăţiri funciare necesită aplicarea unui complex de măsuri agroameliorative, în cadrul cărora afânarea adâncă a solului prezintă o importantă deosebită.

Maşinile de afânare adâncă a solului cu organe de lucru active au brazdare care acţionează de un mecanism patrulater de la priza de putere a tractorului produc tăierea solului si totodată afânarea acestuia [4].

Forţele rezistente care acţionează asupra principalelor organe ale maşinilor de afânare adâncă a solului cu brăzdalele acţionate de un mecanism patrulater sunt prezentate în figura 1.

- forţa rezistenta la deplasarea bielei (\(F_{RH}\));
- fortele rezistente datorate ruperii si accelerarii solului de catre bradulul aflat in miscare de oscilatie(\(Q\));
- forta rezistenta la inaintare (\(F_{R}\)).
MATERIALS AND METHODS

To determine the resistant force to the displacement of the connecting rod \( F_{RH} \), it can be assimilated with a double wedge (figure 2) on which the normal forces \( F_N \) and \( N \), and the soil friction forces \( \mu N \) and \( \mu F_n \).

The normal forces of the rod on the inclined surface \( F_N \) and on the side surface are [1]:

\[
F_N = k_1 \cdot S_1
\]

where:
- \( k_1 \) is the specific resistance of soil deformation in the advancing direction
- \( k_2 \) is the specific resistance of soil deformation perpendicular to the advancing direction [2, 5];
- \( S_1, S_2 \) are the wedge surfaces, and the side surface of the connecting rod.

The total resistant force, on the machines movement direction is:

\[
F = 2 \cdot F_N \sin \left( \frac{\phi}{2} \right) + 2 \cdot \mu \cdot N
\]

Fig. 2 - The forces acting on plowshares support [1]

The normal resistance force on the connecting rod \( F_{HN} \), the soil friction force with the connecting rod \( F_{HF} \) and the resultant force \( F_{RH} \) (figure 1) is determined by relations:

\[
F_{RN} = \frac{F \cdot \cos \phi}{\cos \varphi_{FH}} \quad F_{HF} = \mu \cdot F_{HN} \quad F_{RH} = \sqrt{F_{HN}^2 + F_{HF}^2}
\]

Fig. 3 - The transverse section shape of the soil displaced by a plowshare

MATERIALE ŞI METODE

Pentru determinarea forţei rezistente la deplasarea biei (\( F_{RH} \)), aceasta poate fi asimilată cu o pană dublă (figura 2) asupra careia acționează forțele normale \( F_N \) și \( N \) și forțele de frecare \( \mu N \) și \( \mu F_n \).

Forțele normale pe suprafețele încinate ale biei \( F_N \) și pe suprafețele laterale \( N \) sunt [1]:

\[
N = k_2 \cdot S_2
\]

unde:
- \( k_1 \) este rezistența specifică la deformarea solului pe direcția de înaintare;
- \( k_2 \) este rezistența specifică la deformarea solului perpendiculară pe direcția de înaintare [2, 5];
- \( S_1, S_2 \) suprafața penei, respectiv suprafața laterală a biei.

Forța rezistentă totală, pe directia de deplasare a mașinii este:

\[
F = 2 \cdot F_N \sin \left( \frac{\phi}{2} \right) + 2 \cdot \mu \cdot N
\]

Mașina de afânare adâncă a solului are două organe de lucru care dislocă solul pe o lațime mult mai mare decât lațimea brăzdarului. Dacă se înălță solul dislocat de un brăzdar, pe o porțiune perpendiculară pe direcția de deplasare, se obține un trapez isoscel cu baza mică aflată la adâncimea de lucru aproximativ egală cu lațimea brăzdarului \( l_b \) (figura 4). Pentru adâncimea de lucru de 50 cm, latura mare a trapezului, aflată la nivelul solului, este de 70 cm rezultând un unghi de înclinare a laaturilor laterale ale trapezului față de planul orizontal \( \beta_1 = 1.03 \text{ rad} = 59.036^0 \) (figura 3).
The volume of soil displaced is shown in figure 4 [3]. In longitudinal section, the plowshare EF breaks the soil after a plan whose result, the median longitudinal vertical plane is inclined at an angle $\psi = 45^0$ [6].

The volume of soil displaced is:

$$V = \frac{a_d (S + l + \frac{1}{2}Sx)}{3} - \frac{EF^2 l_b \cos \alpha_{med} \cdot \sin \alpha_{med}}{2}$$

Where:
- $\alpha_{med}$ is the average angle of inclination from the horizontal plowshares;
- $S = L \cdot (EF \cdot \cos \alpha_{med} + EO) + \frac{l_b^2}{8}$;
- $s = l_b \cdot EF \cdot \cos \alpha_{med}$ is the large base area,
- respectively the lower base of the soil displacement;
- $EO = a_d \cdot \text{ctg} \psi - \frac{L}{2}$;
- $a_d$ – working depth;
- $L$ – maximum working width of a plowshare.

When the plowshare rotates around the joint $D$ with the angular velocity $\omega_3 > 0$ EF = DT (figure 1) and when $\omega_3 < 0$, FE = CD then the working depth is $(a_d - CD \cdot \sin \alpha_{med})$.

The lateral area of the soil volume driven by the plowshare found in oscillation motion is calculated by the relationship:

$$A = \frac{\pi L}{2} \cdot \sqrt{\frac{l_b^2}{4} + a_d^2} + (2 \cdot a_d - EF \cdot \sin \alpha_{med}) \cdot EF \cdot \cos \alpha_{med}$$

For tearing the soil under the forces exerted by the plowshare, it is necessary to overcome the forces of cohesion that manifests between soil particles. These can be calculated using the equation:

$$F_{coe} = A \cdot (c + \sigma_a \cdot \text{tg} \varphi_o)$$

Where:
- $c$ is the cohesion coefficient;
- $\sigma_a = 10-60$ kPa is the normal tension (compression) [7];
- $\mu_o = \text{tg} \varphi_o = 0.35 \cdot 0.9$ [7] is the coefficient of internal friction of the soil.

Volumul de sol dislocat de brăzdar este prezentat în figura 4 [3]. În secțiune longitudinală, brăzdarul EF rupe solul după un plan a cărui urmă, în planul longitudinal vertical median, este înclinată cu un unghi $\psi = 45^0$ [8].

Volumul de sol dislocat este:

$$V = \frac{a_d (S + l + \frac{1}{2}Sx)}{3} - \frac{EF^2 l_b \cos \alpha_{med} \cdot \sin \alpha_{med}}{2}$$

Unde:
- $\alpha_{med}$ – unghiul mediu de înclinare a brăzدارului faţă de orizontală;
- $S = L \cdot (EF \cdot \cos \alpha_{med} + EO) + \frac{l_b^2}{8}$;
- $s = l_b \cdot EF \cdot \cos \alpha_{med}$ este suprafaţa bazei mari,
- respective a bazei mici a solului dislocat;
- $EO = a_d \cdot \text{ctg} \psi - \frac{L}{2}$;
- $a_d$ – adâncimea de lucru;
- $L$ – latimea maxima de lucru a unui brazdar.

Atunci când brăzdarul se roteste în jurul articulației $D$ cu viteza unghiulară $\omega_3 > 0$ EF = DT (figura 1) iar atunci când $\omega_3 < 0$, FE =CD iar adâncimea de lucru este $(a_d - CD \cdot \sin \alpha_{med})$.

Aria laterală a volumului de sol actionat de brăzdarul aflat în miscare de oscilație se calculează cu relația:

$$A = \frac{\pi L}{2} \cdot \sqrt{\frac{l_b^2}{4} + a_d^2} + (2 \cdot a_d - EF \cdot \sin \alpha_{med}) \cdot EF \cdot \cos \alpha_{med}$$

Pentru ruperea solului, sub acțiunea forțelor exercitate de brăzdar, este necesară învingerea forțelor de coeziune ce se manifestă între particulele de sol. Acestea se pot calcula cu relația:

$$F_{coe} = A \cdot (c + \sigma_a \cdot \text{tg} \varphi_o)$$

Unde:
- $c$ – coeficientul de coeziune;
- $\sigma_a = 10-60$ kPa este tensiunea normală (de compresiune) [7];
- $\mu_o = \text{tg} \varphi_o = 0.35 \cdot 0.9$ [7] este coeficientul de frecare internă a particulelor de sol.
The normal cohesive force of the plowshare is calculated using the equation:

$$F_{coexn} = F_{coexl} \cdot \sin \beta_l \cdot \cos \alpha_{med}$$  \hspace{1cm} (7)

Where the inclined angle of the lateral side walls of the furrow is:

$$\beta_l = \arctg \frac{2a_d}{L}$$  \hspace{1cm} (8)

Because the aggregate is moving with the working speed $v$, the speeds of the extreme points of the plowshare $C$ and $T$ (Figure 5), on the direction of movement, are:

$$v_{c1x} = v_{cx} + v_l$$

The speeds of the extreme points of the plowshare is determined by the relationship:

$$v_{c1} = \sqrt{v_{c1x}^2 + v_{c1y}^2}$$

The normal speeds on the surface of the plowshare in its extreme points are:

$$v_{c1n} = v_{cx} \cdot \sin(\theta_c + \alpha_{med})$$

Where: $\theta_c = \arctg \frac{v_{cy}}{v_{cx}}$, $\theta_l = \arctg \frac{v_{ly}}{v_{lx}}$

Given that rotation speeds of the plowshare points are maximum in extreme and zero points in joint $D$, average speeds of rotation are applied at the point $P$ for $\omega_3 > 0$ and $P'$ for $\omega_3 < 0$, located at a distances $d$, and have the values:

$$v_{ppn} = \frac{2}{3} \cdot v_{c1n}$$

The plowshare forces acting on soil $Q$, whose support through the point $P$ if $\omega_3 > 0$ and the point $P'$ if $\omega_3 < 0$ causing its acceleration. To determine these forces we applied the kinetic energy theory [8].

$$dl = dE$$  \hspace{1cm} (13)

Where:

$-dl$ is the variation of mechanical work forces $Qv$;

$-dE$ is the variation of the kinetic energy of the soil dislodged plowshare.

$$Q_p \cdot d = \rho_{sol} \left(\frac{v_{max}^2 - v_{min}^2}{2}\right)$$  \hspace{1cm} (14)

The plowshare normal force which causes the accelerated soil is calculated using the equation:

$$F_{coexn} = F_{coexl} \cdot \sin \beta_l \cdot \cos \alpha_{med}$$  \hspace{1cm} (7)

Where unghiul de înclinare al pereților laterali ai brăzdei este:

$$\beta_l = \arctg \frac{2a_d}{L}$$  \hspace{1cm} (8)

Deoarece agregatul se deploasează cu viteză de lucru $v$, vitezele punctelor extreme ale brăzdarului $C$ și $T$ (figura 5), pe direcția de deplasare, sunt:

$$v_{c1x} = v_{cx} + v_l$$

Vitezele punctelor extreme ale brăzdarului se determină cu relațiile :

$$v_{c1} = \sqrt{v_{c1x}^2 + v_{c1y}^2}$$

Vitezele normale pe suprafața brăzdarului în punctele extreme ale acestuia sunt:

$$v_{r1n} = v_{rx} \cdot \sin(\theta_t + \alpha_{med})$$  \hspace{1cm} (11)

Unete: $\theta_t = \arctg \frac{v_{ty}}{v_{tx}}$, $\theta_l = \arctg \frac{v_{ly}}{v_{lx}}$

Având în vedere că vitezele de rotație ale punctelor brăzdarului au valoarea maximă în punctele extreme și zero în articulația $D$, vitezele medii de rotație sunt aplicate în punctul $P$ pentru $\omega_3 > 0$, respectiv $P'$ pentru $\omega_3 < 0$, aflate la distanțe $d$, și au valorile:

$$v_{ppn} = \frac{2}{3} \cdot v_{r1n}$$  \hspace{1cm} (12)

Brăzdarul acționează asupra solului cu forțele $Qv$, a căror suport trece prin punctul $P$ dacă $\omega_3 > 0$ și prin punctul $P'$ dacă $\omega_3 < 0$ determinând accelerarea acestuia. Pentru determinarea acestor forțe se aplica teoria energiei cinetice [8].
The normal resultant force on the plowshare, which causes tearing and the accelerated soil will be:

\[ Q_r = Q_v + F_{coef} \]  

For the resultant normal force on the plowshare, which causes tearing and the accelerated soil, we have:

\[ Q_r = Q_v \]  

**RESULTS**

These forces acting in point P for \( \omega_3 > 0 \) and \( P' \) for \( \omega_3 < 0 \) causing the load the tractor PTO shaft.

The normal force on the plowshare \( Q_v \) and the resultant force \( Q_r \) depends on the machines working depth \( a_d \), with values between 50 – 70 cm, on the working speed \( v \) and the angular velocity of the crank driven quadrangle mechanism. For the deep soil loosening machine EAA – 220 the normal force on a plowshare with angular velocity of the crank \( \omega = 57.56 \) rad/s, were calculated for a working depth of \( a_d = 0.5 – 0.7 \) m, work speeds of \( v = 0.2 – 1.5 \) m/s and angular velocity of the crank \( \omega = 57.56 \) rad/s, data being presented in Table 1.

With the values in Table 1, we determined the multivariate function for calculating the normal forces on the plowshare when \( \omega_3 > 0 \) equation 17 and for \( \omega_3 < 0 \) equation presented in figure 6 and figure 7.

\[ Q_v = 1964 - 63.251 \cdot a_d - 505.435 \cdot v + 0.609 \cdot a_d^2 + 9.814 \cdot a_d \cdot v + 26.542 \cdot v^2 \]  

\[ Q_v = 1571 - 52.165 \cdot a_d - 375.7 \cdot v + 0.491 \cdot a_d^2 + 6.864 \cdot a_d \cdot v + 17.389 \cdot v^2 \]  

**REZULTATE**

Aceste forţe acţionează în punctul P pentru \( \omega_3 > 0 \) şi \( P' \) pentru \( \omega_3 < 0 \) determinând încarcarea arborelui prizei pe deget spate a tractorului.

Forţa normală pe brăzdar \( Q_v \) şi forţa rezultantă \( Q_r \) depind de adâncimea de lucrare \( a_d \), a vitezei \( v \) şi vitezei unghiolare a mecanismului patrulater de acţionare. Pentru masina de afânare adâncă a solului EAA – 220 s-a calculat forţa normală pe un brăzdar şi forţa normală rezultantă pentru viteza unghiolară a brăzdarului \( \omega_3 > 0 \) şi pentru \( \omega_3 < 0 \), pentru adâncimea de lucrare \( a_d = 0.5 – 0.7 \) m, viteza de lucrare \( v = 0.2 – 1.5 \) m/s şi viteza unghiolară a manivelei \( \omega = 57.56 \) rad/s, datele fiind prezentate în tabelul 1.

**Tabel 1**

<table>
<thead>
<tr>
<th>Nr.</th>
<th>Depth/ [cm]</th>
<th>Work speed/ [km/h]</th>
<th>( Q_v ) [daN] ( \omega_3 &gt; 0 )</th>
<th>( Q_v ) [daN] ( \omega_3 &lt; 0 )</th>
<th>( Q_r ) [daN] ( \omega_3 &gt; 0 )</th>
<th>( Q_r ) [daN] ( \omega_3 &lt; 0 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>5.4</td>
<td>991</td>
<td>504</td>
<td>2025</td>
<td>1330</td>
</tr>
<tr>
<td>2</td>
<td>70</td>
<td>5.4</td>
<td>2284</td>
<td>1409</td>
<td>3924</td>
<td>2842</td>
</tr>
<tr>
<td>3</td>
<td>50</td>
<td>0.72</td>
<td>298</td>
<td>152</td>
<td>1333</td>
<td>979</td>
</tr>
<tr>
<td>4</td>
<td>70</td>
<td>0.72</td>
<td>687</td>
<td>426</td>
<td>2333</td>
<td>1859</td>
</tr>
<tr>
<td>5</td>
<td>70</td>
<td>4.32</td>
<td>1831</td>
<td>1122</td>
<td>3477</td>
<td>2554</td>
</tr>
<tr>
<td>6</td>
<td>50</td>
<td>4.32</td>
<td>795</td>
<td>401</td>
<td>1829</td>
<td>1228</td>
</tr>
<tr>
<td>7</td>
<td>60</td>
<td>4.32</td>
<td>1243</td>
<td>704</td>
<td>2571</td>
<td>1922</td>
</tr>
<tr>
<td>8</td>
<td>60</td>
<td>1.8</td>
<td>576</td>
<td>318</td>
<td>1904</td>
<td>1436</td>
</tr>
<tr>
<td>9</td>
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<td>2.52</td>
<td>468</td>
<td>232</td>
<td>1502</td>
<td>1058</td>
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<td>70</td>
<td>2.52</td>
<td>1077</td>
<td>648</td>
<td>2723</td>
<td>2080</td>
</tr>
<tr>
<td>11</td>
<td>60</td>
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<td>1550</td>
<td>884</td>
<td>2879</td>
<td>2002</td>
</tr>
<tr>
<td>12</td>
<td>60</td>
<td>0.72</td>
<td>467</td>
<td>287</td>
<td>1795</td>
<td>1385</td>
</tr>
<tr>
<td>13</td>
<td>60</td>
<td>2.52</td>
<td>732</td>
<td>407</td>
<td>2060</td>
<td>1524</td>
</tr>
</tbody>
</table>
The resultant normal force on the plowshare for $\omega_3 > 0$ can be calculated using the equation 19 and for $\omega_3 < 0$ using the equation 20. The graphical representation is shown in figure 8 and figure 9.

\[
Q_r = 1883 - 46.845 \cdot a_d - 505.819 \cdot v + 0.727 \cdot a_d^2 + 9.816 \cdot a_d \cdot v + 26.581 \cdot v^2
\]  
\[
Q_r = 1293 - 35.885 \cdot a_d - 376.709 \cdot v + 0.607 \cdot a_d^2 + 6.686 \cdot a_d \cdot v + 17.507 \cdot v^2
\]

For the plowshare friction force $Q_f$ and the resultant force $Q$ are determined by the relations:

\[
Q_f = \mu \cdot Q_r
\]

Forța rezultantă normală pe brăzdar pentru $\omega_3 > 0$ se poate calcula cu relația 19 iar pentru $\omega_3 < 0$ cu relația 20. Reprezentarea grafică a acestor funcții este prezentată în figura 8 și figura 9.

\[
Q_r = 1883 - 46.845 \cdot a_d - 505.819 \cdot v + 0.727 \cdot a_d^2 + 9.816 \cdot a_d \cdot v + 26.581 \cdot v^2
\]  
\[
Q_r = 1293 - 35.885 \cdot a_d - 376.709 \cdot v + 0.607 \cdot a_d^2 + 6.686 \cdot a_d \cdot v + 17.507 \cdot v^2
\]

\[
Q_f = \mu \cdot Q_r
\]

\[
Q = \sqrt{Q_r^2 + Q_f^2}
\]

\[
Q_f = \mu \cdot Q_r
\]
The drag force of the deep soil loosening machine can be calculated using the formula developed by V.P. Goreacikin. This force is considered proportional to loosened soil section:

\[ F_i = k \cdot \frac{a_d(L+ib)}{2} \]

Where: \( k \) is the plowing resistance coefficient.

The drag force for normal movement on the surface of the plowshare is:

\[ F_{im} = \sum F_{in} \]

Where:
- \( -\varphi \) is the angle of friction between soil and plowshare surface;
- \( -\alpha \) is the angle of inclination to the horizontal plane

The resulting resistance force is:

\[ F_R = \sqrt{\sum F_{in}^2 + F_f^2} \]

For the deep soil loosening machine EAA 220, for two working deeps, working speed \( v = 0.76 – 1.4 \) m/s, a soil density of 1500 kg/m\(^3\) and plowing resistance coefficient \( k = 0.46 \) daN/cm\(^2\) we calculated with the equations presented the strength and fracture resistance due to ground acceleration \( Q \), the resistant force of the connection rods movement \( F_{RH} \), the drag force \( F_f \), the values calculated and the experimentally determined traction force \( F_t \) and the momentum necessary for operating the plowshare \( M_e \).

The data are shown in Table 2.

**CONCLUSIONS**

From the data presented in Table 2 it results that the resistance forces were correctly determined considering that between the calculated and experimental values of traction and momentum required to operate the plowshare there are very small differences.

Also:
- the resistant force to movement of the connecting rods \( F_{RH} \) and drag force \( F_f \) is independent of the work speed but it depends only on the working depth and soil characteristics;
- the resistant force due to the tear and accelerating soil has different values depending on the angle of rotation of the crank handles operating mechanism \( \omega_k \);
- the small difference between the calculated and experimentally determined values for traction force and momentum required to operate the plowshare enables us to say that the assumptions considered in calculating the resistant forces are correct.

Força rezistentă la încălare a mașinii de afânare adâncă a solului F\(_i\) se poate calcula folosind formula elaborată de V.P. Goreacikin. Aceasta forță se consideră proporcională cu secțiunea solului afănat:

\[ F_i = k \cdot \frac{a_d(L+ib)}{2} \] (22)

Unde: \( k \) – este coeficientul de rezistență la arat;

Forța rezistentă la încălare normală la suprafața brăzdarului este:

\[ F_{f} = \frac{F_{t} \cdot \cos \alpha}{\sin(\alpha + \varphi)} \] (23)

Unde:
- \( -\varphi \) este unghiul de frecare dintre sol și suprafața brăzdarului;
- \( -\alpha \) este unghiul de înclinare al brăzdarului față de planul orizontal.

Forța rezistentă la încălare normală medie și forța de frecare pe suprafața brăzdarului se calculează cu relațiile:

\[ F_f = \mu \cdot F_{im} \] (24)

Forța rezistentă rezultantă este:

\[ F_R = \sqrt{F_{im}^2 + F_f^2} \] (25)

Pentru mașina de afânare adâncă a solului EAA – 220, pentru două adâncimi de lucru, viteză de lucru \( v = 0.76 – 1.4 \) m/s și un sol cu densitatea de 1500 kg/m\(^3\) și coeficientul de rezistență la arat \( k = 0.46 \) daN/cm\(^2\) s-au calculat, cu relațiile prezentate, forța rezistentă datorată ruperii și accelerării solului Q, forța rezistentă la deplasarea bielei \( F_{RH} \) și forța rezistentă la înaintare \( F_f \) precum și valorile calculate și cele determinate experimentale pentru forța de tracțiune \( F_t \) și momentul necesar actionării brăzdarului \( M_e \).

Datele sunt prezentate în tabelul 2.

**Tabel 2**

<table>
<thead>
<tr>
<th>Nr. crt.</th>
<th>Depth [m]</th>
<th>Speed [m/s]</th>
<th>Q [daN]</th>
<th>( F_{RH} ) [daN]</th>
<th>( F_R ) [daN]</th>
<th>( F_t ) [daN]</th>
<th>( M_e ) [Nm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>0.76</td>
<td>2175</td>
<td>1620</td>
<td>1247</td>
<td>3589</td>
<td>133</td>
</tr>
<tr>
<td>2</td>
<td>1.25</td>
<td>2924</td>
<td>1992</td>
<td></td>
<td></td>
<td>4027</td>
<td>158</td>
</tr>
<tr>
<td>3</td>
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<td>2371</td>
<td></td>
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</tr>
<tr>
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<td>1.4</td>
<td>4338</td>
<td>3043</td>
<td></td>
<td></td>
<td>5565</td>
<td>230</td>
</tr>
</tbody>
</table>

**CONCLUZII**

Din datele prezentate în tabelul 2 rezultă că forțele rezistente au fost corect determinate având în vedere că între valorile calculate și cele experimentale ale forței de tracțiune și momentului necesar acționării brăzdarului diferentele sunt foarte mici.

De asemenea:
- forțele rezistente la deplasarea bielei \( F_{RH} \) și forța rezistentă la înaintare \( F_f \) nu depind de viteză de lucru ci numai de adâncimea de lucru și caracteristicile solului;
- forța rezistentă datorată ruperii și accelerării solului are valori diferite în funcție de unghiul de rotație al manivelii mecanismului de acționare \( \omega_k \);
- diferența mică dintre valorile calculate și cele determinate experimentale pentru forța de tracțiune și momentul necesar acționării unui brăzdar ne permite să afirmăm că ipotezele avute în vedere la calculul forțelor rezistente sunt corecte.
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EXPERIMENTAL RESEARCH ON MOISTURE TRANSMITTING RATE BETWEEN HUMIDITY SENSITIVE MATERIAL AND THE EXTERNAL ENVIRONMENT

Abstract: Shortage of water resources has become a serious problem of the world. With the growing increasingly reduction of water and energy resources, the agricultural irrigation method of water-saving and energy-saving should be adopted. In developed countries, control and monitoring of agricultural water-saving irrigation products are mostly dependent on computer technology, which need an external power source, and the price of the whole irrigation system is very expensive. So, it is not suitable to remote forest areas in China. In this paper, a new type of water-saving valve was introduced and is characterized by high automation, low costs and is capable of controlling without power supply. In order to make the valve to be used better in agricultural irrigation, experiments on moisture transmission rate between humidity sensitive materials and the external environment were conducted. And the results showed that the control unit of the valve could realize the irrigation automatically and timely according to the transmission rate between humidity sensitive material and the external environment, which would provide theoretical and experimental basis for the accurate control of the valve. It would play an important role for expanding agricultural water-saving irrigation and accelerating the speed of rational use of water resources.

Keywords: Water-saving valve; Humidity sensitive material; Transmission rate; Agricultural irrigation; Water Crisis

INTRODUCTION

Water is the most important limited resources among all the natural resources, thus it should be tapped and utilized rationally. China accounts for only 9% of arable land resources in the world, and even less percent of 6% of world’s water resources. At the same time, half of more than 600 cities in China are deficient in water resources. What’s more, the distribution of water resources in China is not even. For example, North China and Northeast account for 40% of national population with only about 5% of national water resources, and the 25% fresh water resources in North China is from South China. At present, the water supply is only 6180 billion cubic meters in China [9], while it is estimated that water demand will amount to 8180 billion cubic meters by 2030. In addition, China is an agricultural country and 40% arable land needs irrigation [10]. Therefore, agricultural water-saving and energy-efficient irrigation has become an irresistible trend to relief the water resource crisis and realize agricultural modernization.

In recent years, agricultural water-saving irrigation equipment in the world still faces many problems in spite of certain development. In China, the automation level of water-saving irrigation equipment especially in remote
自动控制系统大多都通过采用计算机、传感器、遥感遥测等来实现[7]。虽然实现了高水平的灌溉自动化，但成本都比较高，不适合中国广大农民使用。早在 20 世纪 40 年代，美国康奈尔大学的 L.A.Richards 博士就发明出了一种测试水势的张力计，它虽然能够取代滴灌系统中的滴头，并实现无源控制，但结构比较复杂，造价太高，而且灵敏度不高[6]。1980 年，美国华盛顿州立大学的 L. Ornstein 教授研制的无源智能控制阀 Irristat 能够实现低成本、节能、无源高自动化的要求，但由于 Irristat 自身结构的问题，使得在灌溉过程中的安装和监测比较麻烦，不适合推广普及[8]。目前，兼具低成本、节能、高自动化和适合推广普及的节水灌溉设备在国内外仍是一个亟待解决的问题[1]。

北京林业大学（中国）的研究团队从 2006 年开始研制一种新型的无需电源供给的智能节水阀门，它具有高自动化、低成本和无需电控的特点。控制单元是无电源节水阀门的核心部件，它利用其控制单元中湿敏材料吸水膨胀失水收缩的特性来开启或关闭阀门进水口，从而指导灌溉。阀门能否及时开启或关闭的关键在于控制单元内的湿敏材料与外界水分能否及时的交换，因此，掌握水分在控制单元内的湿敏材料与外界环境的交换速率及规律，对控制阀门应用于生产灌溉极其必要。

无电源智能节水阀门是利用湿敏材料吸水膨胀失水收缩的特性来控制阀门的关闭和打开，结构如图 1 所示，初始时进水口和出水口为连通状态。阀门插入土壤中，水从出水口流出进入土壤后，控制元件 3 即湿敏材料吸水膨胀，阀芯 7 在材料膨胀推力的作用下向上移动，当其锥形头部将进水口 11 完全堵上时，水就不再进入设备，从而停止灌溉。土壤中的水分随着植物的吸收和蒸发会渐渐减少，根据水分平衡原理，控制元件 3 中的水分也随之减少，材料失水体积收缩，从而阀芯 7 在复位弹簧 9 的作用下反向移动，进水口重新打开，水从出水口流出。另外，还可以根据作物的需水量来调节阀门的调节螺钉 1，满足不同作物在不同季节、不同质地的土壤中的水分需求，进而提高作物产量[2-4]。
MATERIALS AND METHODS

Purpose of the experiment

The following experiments were designed to measure the moisture transmitting rate between humidity sensitive materials and the external environment. It has mainly studied the transmission rate between moisture and external environment at different ratio of humidity sensitive materials and different distances between the dripper and valve body. The experiment focused on the time to close the valve and to open it again at the above conditions.

Rate conversion of the experiment

The common way to get moisture transmission rate was to calculate the relationship between time and soil moisture content by using soil moisture sensor and data collector, and then obtain the result through data analysis. However, the requirement of connection between soil moisture sensor and computer made the whole system heavy and hard to operate, and the circuit was complex with limited application (shown in the figure 2, part A). So the common way was unfeasible upon all these conditions. A new way (shown in figure 2, part B) was adopted to convert the moisture transmitting rate between humidity sensitive materials and external environment to the rising rate of the valve’s spool, which could also be converted to the relationship between the time and the distances (from the dripper to valve body, named C in figure 2, part B). So the moisture transmitting rate would be obtained by calculating the relationship between distances and time measured from opening the dripper to closing the corresponding valve.

Note: A. Common method of measuring system; B. A new way to get transmission rate; C. Distance between Valve body and Drippers

Fig.2 - Common and new method of measuring transmission rate
**Summary of the experimental field**

The experiment was conducted in vehicle internship center of Beijing Forestry University (located in Haidian District, Beijing) with the accurate position of 39 degrees north latitude, 116 degrees east longitude and the altitude of 20m to 60m. This place has a warm temperate, semi-humid and semi-arid monsoon climate with an annual mean temperature of 11~13℃, annual precipitation of 600~700mm and an annual average sunshine time of 2780.2 hours.

**Experiment materials**

Known from previous researchers, a kind of France water-retaining agent, named SNF, has better comprehensive performance of water swelling and drying shrinkage. It is the copolymerization of acrylamide-acrylate, which can endure for about four years [11]. Based on early research, the mixture of SNF with the diameter of 0.5mm and sand with the diameter of 1~2mm was selected as the control unit in the valve so as to increase the rate of water absorption and loss [5]. Above mixed materials which volume ratio was 1:1 and 1:3 were selected in the following experiments. Total volume was 2ml or 4ml.

Three kinds of soil at Beijing were also involved, namely sand, loam and clay, with the clearance of sand being the biggest and of clay being the smallest. The loam was produced by mixing the sand and clay with the volume ratio of 1:1.

**Experimental methods**

Three kinds of soil, three distances, as well as the different mixture ratio, volume, and inserting depth of the mixed materials were involved in the experiments. The whole experiment was divided into 2 categories and 45 groups.

1. Firstly, let half part of humidity sensitive materials in the valve exposed to the air.
   a) Insert a valve with humidity sensitive materials into sand soil. The distances between the dripper and valve body were respectively set to 5cm, 10cm, and 20cm.
   b) Mixed materials at ratio of 1:1 and the total volume 2ml or 4ml were respectively put into the control unit of the valve. When irrigation experiment was starting, time to close and open the dripper (on the valve body, seen in the figure 2(B)) again should be observed carefully and be recorded. Moisture transmission rate could be calculated through the set distances and recorded time.
   c) After that, mixed materials at ratio of 1:3 and the total volume 2ml or 4ml were put into the control unit. Data should be recorded as well.
   d) According to the step (a-c), conducted the above experiments in the conditions of clay soil and loam soil in order, and recorded data.

2. Then, let the whole mixed materials into soil isolated from air.

In contrast, experiments in three kinds of soil respectively at ratio of 1:1 and volume 2ml would be done in the condition of isolated from air, i.e., the control unit including humidity sensitive material was totally inserted into soil. Also observed the time to close and open the dripper again, and recorded data.

**试验地概括**

试验于北京市海淀区北京林业大学车辆实习中心进行。地理位置为北纬 39 度，东经 116 度，海拔为 20~60 米。气候条件为暖温带半湿润半干旱季风气候，全年平均气温为 11~13℃，年降水量 600~700 毫米之间，年平均日照 2780.2 小时。

**试验方法**

试验中涉及三种土壤，分别为砂土，壤土和粘土，三种土壤中，砂土的间隙最大，粘土的间隙最小，壤土的间隙居中，并且壤土是砂土与粘土按体积 1:1 混合而得到的。

试验中涉及三种土壤，三种距离，两种湿敏材料的配比，两种湿敏材料的体积，两种湿敏材料的插入深度，整个试验可分为 2 大类 45 组。

1. 先将湿敏材料的一半与空气接触进行试验。
   a) 具体操作：将节水阀插入砂土中，其滴口与阀体距离分别为 5cm，10cm，20cm。

   b) 将比例为 1:1 总体积为 2ml 或 4ml 的混合湿敏材料分别放入阀门的控制单元中。然后开始灌溉试验，仔细观察节水阀关闭和再次打开的时间，并记录数据。通过预设的距离以及时间就可以计算出水分传输的速率。

   c) 接下来，选用比例 1:3 总体积为 2ml 或 4ml 的混合湿敏材料放入阀门的控制单元中，同样记录节水阀关闭和再次打开的时间数据。

   d) 按照步骤 (a-c)，依次在上述条件下进行粘土和壤土的试验，并记录数据。

2. 然后，将整个阀门控制单元插入土中，即湿敏材料与空气完全隔离。

该部分作为对照组，进行的是节水阀中的湿敏材料与空气不接触。即阀门完全插入土壤中，混合湿敏材料比例为 1:1 总体积为 2ml，依次在上述三种土壤中的试验，观察节水阀关闭时间和再次打开的时间并记录数据。
RESULTS AND DISCUSSIONS

Overall results of the experiment

The results of test (1) and (2) above were shown in Table 1 and Table 2. Analyses results were mainly reflected in the figure, shown in the following:

---

Table 1

<table>
<thead>
<tr>
<th>Serial No.</th>
<th>Volume ratio</th>
<th>Volume/ml</th>
<th>Distance between dripper and valve/cm</th>
<th>Type of soil</th>
<th>Time to close/h</th>
<th>Time to open/h</th>
<th>Temperature /humidity when closed</th>
<th>Temperature /humidity when opened</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1:1</td>
<td>2</td>
<td>5</td>
<td>sand</td>
<td>3.5</td>
<td>8</td>
<td>11 °C /63%</td>
<td>12 °C /53%</td>
</tr>
<tr>
<td>2</td>
<td>1:1</td>
<td>2</td>
<td>10</td>
<td>sand</td>
<td>4.5</td>
<td>9</td>
<td>11 °C /75%</td>
<td>11 °C /52%</td>
</tr>
<tr>
<td>3</td>
<td>1:1</td>
<td>2</td>
<td>20</td>
<td>sand</td>
<td>8</td>
<td>109</td>
<td>12 °C /76%</td>
<td>13 °C /77%</td>
</tr>
<tr>
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<td>1:1</td>
<td>4</td>
<td>5</td>
<td>sand</td>
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<td>91</td>
<td>13 °C /77%</td>
<td>14 °C /89%</td>
</tr>
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<td>1:1</td>
<td>4</td>
<td>10</td>
<td>sand</td>
<td>5</td>
<td>95</td>
<td>14 °C /78%</td>
<td>11 °C /63%</td>
</tr>
<tr>
<td>6</td>
<td>1:1</td>
<td>4</td>
<td>20</td>
<td>sand</td>
<td>6</td>
<td>101</td>
<td>12 °C /65%</td>
<td>12 °C /76%</td>
</tr>
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<td>5</td>
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<td>4.5</td>
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<td>11 °C /63%</td>
<td>12 °C /53%</td>
</tr>
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<td>2</td>
<td>10</td>
<td>sand</td>
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<td>88.5</td>
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<td>11 °C /52%</td>
</tr>
<tr>
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<td>sand</td>
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<td>104.5</td>
<td>12 °C /76%</td>
<td>13 °C /77%</td>
</tr>
<tr>
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<td>sand</td>
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<td>14 °C /89%</td>
</tr>
<tr>
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<td>4</td>
<td>10</td>
<td>sand</td>
<td>5.5</td>
<td>78</td>
<td>14 °C /78%</td>
<td>13 °C /77%</td>
</tr>
<tr>
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<td>1:3</td>
<td>4</td>
<td>20</td>
<td>sand</td>
<td>7</td>
<td>92</td>
<td>15 °C /89%</td>
<td>15 °C /89%</td>
</tr>
<tr>
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<td>1:1</td>
<td>2</td>
<td>5</td>
<td>clay</td>
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<td>97</td>
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<td>12 °C /76%</td>
</tr>
<tr>
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<td>2</td>
<td>10</td>
<td>clay</td>
<td>8</td>
<td>104</td>
<td>12 °C /65%</td>
<td>13 °C /77%</td>
</tr>
<tr>
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<td>2</td>
<td>20</td>
<td>clay</td>
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<td>11 °C /63%</td>
</tr>
<tr>
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<td>4</td>
<td>5</td>
<td>clay</td>
<td>4.5</td>
<td>101</td>
<td>12 °C /65%</td>
<td>13 °C /66%</td>
</tr>
<tr>
<td>17</td>
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<td>4</td>
<td>10</td>
<td>clay</td>
<td>7</td>
<td>109</td>
<td>12 °C /76%</td>
<td>14 °C /67%</td>
</tr>
<tr>
<td>18</td>
<td>1:1</td>
<td>4</td>
<td>20</td>
<td>clay</td>
<td>8</td>
<td>131</td>
<td>13 °C /66%</td>
<td>13 °C /77%</td>
</tr>
<tr>
<td>19</td>
<td>1:3</td>
<td>2</td>
<td>5</td>
<td>clay</td>
<td>7.5</td>
<td>95.5</td>
<td>13 °C /66%</td>
<td>12 °C /76%</td>
</tr>
<tr>
<td>20</td>
<td>1:3</td>
<td>2</td>
<td>10</td>
<td>clay</td>
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<td>100</td>
<td>12 °C /65%</td>
<td>13 °C /77%</td>
</tr>
<tr>
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<td>2</td>
<td>20</td>
<td>clay</td>
<td>12</td>
<td>117</td>
<td>13 °C /77%</td>
<td>11 °C /63%</td>
</tr>
<tr>
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<td>1:3</td>
<td>4</td>
<td>5</td>
<td>clay</td>
<td>6.5</td>
<td>95</td>
<td>12 °C /65%</td>
<td>13 °C /66%</td>
</tr>
<tr>
<td>23</td>
<td>1:3</td>
<td>4</td>
<td>10</td>
<td>clay</td>
<td>8</td>
<td>107</td>
<td>12 °C /76%</td>
<td>14 °C /67%</td>
</tr>
<tr>
<td>24</td>
<td>1:3</td>
<td>4</td>
<td>20</td>
<td>clay</td>
<td>9.5</td>
<td>129.5</td>
<td>13 °C /66%</td>
<td>13 °C /77%</td>
</tr>
<tr>
<td>25</td>
<td>1:1</td>
<td>2</td>
<td>5</td>
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<td>4</td>
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<td>11 °C /63%</td>
<td>12 °C /65%</td>
</tr>
<tr>
<td>26</td>
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<td>2</td>
<td>10</td>
<td>loam</td>
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<td>12 °C /65%</td>
<td>12 °C /53%</td>
</tr>
<tr>
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<td>1:1</td>
<td>2</td>
<td>20</td>
<td>loam</td>
<td>9</td>
<td>118</td>
<td>11 °C /63%</td>
<td>13 °C /66%</td>
</tr>
<tr>
<td>28</td>
<td>1:1</td>
<td>4</td>
<td>5</td>
<td>loam</td>
<td>4</td>
<td>95</td>
<td>13 °C /77%</td>
<td>13 °C /77%</td>
</tr>
<tr>
<td>29</td>
<td>1:1</td>
<td>4</td>
<td>10</td>
<td>loam</td>
<td>6</td>
<td>102</td>
<td>14 °C /78%</td>
<td>14 °C /78%</td>
</tr>
<tr>
<td>30</td>
<td>1:1</td>
<td>4</td>
<td>20</td>
<td>loam</td>
<td>7</td>
<td>115</td>
<td>13 °C /77%</td>
<td>15 °C /89%</td>
</tr>
<tr>
<td>31</td>
<td>1:3</td>
<td>2</td>
<td>5</td>
<td>loam</td>
<td>6</td>
<td>89</td>
<td>11 °C /63%</td>
<td>12 °C /65%</td>
</tr>
<tr>
<td>32</td>
<td>1:3</td>
<td>2</td>
<td>10</td>
<td>loam</td>
<td>8</td>
<td>94</td>
<td>12 °C /65%</td>
<td>12 °C /53%</td>
</tr>
<tr>
<td>33</td>
<td>1:3</td>
<td>2</td>
<td>20</td>
<td>loam</td>
<td>10</td>
<td>110</td>
<td>11 °C /63%</td>
<td>13 °C /66%</td>
</tr>
<tr>
<td>34</td>
<td>1:3</td>
<td>4</td>
<td>5</td>
<td>loam</td>
<td>5</td>
<td>78</td>
<td>13 °C /77%</td>
<td>13 °C /77%</td>
</tr>
<tr>
<td>35</td>
<td>1:3</td>
<td>4</td>
<td>10</td>
<td>loam</td>
<td>7</td>
<td>90</td>
<td>14 °C /78%</td>
<td>15 °C /89%</td>
</tr>
<tr>
<td>36</td>
<td>1:3</td>
<td>4</td>
<td>20</td>
<td>loam</td>
<td>8</td>
<td>112</td>
<td>15 °C /78%</td>
<td>16 °C /89%</td>
</tr>
</tbody>
</table>
Table 2
Experimental data of humidity sensitive materials completely inserted into the soil in the control groups

<table>
<thead>
<tr>
<th>Serial No.</th>
<th>Volume ratio</th>
<th>Volume/ml</th>
<th>Distance between dripper and valve/cm</th>
<th>Type of soil</th>
<th>Time to close/h</th>
<th>Time to open/h</th>
<th>Temperature/humidity when closed</th>
<th>Temperature/humidity when opened</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1:1</td>
<td>2</td>
<td>5</td>
<td>sand</td>
<td>5</td>
<td>92</td>
<td>15°C/78%</td>
<td>15°C/89%</td>
</tr>
<tr>
<td>2</td>
<td>1:1</td>
<td>2</td>
<td>10</td>
<td>sand</td>
<td>6.5</td>
<td>99</td>
<td>16°C/89%</td>
<td>17°C/90%</td>
</tr>
<tr>
<td>3</td>
<td>1:1</td>
<td>2</td>
<td>20</td>
<td>sand</td>
<td>9</td>
<td>115</td>
<td>15°C/89%</td>
<td>16°C/79%</td>
</tr>
<tr>
<td>4</td>
<td>1:1</td>
<td>2</td>
<td>5</td>
<td>clay</td>
<td>8</td>
<td>101</td>
<td>14°C/78%</td>
<td>14°C/78%</td>
</tr>
<tr>
<td>5</td>
<td>1:1</td>
<td>2</td>
<td>10</td>
<td>clay</td>
<td>9</td>
<td>112</td>
<td>15°C/89%</td>
<td>15°C/78%</td>
</tr>
<tr>
<td>6</td>
<td>1:1</td>
<td>2</td>
<td>20</td>
<td>clay</td>
<td>12</td>
<td>123</td>
<td>16°C/89%</td>
<td>16°C/89%</td>
</tr>
<tr>
<td>7</td>
<td>1:1</td>
<td>2</td>
<td>5</td>
<td>loam</td>
<td>7</td>
<td>97</td>
<td>16°C/89%</td>
<td>16°C/89%</td>
</tr>
<tr>
<td>8</td>
<td>1:1</td>
<td>2</td>
<td>10</td>
<td>loam</td>
<td>8</td>
<td>110</td>
<td>15°C/78%</td>
<td>17°C/90%</td>
</tr>
<tr>
<td>9</td>
<td>1:1</td>
<td>2</td>
<td>20</td>
<td>loam</td>
<td>10.5</td>
<td>122</td>
<td>17°C/90%</td>
<td>15°C/78%</td>
</tr>
</tbody>
</table>

The relationship between transmission rate and type of soil

From the data obtained from the experiment, it could be known the relationship between type of soil and moisture transmission rate between humidity sensitive materials and soils.

Figure 3 and 4 displayed the rising rate and falling rate of the valve’s spool (that is, the rate of closing and opening the valve again) at the mixture ratio of 1:1 and volume 2ml when half of the humidity sensitive materials were contacted with air. In the figure, X-axis and Y-axis separately denoted the distance between dripper and valve body with unit cm and the time (to close and open the dripper again) with unit hour.

By observing the data in Table 1 and Table 2 at different type of soil but with same ratio, volume and area contacted with air.

This phenomenon results from the different clearance of three types of soils. It was easy to find that the biggest clearance was in sand and the smallest in clay. So moisture transmission rate was the fastest in sand, and moisture could reach into the valve at the fastest speed and make humidity sensitive materials in valve swell quickly. But on the contrary, with transmission rate being

Transmission rate with soil kinds' relationship

According to the data obtained from the experiment, the relationship between type of soil and moisture transmission rate between humidity sensitive materials and soils can be known.

Figure 3 and 4 showed the rising rate and falling rate of the valve’s spool (that is, the rate of closing and opening the valve again) at the mixture ratio of 1:1 and volume 2ml when half of the humidity sensitive materials were contacted with air. In the figure, X-axis and Y-axis separately denoted the distance between dripper and valve body with unit cm and the time (to close and open the dripper again) with unit hour.

Seen from the figure 3 and 4, time to close the valve or open it again in sand soil was shortest while in clay soil was longest at the same distance between dripper and valve body, which illustrated that the fastest moisture transmission rate between humidity sensitive materials and soils could be found in sand and the slowest in clay. Same conclusion should be obtained after observing the data in Table 1 and Table 2 at different type of soil but with same ratio, volume and area contacted with air.

This phenomenon results from the different clearance of three types of soils. It was easy to find that the biggest clearance was in sand and the smallest in clay. So moisture transmission rate was the fastest in sand, and moisture could reach into the valve at the fastest speed and make humidity sensitive materials in valve swell quickly. But on the contrary, with transmission rate being
the slowest in clay, humidity sensitive materials swell slowly. For the same reason, moisture evaporation speed was the fastest after the closure of the valve due to the big clearance in sand. Therefore, humidity sensitive materials had the fastest dehy-
dration speed and the shortest time to open the valve again. However, the slow moisture evaporation rate caused by small clearance in clay would result in a longer time of dehy-
dration and shrinkage, and a longer time to open the valve again. The clearance in loan fell somewhere between the sand and clay.

The relationship between transmission rate and ratio of humidity of sensitive materials

The relationship between transmission rate and ratio of humidity of sensitive materials would be analyzed by using the data obtained from the experiment. Figure 5-10 indicated the rising rate and falling rate of the valve’s spool in three types of soils at the mixed ratio of 1:1 and volume 2ml when half of the humidity sensitive materials contacted with air.

It could be obtained from figure 5-10 that the spool has risen faster at the mixed ratio of humidity sensitive materials fastest膨胀;而粘土间隙最小,水分在粘土中传输速率最慢,所以湿敏材料膨胀速率最慢;同样的道理,因为砂土间隙大,所以在节水阀门关闭后,水分从砂土中蒸发的速度也最快,所以湿敏材料能最快脱水收缩,所以砂土中节水阀门再次打开所需的时间最短,而粘土则因间隙小,水分蒸发慢导致湿敏材料脱水收缩的时间变长,所以节水阀门再次打开的时间长,而壤土间隙介于二者之间,所以所需时间也处在砂土与粘土之间。

传输速率与湿敏材料配比之间的关系

利用试验所得到的数据可以分析出水分传输速率和湿敏材料配比的关系。图 5-10 表示在混合比为 1:1, 体积为 2ml、湿敏材料一半与空气接触的条件下,节水阀阀芯在三种土壤类型中上升和下降速率。
materials 1:1 than that of 1:3, and fell slower when the ratio was 1:1 than that of 1:3 under the same conditions. The expansion amount of the mixture materials was larger because of more SNF at higher mixed ratio. Shrinkage was less because more SNF needed to dry in the valve, so time to open the valve again would be longer, and the spool had a slower moving. The relationship between transmission rate and whether humidity sensitive materials exposed to the air

Based on the mixture materials contacting the air or not, an analysis was done comparatively to the condition of volume 2ml, ratio 1:1. Analysis results of the three types of soils were shown in figure 11-16.

The spool's rising rate in sand soil

The spool's falling rate in sand soil

The spool's rising rate in clay soil

The spool's falling rate in clay soil

The spool's rising rate in loam soil

The spool's falling rate in loam soil
It could be seen from figure 11-16 that the spool rose or fell faster when the mixture materials in valve contacted the air in all three soils at the mixing ratio of 1:1 and volume 2ml, which indicated that moisture transmission rate between humidity sensitive materials and external environment was faster when the valve half inserted into soil. It was mainly because that moisture needed evaporation after the closure of the valve caused by a certain degree of soil moisture, then the valve should be opened again. In the process, the humidity of air was less than that of soil, so humidity sensitive materials contacted with air had a faster dehydration speed, a shorter shrinkage time and a shorter time to open the valve again.

CONCLUSIONS
The new valve type was developed with the idea of water saving and energy conservation, which could control irrigation on-off without computer and sensors. It was especially suitable for popularization and promotion in agricultural and forestry irrigation of poor condition area.

Following conclusions were mainly found that moisture transmitting rate between humidity sensitive materials and the soils or the air was influenced by clearance of the soil, ratio of humidity sensitive materials, and whether exposure to the air through the above experiments and analyses.

(1) The fastest transmission rate of moisture between humidity sensitive materials and soil could be found in sand and the slowest in clay for different kinds of soils.

(2) The speed of material water-absorption was faster when its ratio was 1:1 than that of 1:3, and speed of material water-loss was slower at the ratio 1:1 than that of 1:3.

(3) The transmission rate of moisture was faster when contacting with air. Besides, a general time range (time to close the valve from 3 to 12 hours and time to open it again from 70 to 130 hours) could be summarized from the experimental data.

It would provide reference for the further application of the new water-saving valve, and it is helpful to develop rapidly water-and energy-efficient technologies to promote the steady and efficient development of agriculture and forestry products.

ACKNOWLEDGEMENT
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From figure 11-16 it can be seen, in other conditions, the moisture content in the valve range is 2ml. The situation of 1:1 indicates that, for the same soil moisture, the moisture content in a mixture with 1:1 and volume 2ml, which indicated that moisture transmission rate between humidity sensitive materials and external environment was faster when the valve half inserted into soil. It was mainly because that moisture needed evaporation after the closure of the valve caused by a certain degree of soil moisture, then the valve should be opened again. In the process, the humidity of air was less than that of soil, so humidity sensitive materials contacted with air had a faster dehydration speed, a shorter shrinkage time and a shorter time to open the valve again.

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EFFECT OF ALTERNATE PARTIAL ROOT-ZONE IRRIGATION AND INFILTRATING IRRIGATION ON PHOTOSYNTHETIC CHARACTERISTICS AND YIELD OF JUJUBE TREES

Abstract: At present, irrigation in Ziziphus Jujuba orchards around Tarim basin in Xinjiang Province, China, is mainly surface irrigation. Due to outdated irrigation technology and low irrigation efficiency, the fruit yields are low, which seriously affects sound development of local special forest fruit industry in Xinjiang. Infiltrating irrigation technology has favorable water-saving effects and studying its impact on the physiological and yield variation of Jujube trees would therefore greatly assist the development of the Jujube industry in Xinjiang China. Several ten-year-old Jujube trees were selected in Akesu area of Xinjiang to investigate the effects of different water-saving irrigation methods on their physiology and yield. Diurnal variation of photosynthetic capacity in Jujube leaves during florescence, young fruit and fruit expanding stages and Jujube yield were measured under 6000 m²/ha of alternate partial root-zone irrigation and conventional infiltrating irrigation. The results indicated that: (1) the diurnal variation of net photosynthetic rate in Jujube leaves presented a bimodal curve with a midday depression phenomenon. The diurnal variation of transpiration rate appeared to single peak type. The diurnal variation of water use efficiency was a single-valley curve. The stomatal conductance varied during the growth season; (2) under conventional irrigation, the net photosynthesis rate, stomatal conductance and transpiration rate increased with increased irrigation volume; and (3) with the same irrigation volume, the root-divided alternative irrigation, compared with conventional irrigation, reduced leaf transpiration rate and increased leaf net photosynthesis rate and water use efficiency, resulting in an increase of Jujube yield by 11% per hectare. The study showed that root-divided alternative irrigation could save water consumption and increase Jujube yield.

Keywords: jujube; root irrigation; root-divided alternative irrigation; photosynthesis

INTRODUCTION

Jujube is the key industry of Xinjiang China, especially for the area around Tarim basin in South Xinjiang China. The region around Tarim basin has advantages in land, light and heat resources, but inadequate water is a major constraint affecting rapid development of the Jujube industry. Most irrigation system in orchards around Tarim basin use surface irrigation. As a result of outdated irrigation technology, extensive irrigation management, poor controllability of irrigating water quotas and low irrigation efficiency, The Chinese data are low and of inferior quality and low benefit fruit, which seriously affects sound development of this fruit industry. Therefore, study of the impact of different irrigation modes and volumes on the water utilization and yield of Jujube tree is necessary.

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Photosynthesis has a close contact with the physiological and ecological indexes of plants, and it is the key factor affecting their yield and quality [10-12, 17]. Study of the diurnal variation of photosynthesis characteristics of potted mango seedlings under different soil water contents allowed determining the optimal soil water content range [16]. Study of photosynthetic function of apple leaves under different irrigation modes by Ma et al. [8] showed that alternate half root-zone irrigation was optimal. Chai et al. [1] determined the diurnal variation of photosynthesis characteristics of fragrant pear during different growing periods. However, there are few reports concerning photosynthesis characteristics of Jujube trees under different moisture regulation. This study analyzed the diurnal variation of photosynthesis of Jujube leaves and yield during different growth periods under conditions of regular infiltrating irrigation and alternate partial root-zone irrigation (APRI). The results will provide a scientific foundation for saving water resources, increasing Jujube yield and accelerating the sustainable development of the Jujube industry.

MATERIALS AND METHODS

Study area

The study area located in Team 9 of Experimental Forest Farm, Akesu Prefecture, Xinjiang, China (80°20′E, 41°10′N; 1200 m). The area has a temperate continental climate, with long sunshine duration and large day-night temperature differences. The annual sunshine duration is 2800–3831 h. The total radiation amount is 6000 MJ·hm⁻² and it is one of the areas with the most solar radiation in China. The annual frost-free season is 183–227 d, the annual average temperature is 9.9–11.5°C, and annual precipitation is 42.4–94 mm. Ten-year-old Jujube trees were selected in the study area, with planting interval of 2 m × 4 m. The surface soil texture is sandy, and the profile soil texture is sand over clay. The chemical characteristics of the soil profile are shown in Table 1.

Table 1

<table>
<thead>
<tr>
<th>Depth [cm]</th>
<th>Texture</th>
<th>Saturated moisture content [%]</th>
<th>Unit weight [g/cm³]</th>
<th>Available nitrogen [mg/kg]</th>
<th>Phosphorus concentration [mg/kg]</th>
<th>Available kalium [mg/kg]</th>
<th>Organic content [%]</th>
<th>Salinity [g/kg]</th>
<th>pH</th>
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<tbody>
<tr>
<td>0–20</td>
<td>Sandy soil</td>
<td>28.18</td>
<td>1.46</td>
<td>6.15</td>
<td>14.20</td>
<td>35.52</td>
<td>0.52</td>
<td>1.85</td>
<td>7.64</td>
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<tr>
<td>20–40</td>
<td>Sand</td>
<td>27.34</td>
<td>1.49</td>
<td>2.46</td>
<td>16.54</td>
<td>31.48</td>
<td>0.28</td>
<td>1.23</td>
<td>7.42</td>
</tr>
<tr>
<td>40–60</td>
<td>Clay</td>
<td>31.76</td>
<td>1.48</td>
<td>9.83</td>
<td>9.47</td>
<td>73.34</td>
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<td>1.50</td>
<td>2.46</td>
<td>3.78</td>
<td>21.31</td>
<td>0.13</td>
<td>1.34</td>
<td>7.73</td>
</tr>
</tbody>
</table>

Material of infiltrating irrigation tube

The infiltrating irrigation tube was constructed of special rolled steel, with a pipe diameter of 32 mm, an aperture of 2 mm and a pitch of holes of 1.0 m (fig.1).
**Experimental design**

Two irrigation modes including regular infiltrating irrigation and Alternate Partial Root-zone Irrigation (APRI) were adopted. The regular infiltrating irrigation used three irrigation quotas: 3000 m$^3$/hm$^2$, 6000 m$^3$/hm$^2$ and 9000 m$^3$/hm$^2$, abbreviated as W1, W2 and W3, respectively. The laying method was two rows of infiltrating irrigation tubes placed under one row of fruit trees. The distance between the infiltrating irrigation tubes and trees was 70 cm, and placement depth was 25 cm.

The APRI used only one irrigation quota of 6000 m$^3$/hm$^2$. The laying method was three rows-6 tubes. From east to west, tube no. 1, 4 and 5 were water supply system 1, while tube no. 2, 3 and 6 were system 2, and these two systems supplied irrigation alternately. The water volume was controlled by water meter and the total fertilizer amount was 1995 kg/hm$^2$ (Table 2), with each treatment having three replications.

**Fertilizer design**

<table>
<thead>
<tr>
<th>Total fertilizing amount 1995[kg/hm$^2$]</th>
<th>Fertilizer variety</th>
<th>Fertilizing amount</th>
<th>Base fertilizer amount</th>
<th>Additional fertilizer before flowering</th>
<th>Additional fertilizer after flowering</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>997.5</td>
<td>72</td>
<td>587.1</td>
<td>334.5</td>
</tr>
<tr>
<td></td>
<td>P$\text{$_2$O}_5$</td>
<td>726</td>
<td>276</td>
<td>162</td>
<td>270</td>
</tr>
<tr>
<td></td>
<td>K$_2$O</td>
<td>262.5</td>
<td>37.5</td>
<td>37.5</td>
<td>187.5</td>
</tr>
</tbody>
</table>

**Determination and control of soil moisture**

A TRIME instrument was used to measure moisture before and after irrigation during the growth period, while a SM100 Soil Moisture Timing Collector was also used to measure before and after rainfall. Five points were fixed in two sides by taking the pipeline as the center, i.e., the horizontal perpendicular distances between the pipeline and the five points were respectively 0, ±35, ±70, ±105, and ±140 cm. In addition, six points were fixed in the vertical direction of the ground to monitor soil moisture variation (of vertical depths of 0, 20, 40, 60, 80 and 120 cm) giving a monitoring depth of 0–120 cm. Then, soil was extracted using a soil auger, dried and measured by TRIME instrument and SM100 Soil Moisture Timing Collector.

The following formula is used for calculating the irrigation period.

**Fig. 1 - Section of infiltrating irrigation tube**

---

**Table 2**

<table>
<thead>
<tr>
<th>Growth period</th>
<th>Budding period</th>
<th>Full-blossom period</th>
<th>Fruitlet period</th>
<th>Expanding period</th>
<th>Mature period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Additional fertilizer 11 times</td>
<td>1</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

**土壤水分测定及控制**

采用随机取样的方法，生育期内灌前灌后水分监测采用trime 仪观测，sm100 土壤水分定时采集器，降雨前后加测。以管道为中心两边分别定 5 个点，即在垂直管道距离为 0cm、±35cm、±70cm、±105cm、±140cm，5 个点，垂直地面 6 个深度，即垂直地面向下 0cm、20cm、40cm、60cm、80cm、120cm、6 个深度监测土壤含水变化，监测深度 0-120cm。土钻取土、烘干对 trime 仪和 sm100 进行校核。

灌溉周期:
Where, $T$ is irrigation period (d), $m$ is irrigation quota $(m^3/hm^2)$ and $ET_a$ is daily water consumption $(m^3/hm^2)$. The detailed moisture adjustment program is shown in Table 3.

![Image of Table 3](image-url)

**Table 3**
The root penetration irrigation systems in Jujube orchard

<table>
<thead>
<tr>
<th>Irrigation quota: 3000, 6000, 9000 $(m^3/hm^2)$</th>
<th>Total</th>
<th>Budding period</th>
<th>Full-blossom period</th>
<th>Fruitlet period</th>
<th>Expanding period</th>
<th>Mature period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigation quota</td>
<td>100%</td>
<td>5%</td>
<td>35%</td>
<td>30%</td>
<td>25%</td>
<td>5%</td>
</tr>
<tr>
<td>Irrigation frequency</td>
<td>26</td>
<td>3</td>
<td>6</td>
<td>7</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Irrigation period</td>
<td>6.2 days</td>
<td>8 days</td>
<td>6 days</td>
<td>5 days</td>
<td>6 days</td>
<td>8 days</td>
</tr>
</tbody>
</table>

**Determination of photosynthetic rate and physiological index**

The Li-6400 Portable Photosynthesis Meter equipped with red and blue light (6400-02B) was used to determine the following indices of environmental factors during the flowering period (30 May 2012), the fruit period (25 June) and the expanding period (25 July), including photosynthetic active radiation (PAR) and atmospheric CO$_2$ concentration (Ca). The following photosynthetic physiological indices were also determined: net photosynthetic rate (Pn), stomatal conductance (Gs) and evaporation rate (Evap). Three plants were selected in each treatment with relatively consistent growth and two healthy leaves from the middle and upper parts of young shoots were measured on cloudless days. The average value of three reading values of each leaf was regarded as the measured value. The period of time was 09:00–21:00, with one measurement every 2 h. The limiting value of water use efficiency (WUE) was calculated using the obtained parameters, using the formula: $WUE = \frac{Pn}{Evap}$.

**Determination of meteorological factors**

A Vantage Pro2 wired automatic meteorological station was used to measure precipitation (P), solar radiation (Rs), air temperature (Ta), relative humidity (RH) and wind speed (Ws).

**Yield determination**

During the harvest time of Jujube, five plants were randomly selected in each treatment respectively, and the statistic was made by taking the plot as a unit. The quantity and weight of fruit, average weight of single fruit and total yield in each treatment were recorded to calculate the yield per hectare in accordance with single-plant yield and planting density.

**Data processing**

Excel 2010 and SPSS 18.0 were used for data processing and statistical analysis.

**RESULTS AND ANALYSIS**

**Environmental factor analysis of Jujube orchard**

Under natural conditions, variation in Rs, PAR, Ca, Ta, RH and other environmental factors all affected the photosynthesis characteristics of Jujube leaves. Rs and PAR among measured external environmental indices increased gradually with time from 9:00, reached peaks.

光合速率及生理指标测定

于花期（2012 年 5 月 30 日）、幼果期（6 月 25 日）、膨大期（7 月 25 日），采用 Li-6400 便携式光合仪，配备红蓝光源（6400-02B），测定环境因子指标：光合有效辐射（PAR）和大气 CO$_2$ 浓度（Ca），光合生理指标：净光合速率（Pn）、气孔导度（Gs）和蒸腾速率（Evap）。每处理选取生长较为一致的植株 3 株，选光照较好的新梢中上部健康叶 2 片并标记，每叶片以 3 次读数的平均值作为测定值，时间为 09:00-21:00，每隔两个小时测定一次。根据所获取的参数计算水分利用效率 WUE。公式为 $WUE = \frac{Pn}{Evap}$。

气象因子测定

采用 Vantage Pro2 有线自动气象站测定降雨量（precipitation, P）和太阳辐射（solar radiation, Rs），气温（air temperature, Ta），相对湿度（relative humidity, RH）和风速（wind speed, Ws）。

产量测定

在红枣收获期，每个处理随机选取 5 株进行单采单收，以小区为单位进行统计。采收时，记载各处理的果实数目、果实重量，平均单果重及总产量，根据单株产量和栽植密度计算出每亩产量。

数据处理

本文采用 Excel 2010 与 SPSS 18.0 进行数据处理与统计分析。

结果与分析

枣园环境因子分析

自然条件下，太阳辐射、光合有效辐射、大气 CO$_2$ 浓度、大气温度以及大气相对湿度等环境因子的变化都会给果树叶片的光合特性带来影响。由表 4 可知，在测定的外界环
around 15:00 and then dropped gradually (Table 4). Rs and PAR in different growth periods increased gradually from 30 May, reached peaks on 25 June and dropped on 25 July. Ta presented a variation trend of initial increase followed by a decrease, with peak values all at 17:00. Diurnal variation amplitudes of Ta on 30 May, 25 June and 25 July were 20.6°C, 17.2°C and 19.8°C, respectively. That of the earlier growth period was higher than the latter, mainly because Ta at 9:00 was low in the earlier growth period.

This showed that large day-night temperature differences, strong Rs and low RH are typical climatic features of this desert-oasis zone. However, great variation in temperature and RH could improve the yield and quality of fruit trees as it increased the carbon assimilation capacity of plants in day-time and decreased the consumption of dry matter by plant respiration at night.

<table>
<thead>
<tr>
<th>Date</th>
<th>Indices</th>
<th>Determined time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>9:00</td>
</tr>
<tr>
<td>30 May</td>
<td>Solar radiation [W/m²]</td>
<td>92</td>
</tr>
<tr>
<td></td>
<td>Air temperature [°C]</td>
<td>11.7</td>
</tr>
<tr>
<td></td>
<td>Relative humidity [%]</td>
<td>73</td>
</tr>
<tr>
<td></td>
<td>Photosynthetic active radiation [μmol/(m²·s)]</td>
<td>597.33</td>
</tr>
<tr>
<td></td>
<td>Atmospheric CO₂ concentration [μmol/mol]</td>
<td>404.67</td>
</tr>
<tr>
<td>25 June</td>
<td>Solar radiation [W/m²]</td>
<td>127</td>
</tr>
<tr>
<td></td>
<td>Air temperature [°C]</td>
<td>18.1</td>
</tr>
<tr>
<td></td>
<td>Relative humidity [%]</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td>Photosynthetic active radiation [μmol/(m²·s)]</td>
<td>1,397.67</td>
</tr>
<tr>
<td></td>
<td>Atmospheric CO₂ concentration [μmol/mol]</td>
<td>409.57</td>
</tr>
<tr>
<td>25 July</td>
<td>Solar radiation [W/m²]</td>
<td>104</td>
</tr>
<tr>
<td></td>
<td>Air temperature [°C]</td>
<td>16.6</td>
</tr>
<tr>
<td></td>
<td>Relative humidity [%]</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>Photosynthetic active radiation [μmol/(m²·s)]</td>
<td>673.67</td>
</tr>
<tr>
<td></td>
<td>Atmospheric CO₂ concentration [μmol/mol]</td>
<td>437.53</td>
</tr>
</tbody>
</table>

Table 4

Daily changes of environmental factors in different growth periods

Note: The former three items were from the observed results of the meteorological station (observation once every 15 min), while the latter two were from the measured results of the photosynthesis meter.

Diurnal variation of photosynthesis under infiltrating irrigation

1) Diurnal variation of net photosynthetic rate

The diurnal variation of Pn of jujube leaves at different growth periods presented an ‘M’ shape (Fig. 2), with the peak value usually at 11:00 and 17:00; and it always showed a ‘noon break’ appearance during 14:00–16:00, especially under W1 treatment. Under regular infiltrating irrigation, the Pn of Jujube leaves showed a steady increasing trend with increased irrigation volume. For the daily average Pn on 30 May (Table 5), that of W1 significantly decreased by 23% compared with that of W3 (P < 0.05). Meanwhile, the difference in Pn between W2 and APRI was not significant, and the Pn of APRI increased slightly compared with that of W2. On 25 June, the Pn of W1 significantly decreased by 21.2% compared with W3.

1) 净光合速率(Pn)的日变化规律

由图 2 可知，不同生育期枣树叶片净光合速率日变化呈“M”型，峰值基本都出现在 11:00 和 17:00。14:00-16:00

均出现“午休”现象。W1 处理下“午休”现象最明显。常规渗灌下随着灌溉量的增加，叶片的光合速率呈明显的稳定上升的趋势。5 月 30 日的平均光合速率（表 5）W1 与

W3 相比降低 23%，差异显著（P<0.05）, W2 和 APRI

净光合速率差异不显著；APRI 和 W2 相比略有上升。6 月

25 日 W1 与 W3 相比降低了 21.2%，差异显著
with that of W3 ($P < 0.05$). On 25 July, the Pn of W1 and W2 decreased by 33% and 13%, respectively, compared with that of W3 ($P < 0.05$). The Pn of APRI increased by 14% compared with that of W2 ($P < 0.05$). Thus APRI significantly increased the Pn of Jujube leaves under the same irrigation volume compared to regular infiltrating irrigation.

（P<0.05）。7月25日W1、W2与W3相比分别降低了33%和13%，差异显著（P<0.05）；APRI与W2相比上升了14%，差异显著（P<0.05），表明同一灌溉量，APRI能够显著提高枣树叶片净光合速率。

**Table 5**

<table>
<thead>
<tr>
<th>Date</th>
<th>Treatment</th>
<th>Net photosynthetic rate [μmol·m⁻²·s⁻¹]</th>
<th>Evaporation rate [mmol·m⁻²·s⁻¹]</th>
<th>Water use efficiency [μmol/mmol]</th>
<th>Stomatal conductance [mol/m²·s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 May</td>
<td>APRI</td>
<td>6.48±0.52a</td>
<td>1.86±0.24b</td>
<td>3.46±0.39a</td>
<td>71.52±19b</td>
</tr>
<tr>
<td></td>
<td>W1</td>
<td>5.19±0.47b</td>
<td>1.69±0.21b</td>
<td>3.00±0.40b</td>
<td>45.52±16b</td>
</tr>
<tr>
<td></td>
<td>W2</td>
<td>6.45±0.54a</td>
<td>2.04±0.22b</td>
<td>3.13±0.47b</td>
<td>79.05±19b</td>
</tr>
<tr>
<td></td>
<td>W3</td>
<td>6.59±0.53a</td>
<td>2.15±0.26b</td>
<td>3.04±0.36b</td>
<td>84.67±20b</td>
</tr>
<tr>
<td>25 June</td>
<td>APRI</td>
<td>9.97±1.0b</td>
<td>3.64±0.32a</td>
<td>2.85±0.18a</td>
<td>150.57±439b</td>
</tr>
<tr>
<td></td>
<td>W1</td>
<td>7.87±0.95b</td>
<td>3.37±0.37a</td>
<td>2.45±0.22b</td>
<td>114.42±38b</td>
</tr>
<tr>
<td></td>
<td>W2</td>
<td>9.23±0.97b</td>
<td>3.84±0.39a</td>
<td>2.55±0.19b</td>
<td>162.71±38b</td>
</tr>
<tr>
<td></td>
<td>W3</td>
<td>10.13±1.00b</td>
<td>4.19±0.40a</td>
<td>2.50±0.17b</td>
<td>188±40b</td>
</tr>
<tr>
<td>25 July</td>
<td>APRI</td>
<td>14.33±1.20b</td>
<td>3.24±0.73b</td>
<td>5.25±0.82b</td>
<td>172.08±52b</td>
</tr>
<tr>
<td></td>
<td>W1</td>
<td>9.60±0.82c</td>
<td>2.82±0.56c</td>
<td>4.40±0.88b</td>
<td>123.57±37b</td>
</tr>
<tr>
<td></td>
<td>W2</td>
<td>12.54±1.09b</td>
<td>3.43±0.64b</td>
<td>4.68±0.90b</td>
<td>198.22±48b</td>
</tr>
<tr>
<td></td>
<td>W3</td>
<td>14.36±1.16b</td>
<td>3.86±0.75c</td>
<td>4.50±0.78bc</td>
<td>205.18±53c</td>
</tr>
</tbody>
</table>

Notes: Different letters (i.e. a, b and c) indicate significant difference at $P < 0.05$. 

**Fig.2** Diurnal variation of net photosynthetic rate of jujube leaves under infiltrating irrigation
2) Diurnal variation of evaporation rate

Evaporation is an important physiological index reflecting the water status of plants. The ability of plants to adapt to arid environments is strong when Evap is low[2]. The diurnal variation curves of Evap were uniformly of unimodal type under different treatments during main growth periods, with the peak values always during 14:00-16:00 (Fig.3). Under regular infiltrating irrigation, the Evap increased gradually with increased irrigation volume. The daily average Evap (Table 5) of W1 were all significantly different ($P < 0.05$) on 30 May, 25 June and 25 July compared with those of W3, while the corresponding values of APRI decreased by 9%, 6% and 7% compared with those of W2. Thus APRI decreased the Evap of jujube leaves under the same irrigation level compared to regular infiltrating irrigation.

![Diurnal variation of evaporation rate of jujube leaves under infiltrating irrigation conditions](image)

3) Diurnal variation of water use efficiency

The WUE reflects the short-term or instantaneous behavior of plant leaves to water conditions. To some extent, it reflects the water consumption of plants and their adaptability to an arid environment[9]. The diurnal variation curves of WUE of Jujube leaves presented a single-valley shape during main growth periods (Fig. 4). WUE reached a maximum at 9:00. The main reasons for this phenomenon include that the $Pn$ of leaves increased with increased PAR (external environmental factor) by this time, the stomatal aperture of leaves was larger, the RH of air was still high and the Evap had not reached a maximum. WUE of plants was high, and dropped to a minimum at 15:00. The daily average WUE of leaves of W2 and APRI on 30 May increased by 3% and 14% compared with that of W3, they thereafter increased by

![Diurnal variation of water use efficiency](image)
2% and 14% on 25 June, and by 2% and 15% on 25 July. The results implied that slight moisture loss could improve the WUE of leaves. The daily average WUE of leaves of APRI on 30 May, 25 June and 25 July increased by 11%, 12% and 13%, respectively, compared with those of W2. Thus APRI significantly increased the WUE of Jujube leaves under the same irrigation level.

**Fig. 4** - Diurnal variation of water use efficiency of Jujube leaves under infiltrating irrigation conditions

4) **Diurnal variation of stomatal conductance**

The Gs of leaves reached a maximum on 9:00 on May 30 (Fig.5) and then declined gradually and remained stable after 15:00. The main reason for the aforesaid phenomenon is that PAR was relatively low in the morning and the air RH was high, which led to high stomatal apertures, and then Gs decreased gradually with increasing PAR and decreasing RH. The daily average value of Gs of W1 was notably lower than those of other treatments (P < 0.05). The variation trends of Gs and Pn of Jujube leaves were similar, both with a bimodal pattern on 25 June, and peak values always at 11:00 and 17:00. The Gs of treatments all showed a trend of initially high followed by low values. The daily average value of Gs of W1 decreased by 31% compared with that of W3 (P < 0.05). The diurnal variation curve of Gs of Jujube leaves showed a bimodal pattern on 25 July, and peak values occurred at 13:00 and 17:00 with the former higher than the latter. The daily average values of Gs of W1 and APRI decreased by 39% and 16%, respectively, compared with those of W3. The daily average values of Gs of APRI on 30 May, 25 June and 25 July decreased by 9%, 7% and 12%, respectively, compared with those of W2 (P < 0.05).

4) **气孔导度（Gs）的日变化规律**

由图5可知，5月30日叶片气孔导度在9:00达到最大，随后逐渐降低，15:00后趋于平缓，主要原因是早上太阳光合有效辐射较低，空气湿度较高，导致气孔高度开放，随后随着光合有效辐射升高和空气湿度降低气孔导度逐渐降低；W1处理下气孔导度日均值显著低于其他处理（P<0.05）。6月25日叶片气孔导度变化趋势与净光合速率一致，呈双峰型，峰值出现在11:00和17:00点，不同处理气孔导度均呈现前高后低的趋势，W1的叶片气孔导度日均值比W3下降了31%，差异显著（P<0.05）；7月25日枣树叶片的气孔导度日变化曲线呈双峰型。气孔导度峰值出现在13:00和17:00。第一次峰值明显高于第二次，与W3气孔导度日均值相比W1和APRI分别下降了39%和16%，5月30日、6月25日和7月25日APRI处理下的叶片气孔导度日均值比W2分别降低了9%、7%和12%，差异不显著（P<0.05）。
Influence of infiltrating irrigation and APRI on yield of Jujube

The weight of fresh fruit, weight of dry fruit, fruit setting quantity, fruit width and yield per hectare all increased gradually with increased irrigation volume under regular infiltrating irrigation (Table 6). APRI increased weight of fresh fruit, weight of dry fruit, fruit setting quantity and fruit width of Jujube under the same irrigation level compared to regular infiltrating irrigation. The yield per hectare of APRI increased by 11% compared with that of W2, showing that APRI could save water and increase yield.

### Table 6

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Irrigation quota [m³/hm²]</th>
<th>Weight of fresh fruit [g]</th>
<th>Weight of dry fruit [g]</th>
<th>Fruit setting quantity [Thousand piece]</th>
<th>Fruit width [cm²]</th>
<th>Yield [kg/hm²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>APRI</td>
<td>6000</td>
<td>5.19</td>
<td>3.17</td>
<td>212.22</td>
<td>3.60</td>
<td>16426 a</td>
</tr>
<tr>
<td>W1</td>
<td>3000</td>
<td>4.15</td>
<td>2.67</td>
<td>201.65</td>
<td>3.40</td>
<td>12147 b</td>
</tr>
<tr>
<td>W2</td>
<td>6000</td>
<td>4.70</td>
<td>3.15</td>
<td>207.40</td>
<td>3.50</td>
<td>14703 b</td>
</tr>
<tr>
<td>W3</td>
<td>9000</td>
<td>5.25</td>
<td>3.14</td>
<td>216.29</td>
<td>3.80</td>
<td>17100 a</td>
</tr>
</tbody>
</table>

DISCUSSIONS AND CONCLUSIONS

For Jujube trees in the area around Tarim basin in South Xinjiang of China, the daily average values of Pn in the later growth period were higher than that of

### Conclusion

In the study of the net photosynthetic rate of jujube trees in the area around the Tarim Basin in South Xinjiang of China, the daily average values of Pn in the later growth period were higher than that of the earlier growth period. The weights of fresh fruit, dry fruit, fruit setting quantity, fruit width, and yield per hectare increased gradually with increased irrigation volume under regular infiltrating irrigation (Table 6). APRI increased the weight of fresh fruit, weight of dry fruit, fruit setting quantity, and fruit width of jujube under the same irrigation level compared to regular infiltrating irrigation. The yield per hectare of APRI increased by 11% compared with that of W2, indicating that APRI could save water and increase yield.

By Table 6, under regular infiltration irrigation, the weights of fresh fruit, dry fruit, fruit setting quantity, and fruit width of jujube increased with increased irrigation volume. Under the same irrigation level, APRI increased the weights of fresh fruit, dry fruit, and fruit setting quantity, and the fruit width was also higher compared to regular infiltration irrigation (Table 6). The yield per hectare of APRI increased by 11% compared with that of W2, indicating that APRI could save water and increase yield.
earlier periods. The Pn values of this study on 25 June and 25 July were higher than that on 30 May. This phenomenon was possibly due to the peak values of PAR on 30 May, 25 June and 25 July, which were 1928, 2400 and 2155 W/m², respectively. Moreover, Ta difference might also cause different photosynthetic rates. Excessive Ta can decrease the photosynthetic rate of plant leaves [6-7, 14] and generate the photosynthetic ‘noon break’ phenomenon. Low temperature at night can also improve Pn during the day, as research results of McDonald and Paulsen [9] showed that the Pn of pea and other plants under a diurnal temperature of 30/25°C was lower than that of 30/15°C. The decrease of RH and Ta could reduce respiration and consumption by weakening the dark respiration rate. Thus, the fruit setting rate and yield could be improved.

Different irrigation treatments had a significant impact on Pn of Jujube trees, which rose with increased irrigation volume. Under the same meteorological conditions, the lack of soil moisture could result in decreases of Gs and Evap. Thus, the Pn of leaves and the WUE could also be reduced [4-5, 18-19]. This study showed that the WUE of leaves decreased under W1 irrigation treatment. During each growth period, the Pn, Gs and Evap for the W2 treatment were lower than those for W3, but the difference was not significant. However, the WUE for W2 was higher than that for W3 treatment, showing the decrease of irrigation volume to some extent did not decrease the Pn, Gs and Evap, but improved the WUE and enabled the Jujube trees to possess certain drought resistant ability [15, 3].

Under the same irrigation level, the Pn of APRI on 30 May and 25 June increased slightly compared with that of W2, while the Pn and WUE under APRI treatment on 25 July were apparently higher than those of W2, and the Pn and WUE under APRI and W2 treatments were 14.33, 12.54, 5.25 and 4.50 μmol·mmol⁻¹, respectively. The main reason for this phenomenon was the abundant secondary roots produced by jujube under alternate stress of the APRI treatment, and then the absorbing ability of root systems for water and fertilizer was enhanced, and so WUE improved and Pn also increased, the yield therefore also increased. The Evap under APRI treatment in each growth period was higher than that of W2, but the Gs was lower. This was mainly because some roots were in an area of dry soil under APRI, and so the Jujube roots likely formed plenty of abscisic acid due to water stress, which was transferred to leaves to reduce stomatal apertures and water consumption by evaporation. Some roots were in area with irrigated soil, so as to meet the normal physiological activities.

APRI improved the fruit setting rate and yield of Jujube trees under the same irrigation level as regular infiltrating irrigation. The fruit setting rates and yields of APRI and W2 treatments were 212220 and 207400, and 164262 and 147036 kg/hm², respectively. Pn increased when Jujube trees suffered alternate stress under the APRI treatment, and so the fruit setting rate and total yield improved.

Under the same irrigation level, the APRI reduced Evap and Gs, and improved Pn, WUE and yield per hectare and significantly (P < 0.05) improved the yield by 11% compared with regular infiltrating irrigation. The yield per hectare of Jujube showed no difference (P > 0.05) under the APRI compared with W3. The APRI higher than 5/30月。造成这一现象的原因有5月30日、6月25日和7月25日。的光合有效辐射的峰值分别为1928、2400和2155 W/m²，但空气温度的差异则导致其光合速率的不同，过高的空气温度会导致植物叶片光合速率的降低，且会产生“光合午休”现象[6-7, 14]。夜间低温也会提高白天的光合速率，McDonald 等的研究结果表明豌豆等作物昼夜间温度为30/25℃时的光合速率会低于30/15℃时的光合速率[9]。大气相对湿度和空气湿度的降低则导致呼吸速率的减少，从而降低呼吸消耗，提升坐果率和产量。

不同灌溉处理对枣树的光合速率有着显著的影响。随着灌溉量的增加枣树叶片光合速率呈上升趋势。在相同的气象条件下，土壤水分的亏缺会导致气孔导度和蒸腾速率的降低，从而降低光合速率[4-5, 18-19]，并降低叶水分利用效率，本文在W1灌溉处理下叶片水分利用效率下降，与该文章结论相一致。不同时期W2处理下的光合速率，气孔导度和蒸腾速率低于W3处理差异并不显著，但W2处理下的水分利用效率高于W3处理，表明一定程度上降低灌溉量并不会显著降低光合速率、气孔导度和蒸腾速率，但会提高水分利用效率，具有一定的抗旱能力[15, 3]。

同一灌溉水平，5月30日和6月25日APRI的光合速率高于W2，且不显著，7月25日APRI处理下的光合速率和水分利用效率显著高于W2。APRI和W2处理下的光合速率和水分利用效率分别为14.33 μmol·m⁻²·s⁻¹，12.54 μmol·m⁻²·s⁻¹和5.25 μmol·mmol⁻¹，4.50 μmol·mmol⁻¹，造成这一现象的原因可能是因为APRI使枣树根部受到交替胁迫后次生根大量增加，根系吸水吸肥能力增加，水分利用效率明显提高，净光合速率也随之增加，最终产量也得到提升。各时期APRI处理下的蒸腾速率高于W2；气孔导度低于W2，但差异不显著，主要是因为APRI使部分根系处于土壤干燥的区域，枣树受到水分胁迫，根部形成大量脱落酸，传送至叶片，气孔开度减少，降低蒸腾耗水量；还有部分根系处于灌水的区域中，以满足正常的生理活动。

本文中，同一灌溉水平，APRI能够提高枣树坐果率和枣树产量。APRI和W2处理下的坐果率和产量分别为212220个、207400个和164262 kg/hm², 147036 kg/hm²。APRI处理下果树受到交替胁迫能够提高光合速率进而提高坐果率，产量得到提升。

在不同灌溉水平下，分根交替灌溉降低枣树叶片蒸腾速率、气孔导度；提高枣树叶片的光合速率、水分利用率，最终提高枣树达11%，与常规灌溉相比达到显著水平（P<0.05），与W3相比，分根交替灌溉条件下红枣产量
improved Pn and yield on the basis of water saving. This study demonstrated an effective irrigation mode for development of the jujube industry in Xinjiang, and provided a decision basis for saving water resources, increasing Jujube yield and accelerating the sustainable development of this industry.

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REFERENCES

A KINEMATIC ANALYSIS AND SIMULATION BASED ON ADAMS FOR EGGPLANT PICKING ROBOT

Abstract: Eggplant picking robot is a type of complex optical-mechanical-electrical equipment in greenhouse environment. Its structure and control are more exigent than traditional industrial robot. Optimization design method was utilized for the design of the eggplant picking robot body structure parameters in accordance with the eggplant growth and distribution space. In order to determine the spatial position relationship between the eggplant picking robot components and the end effector, the theoretical model of robot was established by virtue of Denavit-Hartenberg approach and the positive solution of the kinematic equation is obtained. Premultiplication decoupling of $A^1$ and matrix $T$, were adopted to inverse kinematic solution with the help of Matlab software. Pro/E software was used to establish 3-D simulation model, and ADAMS (Automatic Dynamic Analysis of Mechanical Systems) simulation software was imported for the kinematics simulation analysis. It was indicated by the simulation results that the kinematic model established by D-H approach reflects the real motion conditions of the robot, and both the positive and inverse kinematic solutions are correct. Structure of four degrees freedom eggplant picking robot was reasonable, it could meet the requirements of eggplant picking in the greenhouse cultivation pattern.

Keywords: Eggplant picking robot, ADAMS, Kinematics simulation, four degrees of freedom, Agricultural machinery

INTRODUCTION

Harvesting or picking is the most effort-requiring and time-consuming procedure in eggplant production operation, which, according to statistics, approximately accounts for from 50% to 70% of all the amount of working [7]. Moreover, it requires timely picking to guarantee the product quality, making it as the hardest work in the whole operation [5]. With the rapid development of agricultural mechanization, considering the problems with aging of population and the decrease of agricultural labor force, it is more and more significant to research and develop fruit and vegetable picking robot [8]. Since the mid 1980s, researches on automatic fruit and vegetable picking have been started in the western developed countries represented by Japan, and some vegetable picking robots with certain intelligence were experimented and developed [9,10,11]. In the intelligent tomato picking robot end effector based on multi-sensor information fusion and open control system designed by Jizhan Liu, etc, the vacuum chuck device of the execution system could separate the fruit from the fruit bunch, its finger gripper mechanism could grasp the tomato firmly, and the fruit stem disconnecting device could cut off the fruit stem with laser [4]. Peng Cui proposed a bionic manipulator which was applied to the apple picking robot end effector and the simple fixture was replaced with the tendon-driven bionic manipulator, enhancing the adaption of the end effector to grab apple in complex environment [6]. Wei Lu designed an original orange picking robot arm and end effector, implemented for Matlab, with the left multiplication decoupling, assistance of $D$年代中期开始,日本等西方发达国家开始了Denavit-Hartenberg软件求出运动学逆解。利用优化设计方法进行了茄子采摘机器人本体结构参数的设计。借助Denavit-Hartenberg法建立了采摘机器人的理论模型,得到机器人的运动学方程的正解,确定机器人各运动构件与末端执行器在空间位置之间的关系。采用$A^1$与矩阵$T$左乘解耦,借助Matlab软件求出运动学逆解。利用pro/e建立茄子采摘机器人三维模型,导入ADAMS仿真软件进行运动学仿真分析。仿真结果表明;D-H法建立的运动学模型反映了采摘机器人的真实运动情况,采摘机器人运动学正逆解正确。设计开发的4自由度采摘机器人结构设计的合理,能够满足温室栽培模式下茄子采摘的要求。

关键词: 茄子采摘机械手, ADAMS, 运动学仿真, 四自由度, 农业机械化

Abstract: Eggplant picking robot is a type of complex optical-mechanical-electrical equipment in greenhouse environment. Its structure and control are more exigent than traditional industrial robot. Optimization design method was utilized for the design of the eggplant picking robot body structure parameters in accordance with the eggplant growth and distribution space. In order to determine the spatial position relationship between the eggplant picking robot components and the end effector, the theoretical model of robot was established by virtue of Denavit-Hartenberg approach and the positive solution of the kinematic equation is obtained. Premultiplication decoupling of $A^1$ and matrix $T$, were adopted to inverse kinematic solution with the help of Matlab software. Pro/E software was used to establish 3-D simulation model, and ADAMS (Automatic Dynamic Analysis of Mechanical Systems) simulation software was imported for the kinematics simulation analysis. It was indicated by the simulation results that the kinematic model established by D-H approach reflects the real motion conditions of the robot, and both the positive and inverse kinematic solutions are correct. Structure of four degrees freedom eggplant picking robot was reasonable, it could meet the requirements of eggplant picking in the greenhouse cultivation pattern.

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considering the tall crown of citrus tree, and the high degree of lignification of its short and stiff fruit stem [12].

However, the above-described robots are still far from practical application owing to the influence factors from technology, market, and price and so on [1]. It can be seen from the analysis of literatures at home and abroad that these researches on the picking robot are mainly focused on identifying, positioning and sorting the target fruit via the vision system [14], while there are rare researches on the basic machine of the picking robot [3].

Robot kinematics is an important constituent part of robotics, whose purpose is to establish the relationships among spatial positions of the robot components and end effectors so as to provide theoretical basis and technical parameters for the optimized control of the robot [2]. However, it requires establishing mathematic model of the robot arm movements to finish most of these tasks, which have tedious process, heavy computation burden, and are error-prone [13]. In this paper, ADAMS simulation software was used for kinematics analysis and simulation study on the eggplant picking robot, which could solve the above-mentioned problem in the course of kinematics analysis in traditional multi-rigid-body system and meanwhile show intuitively the kinematic performance of the robot movement components in the diagram and simulation animation form, providing a powerful guarantee for follow-up programming of robot motion trail and verification of the structure parameter rationality.

MATERIALS AND METHODS

Structure parameter of picking robot

The articulated robot with four degrees of freedom is selected to be the basic machine of the picking robot because the picking object of the eggplant picking robot is the eggplant whose fruit is cylindrical.

The robot structure parameters mainly include: the robot arm length and the rotation angle scope, etc. and these parameters determine the work space of the robot. The optimization design of the eggplant picking robot structure parameters is to use optimal method to analyze and calculate the mechanism size in accordance with the eggplant growth and distribution space.

The purpose of the optimization design is to obtain the most compact mechanical structure. The upper arm length \( x_1 \) and the forearm \( x_2 \) of picking robot are regarded as the design variables, and the actually work space of picking robot is optimization objective. The objective function is shown as follow:

\[
\min f(X) = \frac{1}{4} \pi (x_1 + x_2)^2 + \frac{1}{2} \pi x_1^2 - \frac{1}{2} (x_1^2 + x_2^2 - 2x_1x_2 \cos 30^\circ)
\]

但是由于技术、市场和价格等因素的影响，离实际应用还有很大距离[1]。国内外研究文献中，对于采摘机器人的研究大多集中在视觉系统对果实采摘与分拣目标的识别和定位上[14]，而对于采摘机器人机械本体的研究较少[3]。

机器人运动学是机器人学的重要组成部分，研究机器人运动学的目的是建立机器人各运动构件与末端执行器之间关系的数学模型，为机器人的优化控制提供理论依据和技术参数[2]。但完成这些工作都需要建立机器人手臂运动的数学模型，过程繁琐、计算量大、容易出错[13]。本文运用 ADAMS 仿真软件对茄子采摘机器人进行运动学分析与仿真研究，解决了传统多刚体系统运动学分析过程所发生的上述问题，同时能将机器人各个运动机构的运动性能通过图表和模拟动画的形式直观表现出来，为后续机器人的运动轨迹进行规划，结构参数的合理性验证提供有力保证。

材料与方法

采摘机器人结构参数

由于茄子采摘机器人的采摘对象是茄子，其果实呈圆柱形。所以，选用具有四自由度关节式机器人作为采摘机器人的机械本体。

机器人结构参数，主要包括机械臂的长度及其转角范围等。机器人的结构参数决定了机器人的工作空间。茄子采摘机器人结构参数的优化设计是根据茄子生长分布空间，利用优化方法进行机构设计与计算。

优化设计的目的是得到最紧凑的机械机构。优化设计变量为大臂长 \( x_1 \)，小臂长 \( x_2 \)，优化目标是采摘机器人的实际工作空间。目标函数如下式所示:

\[
\min f(X) = \frac{1}{4} \pi (x_1 + x_2)^2 + \frac{1}{2} \pi x_1^2 - \frac{1}{2} (x_1^2 + x_2^2 - 2x_1x_2 \cos 30^\circ)
\]
The working space of eggplant picking robot is shown as Fig.1. The constraint condition is that it should be the minimum value under the required rectangle work space conditions, i.e., the rectangle work space required by the picking manipulator operation must be confined in the real work space. Using the optimization toolbox of Matlab software for programming, calculating and operation, the optimization result can be obtained as follow:

With an overall consideration, it confirms that $x_1 = x_2 = 350\text{mm}$. The height of pedestals is $340\text{mm}$, rotation angle of the waist $\theta_1$ is $\pm 180^\circ$; the upper arm length $x_3$ is $350\text{mm}$, rotation angle $\theta_4$ is $\pm 90^\circ$; the forearm length $x_4$ is $350\text{mm}$, rotation angle $\theta_5$ is $\pm 150^\circ$.

**Model based on kinematic theory**

D-H model is an approach proposed by Denavit-Hartenberg for the expression and modeling of robot joints and connecting rods, which adopts $4 \times 4$ homogeneous transformation matrix to describe the spatial position relationship of the adjacent robot rod pieces, thus translates the complicated kinematic question into $4 \times 4$ equivalence transformation matrix of the coordinate system of the end effectors and reference coordinate system. As shown in Fig.2, the coordinate system of connecting rods of 4-DOF picking robot is established according to D-H approach.

**Matrix $A_i$** represents 4-order homogeneous transformation matrix between the connecting rod coordinate systems, and is usually expressed as follow:

$$A_i = \text{Rot}(z, \theta_i) \times \text{Trans}(a_i, 0, 0) \times \text{Rot}(x, a_i).$$

The parameters of the picking robot joint connecting rods can be obtained according to the coordinate system of connecting rods of picking robot in Fig.2, as shown in Table1.

---

![Coordinate system of connecting rods of eggplant picking robot](image-url)

**Fig.2 - Coordinate system of connecting rods of eggplant picking robot**

Matrix $A_i$ 表示连杆坐标系之间的 4 阶齐次变换矩阵，一般表达为：

$$A_i = \begin{bmatrix}
\cos \theta_i & -\sin \theta_i & \cos \alpha_i & a_i \cos \theta_i \\
\sin \theta_i & \cos \theta_i & \sin \alpha_i & a_i \sin \theta_i \\
0 & 0 & 1 & d_i \\
0 & -\sin \alpha_i & \cos \alpha_i & 1
\end{bmatrix}.$$  

---

图 1 表示了茄子采摘机器人实际需要的工作空间。约束条件为使其在包含所要求的矩形工作空间条件下为最小值，就是必须使采摘机械手作业要求的矩形工作空间包含在实际工作空间内。使用 Matlab 软件的优化工具箱进行编程计算，运行得到优化结果为：

$$X = [312, 335]$$  

综合考虑，确定 $X_1 = X_2 = 350\text{mm}$。最后确定底座高为 $340\text{mm}$。腰部回转角 $\theta_1$ 为 $\pm 180^\circ$；大臂长 $350\text{mm}$，回转角度 $\theta_2$ 为 $\pm 90^\circ$；小臂长 $350\text{mm}$，回转角度 $\theta_3$ 为 $\pm 150^\circ$。

**运动学理论模型**

D-H 模型是 Denavit 和 Hartenberg 提出的对机器人关节和连杆进行表示和建模的方法。它采用 $4 \times 4$ 齐次变换矩阵来描述相邻机器人杆件的空间位置关系，将复杂的运动学问题转化为末端执行器的坐标系与参考坐标系的 $4 \times 4$ 等价变换矩阵。如图 2 所示，按照 D-H 法建立四自由度采摘机器人各连杆坐标系。
In Table 1, \( \theta_i \) is the included angle between the two
common perpendiculars in a plane perpendicular to joint
\( i \) axis. \( a_i \) is the distance of two end joints from \( i \) to \( i+1 \)
along the common perpendicular. \( a_i \) is the included
angle between the two joint axes in a plane perpendicular
to \( a_i \). \( d_i \) is the distance of the two common
perpendiculars along joint \( i \) axis. \( L_i \) is the height of stand
column of the solid of revolution pedestal. \( L_i \) the length
of the upper arm. \( L_i \) the length of the fore arm, while \( L_i \)
is the distance from the central point of the hand gripper
to the wrist reference point.

**Positive kinematic solution**

The positive kinematic solution is to obtain the pose of
the end effector in the given coordinate system with
known joint variables and geometric parameters of the
rod pieces. The expression (4) of the end effector pose of
the picking robot in the reference coordinate system can
be obtained when the parameters in Table 1 are
substituted into formula (3).

\[
0T_4 = A_1A_2A_3A_4 = \begin{bmatrix}
-C_iS_{234} & S_i & C_i(C_{234}L_4 + C_{23}L_3 + C_1L_2) \\
-S_iS_{234} & C_i & -S_i(C_{234}L_4 + C_{23}L_3 + C_1L_2) \\
C_{234} & 0 & \begin{bmatrix} S_{234}L_4 + S_{23}L_3 + S_1L_2 \\
0 & 0 & 1 \end{bmatrix}
\end{bmatrix}
\]

(4)

Wherein, \( C_i = \cos\theta_i \), \( S_i = \sin\theta_i \),
\( C_{23} = \cos(\theta_2 + \theta_3) \), \( S_{23} = \sin(\theta_2 + \theta_3) \),
\( C_{234} = \cos(\theta_2 + \theta_3 + \theta_4) \), \( S_{234} = (\theta_2 + \theta_3 + \theta_4) \).

The coordinate system of the end effector is
established with the hand gripper center as the origin
of coordinates. Axis \( Z \) is represented with vector \( \vec{a} \) in the
direction that the end effector approaches object, axis \( Y \)
is represented with vector \( \vec{b} \) in the direction of the
connecting line of the two fingers, and axis \( X \) is
determined to be represented with vector \( \vec{n} \) in accordance with the right-hand rule. The end effector
posture is determined by vectors \( \vec{n} \), \( \vec{a} \) and \( \vec{b} \). The gripper’s posture is ensured by the rotation vector \( R \),
as shown in expression (5).

\[
0R = \begin{bmatrix} \vec{n} & \vec{a} & \vec{b} \end{bmatrix}
\]

(5)

The gripper’s position is stipulated by its origin of
dimensions and described with position vector \( p \). The
four vectors added to scale factor are expressed in a
\( 4 \times 4 \) homogeneous matrix as shown in expression (6).

In Table 1, \( \theta_i \) is the included angle between the two
columns of革命体底座立柱高度. \( \theta_i \) is the included
angle between the two joint axes in a plane perpendicular
to \( \theta_i \). \( d_i \) is the distance of the two common
perpendiculars along joint \( i \) axis. \( L_i \) is the height of stand
column of the revolution pedestal. \( L_i \) the length
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-S_iS_{234} & C_i & -S_i(C_{234}L_4 + C_{23}L_3 + C_1L_2) \\
C_{234} & 0 & \begin{bmatrix} S_{234}L_4 + S_{23}L_3 + S_1L_2 \\
0 & 0 & 1 \end{bmatrix}
\end{bmatrix}
\]

(4)

Wherein, \( C_i = \cos\theta_i \), \( S_i = \sin\theta_i \),
\( C_{23} = \cos(\theta_2 + \theta_3) \), \( S_{23} = \sin(\theta_2 + \theta_3) \),
\( C_{234} = \cos(\theta_2 + \theta_3 + \theta_4) \), \( S_{234} = (\theta_2 + \theta_3 + \theta_4) \).

The coordinate system of the end effector is
established with the hand gripper center as the origin
of coordinates. Axis \( Z \) is represented with vector \( \vec{a} \) in the
direction that the end effector approaches object, axis \( Y \)
is represented with vector \( \vec{b} \) in the direction of the
connecting line of the two fingers, and axis \( X \) is
determined to be represented with vector \( \vec{n} \) in accordance with the right-hand rule. The end effector
posture is determined by vectors \( \vec{n} \), \( \vec{a} \) and \( \vec{b} \). The gripper’s posture is ensured by the rotation vector \( R \),
as shown in expression (5).

\[
0R = \begin{bmatrix} \vec{n} & \vec{a} & \vec{b} \end{bmatrix}
\]

(5)

The gripper’s position is stipulated by its origin of
dimensions and described with position vector \( p \). The
four vectors added to scale factor are expressed in a
\( 4 \times 4 \) homogeneous matrix as shown in expression (6).
Inverse kinematic solution

The inverse question of robot kinematics is to obtain the joint variables with the known pose of the end effector in the given coordinate system and the known geometrical parameters of the rod pieces. There are many methods for inverse robot kinematic solution. In this paper, premultiplication decoupling of $A^1$ and matrix $^0T_i$ is adopted to the solution with the help of Matlab software, and hence:

$$
^0T_i = \begin{bmatrix} n_x & o_x & a_x & p_x \\
 n_y & o_y & a_y & p_y \\
 n_z & o_z & a_z & p_z \\
 0 & 0 & 0 & 1 \end{bmatrix}
$$

(6)

运动学逆解

机器人运动学的逆问题是已知末端执行器在给定坐标系中的位姿和杆件的几何参数求关节变量。求解机器人运动学逆解的方法很多,本文采用$A^1$与矩阵$^0T_i$左乘解耦，借助Matlab软件求解得：

$$
\begin{cases}
\theta_1 = \arctan \left( \frac{P_z}{P_y} \right) \\
\quad = \arctan \left( \frac{P_z}{P_y} \right) + 180^\circ \\
\theta_2 = -\arctan \left( \frac{m}{n} \right) \pm \arctan \left( \frac{m^2 + n^2 - L_2^2 + L_3^2}{2L_4 \sqrt{m^2 + n^2 - \left( \frac{m^2 + n^2 - L_2^2 + L_3^2}{2L_2} \right)^2}} \right) \\
\theta_3 = \pm \arctan \frac{\sqrt{4L_3L_2 \left( n^2 + m^2 - L_2^2 - L_3^2 \right)}}{n^2 + m^2 - L_3^2 - L_2^2} \\
\theta_4 = -(\theta_3 + \theta_2)
\end{cases}
$$

(7)

由式（7）我们可以观察到$\theta_1, \theta_2, \theta_3$分别有两个解，即此机械系统存在8组不同的逆解，通常根据最短行程或多移动小关节少移动大关节的原则选择。

结果分析与讨论

3-D 仿真的模型的建立

四自由度采摘机器人机械结构由底座、大臂与电机箱体之间的腰部、大臂与腕部之间的肘部、小臂与末端执行器之间的腕部、末端执行器构成，构件之间相互连接形成的腰、肩、肘、腕 4 个旋转关节，前三个关节决定末端执行器在工作空间的位置，后一个关节决定末端执行器在工作空间的姿态。虽然ADAMS软件具有强大的运动学动力学求解功能但在三维实体建模方面相对薄弱，因而根据采摘机器人结构借助三维实体建模功能强大的pro/e软件来构建机器人虚拟样机。建模过程中在满足仿真分析要求的前提下，忽略模型的圆角、倒角、齿轮、轴承、电机等细化的部件，保留主要的实体部件，建立茄子采摘机器人三维仿真模型如下图 3。
**Pretreatment for simulation**

The model built in pro/E software is saved as intermediate format parasolid, and then is imported into ADAMS simulation software. ADAMS motion toolkit is used to add constraint to the imported 3-D simulation model as follows:

Fixed joints are added to between the bed and the ground, revolute joints are added to the waist, shoulder, and elbow and wrist part.

ADAMS drive toolkit is used to add drive to the imported 3-D simulation model as follows:

\[
\text{waist}(\text{time}) = 180 \cdot \sin(75\text{d} \cdot \text{time} - 90\text{d}) + 180\text{d} \\
\text{shoulder}(\text{time}) = -45 \cdot \sin(180\text{d} \cdot \text{time} - 90\text{d}) - 45\text{d} \\
\text{elbow}(\text{time}) = -30\text{d} \cdot \sin(145\text{d} \cdot \text{time} - 90\text{d}) - 30\text{d} \\
\text{wrist}(\text{time}) = 80\text{d} \cdot \sin(145\text{d} - \text{time} - 90\text{d}) + 80\text{d}
\]

With the above mentioned tasks completed, the virtual prototype model of the picking robot is established as in Fig. 4.

**仿真预处理**

将在 pro/e 中建立的模型保存为中间格式 parasolid，然后导入 ADAMS 仿真软件中。运用 ADAMS 运动工具集对导入的三维仿真模型添加约束，如下：

底座与大地之间添加固定副，腰、肩、肘、腕部添加旋转副。

运用 ADAMS 驱动工具集导入的三维仿真模型添加驱动，如下：

完成上述各项工作就建立了采摘机器人虚拟样机模型，如图 4 所示。

**Fig. 4 - Virtual prototype model of the picking robot**
Model Self-test

Before the simulating calculation, inquire the degree of freedom of the system, the components with mass undefined and over-constraint through “model verify” function in “tools” menu. Information such s as “model verified successfully” and “degrees of freedom for model.1” are displayed as shown in Fig.5, which indicates the modeling is correct and the kinematic simulation can be conducted for the next step.

Simulation analysis

The mark point mark-21, which is fixed joint to the centroid part6.cm of the end effector, is taken as the object of study. To study its position relative to fixed coordinate system, the rotational speed of each joint is set as $30^\circ/s$, simulation time is set as 5s, and simulation calculation is performed. After the simulation is completed, “postprocess” interface for post-processing is entered as shown in Fig.6.

Fig. 5 - Self-test interface

Fig. 6 - Speed graph

The solid line, the long broken line and the short broken line in the figure represent respectively the speed in the X, Y and Z directions. It is observed from Fig.6 that the change-in-speed is smooth and steady at the centroid part6.cm of the end effector, which does not generate strenuous vibration phenomenon during the whole course of movement, meeting the task requirements.

模型自检

在仿真计算之前，通过 tools 菜单中的 model verify 功能对系统的自由度、未定义质量的构件和过约束情况进行查询，如图 5 信息显示“model verified successfully”和“0 degrees of freedom for model.1”说明建立模型正确，可以进行下一步的运动学仿真。

仿真分析

以固定在末端执行器质心 part6.cm 上的标记点 mark-21 为研究对象，研究其相对于固定坐标系的位置，设定每个关节的转动速度为 $30^\circ/s$，设定仿真时间为 5s，进行仿真运算。仿真结束后进入 postprocess 界面后处理，如图 6 所示。

图中实线表示 X 方向的速度，长虚线表示 Y 方向速度，短虚线表示 Z 方向的速度，从图 6 中可以看出末端执行器质心 part6.cm 处速度变化相对平稳，末端执行器在整个运动过程中没有产生剧烈震动现象，达到工作要求。
As shown in Fig. 7, the long broken line, the short broken line and the dot-dash line represent respectively the displacement in the X, Y and Z directions. In the postprocessing interface, it can be obtained by virtue of measurement button that the displacement of marker-21 at the initial position is \( x = -66 \text{mm}, y=113 \text{mm}, z=-897 \text{mm} \) when \( t=0 \), which is consistent with the initial conditions of the manipulator. When the manipulator moves to the point of \( t=5s \), the displacement of marker-21 on the three coordinates is \( x=-591 \text{mm}, y=50, z=-236 \). Through test and verification, the theoretical calculation results from expression (4) and (5) in the D-H coordinate system are identical with the simulation results. The graph of displacement and speed can reflect the real motion conditions and apply to picking robot control.

CONCLUSIONS

The application of picking robot in agricultural production can effectively reduce the number of harvest labors and increase the income of farmers, and also has great significance to improve the level of automation and intelligentization for agricultural machinery. In this paper, by applying virtual prototype technology into the design of agricultural machines, the product design cycle can be effectively shortened and product performance can be improved. As a modern design approach, the virtual design technology will have a significant impact to the development of agricultural equipment.

Eggplant picking robot with 4 degrees of freedom is developed in order to improve the economy and adaptability of the picking robot and it adopts 4-DOF open motion chain which is formed by connecting the waist, the upper arm, the fore arm and the wrist in series through the rotational joints. The robot completes the picking operation through movements of each joint. The objective of studying robot kinematics is to establish the relationship of the spatial position between the robot motion components and the end effector, to build mathematic model of the robot arm movements, and to provide theoretical basis and technical parameters for agricultural robotic control.

The optimized design of structure and path planning is based on the kinematics analysis of the manipulator. In order to determine the spatial position relationship between the robot components and the end effector, the theoretical model is established by virtue of Denavit-Hartenberg approach and the positive solution of the kinematic equation is obtained. Premultiplication decoupling of \( A_i^{-1} \) and matrix \( ^{o}T_o \) is adopted to obtain

如图 7 所示，长虚线代表 X 方向的位移，短虚线代表 Y 方向的位移，点划线代表 Z 方向的位移，在后处理界面借助测量按钮可得出当 \( t=0 \) 时 marker-21 在初始位置的位移为 \( x = -66 \text{mm}, y=113 \text{mm}, z=-897 \text{mm} \)，与机械手原始状态相吻合。当机械手运动到 \( t=5s \) 时 marker-21 在三个坐标上的位移是 \( x=-591 \text{mm}, y=50, z=-236 \)。经验证与 D-H 坐标系中联立式 (4)，(5) 所得理论计算结果与仿真结果相同。位移和速度曲线图能够反映真实运动情况，可以应用于采摘机器人的控制。

结论

采摘机器人在农业生产中的应用，大量的减少了收获用工，增加了农民的收入，对于提高农业机械的自动化和智能化水平具有重要意义。本文的研究，将虚拟样机技术应用于农业机械的设计，缩短了设计周期，提高了产品质量，虚拟设计技术作为一种的现代化设计手段，必将对农业装备发展产生重要影响。

为了提高采摘机器人经济性和适应性，开发了 4 自由度茄子采摘机器人。其采用 4 自由度的开式运动链，由腰部、大臂、小臂和手腕通过转动关节串联而成。机器人通过各个关节的运动，来完成采摘作业。研究机器人运动学的目的就是建立机器人各运动构件与末端执行器在空间位置之间的关系，建立机器人手臂运动的数学模型，为机器人的控制提供理论依据和技术参数。

机械手的运动学分析是结构优化设计、轨迹规划的基础，为了确定机器人各运动构件与末端执行器在空间位置之间的关系，建立机器人手臂运动的数学模型，为机器人的控制提供理论依据和技术参数。
inverse kinematic solution with the help of Matlab software. Pro/e software is used to establish 3-D simulation model of the picking robot, whose functions are experimented and tested by means of ADAMS, a dedicated virtual prototype develop tool. ADAMS simulation software is introduced for the kinematics simulation analysis. It is illustrated by the simulation results that the kinematic model established by D-H approach reflects the real motion conditions of the robot, and both the positive and inverse kinematic solutions are correct. The structural design of 4 DOF picking robot designed and developed is rational and it can meet the requirements of eggplant picking in the greenhouse cultivation pattern.

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THEORETICAL ARGUMENTATION OF PARAMETERS OF A WINDROVER STEMS DRIVING AND EVACUATING WORKING PART

ARGUMENTAREA TEORETICĂ A PARAMETRILOR ORGANULUI DE ANTRENARE ȘI EVACUARE A TULPINILOR UNUI VINDROVER

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Abstract: In order to assure the optimum operating conditions for the combine of harvesting thick stem plants, the constructive and kinematic parameters of windrower part performing the stems cut driving, evacuating and transporting to the feeding apparatus, are explained.

Keywords: windrower, thick stems, driving, evacuating, transporting, constructive and kinematic parameters

INTRODUCTION

Efficiency of operating system of combine designed to thick plants harvesting (corn, sorghum saccharate, sunflower) depends on the quality of a whole series of technological phases. Cutting part parameters are explained in paper [1]. Also, the argumentation of parameters of element performing cut stems driving, evacuating from the row and transporting to the feeding apparatus is of a great importance.

MATERIALS AND METHODS

In order to appropriately cut and securely driving with reduced energy consumption the stem should be cut and completely introduced within the disc driving space before contacting the working surface of driving tooth. When the drum tooth top contacts the stem, the correlation between the combine speed \( V_{\text{com}} \) and drum angular speed \( \omega_{\text{tang}} \) should meet the following condition: the stem must penetrate the driving space at equal or bigger distance than its diameter, before being touched by the next tooth wall (fig.1). In this case, the combine will run the distance:

\[ S = l + d \]

(1)

Fig. 1 – Scheme of driving and evacuating the stem from the row
\[ i \text{ is the stem curving; } d \text{ – stem diameter.} \]

For running the distance \( S \), the time period is necessary.

\[ \tau = \frac{S}{V_{\text{com}}} = \frac{i + d}{V_{\text{com}}} . \]  

(2)

Concomitantly, at the same period of time the drum will rotate at angle (fig.1):

\[ \theta - \alpha = \frac{2\pi}{z} - \arctg \frac{r}{R-r}, \]

(3)

where \( z \) is the drum teeth number; \( r \) – stem radius ; \( R \) – drum radius. Then, the time necessary for driving the stem will be equal.

\[ \tau = \frac{\theta - \alpha}{\omega_{\text{ant}}} = \frac{2\pi}{z} - \arctg \frac{r}{R-r} \omega_{\text{ant}} = \frac{i + d}{V_{\text{com}}} . \]  

(4)

As the stem diameter \( d \) of corn, sorghum is much smaller than drum diameter (\( d_{\text{max}} \approx 30...40 \text{ mm} < D_{\text{max}} \approx 550 \text{ mm} \)), and plants stems curving in normal conditions approaches 0 \((i \approx 0)\), formula (2,4) of time period simplifies:

\[ \tau = \frac{2\pi}{z\omega_{\text{ant}}} \omega_{\text{ant}} = \frac{d}{V_{\text{com}}} \text{ sau } \tau = \frac{2\pi V_{\text{com}}}{d}. \]  

(5)

As a general rule, if the stem is placed between the drum teeth when starting the cutting, the constructive and kinematic parameters ratio should correspond to:

\[ z\omega_{\text{ant}} \leq 2\pi V_{\text{com}} / d \]  

(6)

Immediately after the stem cutting, it is necessary to consecutively perform the following operations: evacuating the stem from the row, moving, reorienting from vertical position to horizontal one and its driving towards the relevant assembly rollers. When running a distance of 1 meter, the combine windrower has to cut plant stems (corn, saccharate sorghum, sunflower etc.) in each row and within the period of time \( \tau = 1/V_{\text{com}} \).

RESULTS

Evacuation of stems in row. Having in view the request of an operative evacuation of the stems from the row, each tooth of driving-evacuating drum should transport at the most one plant for each row (fig.1). In this case, for evacuating the stems the drum will rotate with an angle which value will be:

\[ \varphi' = \frac{2\pi}{z} . m \]

(7)

where \( z \) is the number of teeth on drum disc; \( m \) – number of harvested stems in a row at 1 linear meter. For achieving the angle above \( \varphi' \), the disc needs a similar period of time:

\[ \tau' = \varphi' / \omega_{\text{ant}} = \frac{2\pi m}{z\omega_{\text{ant}}} \]

(8)

Unde:

\( i \) este încovoiaerea tulpinii; \( d \) – diametrul tulpinii.

Pentru parcurgerea distanței \( S \) este necesară durata de timp:

\[ \tau = \frac{S}{V_{\text{com}}} = \frac{i + d}{V_{\text{com}}} . \]  

Concomitent, în aceeași perioadă de timp tamburul se va rota la unghiul (fig.1):

\[ \theta - \alpha = \frac{2\pi}{z} - \arctg \frac{r}{R-r}, \]

unde \( z \) este numărul de dinți ai tamburului; \( r \) – raza tulpinii; \( R \) – raza tamburului. Atunci perioada de timp necesară pentru antrenarea tulpinii va fi egală:

\[ \tau = \frac{\theta - \alpha}{\omega_{\text{ant}}} = \frac{2\pi}{z} - \arctg \frac{r}{R-r} \omega_{\text{ant}} = \frac{i + d}{V_{\text{com}}} . \]  

Deoarece diametrul tulpinii \( d \) al porumbului, sorgului este mult mai mic decât diametrul tamburului (\( d_{\text{max}} \approx 30...40 \text{ mm} < D_{\text{max}} \approx 550 \text{ mm} \)), iar încovoiaerea tulpinilor plantelor menționate în condițiile normale se apropie de 0 \((i \approx 0)\), formule (2,4) a duratei de timp se simplifică:

\[ \tau = \frac{2\pi}{z\omega_{\text{ant}}} \omega_{\text{ant}} = \frac{d}{V_{\text{com}}} \text{ sau } \tau = \frac{2\pi V_{\text{com}}}{d}. \]  

(5)

Pentru cazul general, când tulpina în momentul inițierii tăierii se află între dinții tamburului, raportul parametrilor constructive și cinematici trebuie să corespundă:

\[ z\omega_{\text{ant}} \leq 2\pi V_{\text{com}} / d \]  

(6)

Imediat după tăierea tulpinii este necesar de efectuat consecutiv următoarele operații: evacuarea tulpinii din rând, deplasarea, reorientarea din poziția verticală în cea orizontală și antrenarea acesteia către tăvălugii ansamblului respectiv. La parcurgerea distanței de 1 metru liniar vindroverul combinie trebuie să taie m tulpini de plante (porumb, sorg zaharat, floarea-soarelui etc.) în fiecare rând și în perioada de timp \( \tau = 1/V_{\text{com}} \).

REZULTATE

Evacuarea tulpinilor din rând. Având în vedere cerința evacuării operative a tulpinilor din rând, fiecare dintre tamburul de antrenare-evacuare trebuie să transporte maximum câte o plantă din fiecare rând (fig. 1). În acest caz pentru evacuarea m tulpinilor tamburul se va roți la un unghi, a cărui valoarea integrală va fi:

\[ \varphi' = \frac{2\pi}{z} . m \]

unde \( z \) este numărul de dinți pe un disc al tamburului; \( m \) – numărul de tulpini recoltate într-un rând la 1 metru liniar. Pentru a parcurge unghiul menționat \( \varphi' \) discul are nevoie de aceiași perioadă de timp:
where $\omega_{\text{ant}}$ is the angular speed of driving drum.

Operative evacuation of stems from the row requires that the drum runs the angle $\varphi$ within a less period of time than the time necessary for the combine to cross 1 linear meter distance, namely:

$$2\pi n l \omega_{\text{ant}} \leq 1/V_{\text{com}}.$$  \hspace{1cm} (9)

From inequality (9) results that, for operatively evacuating the stems in row, the drum constructive and kinematic parameters ratio should be:

$$z\omega_{\text{ant}} \geq 2\pi n V_{\text{com}}$$ \hspace{1cm} (10)

Respecting both efficient operating conditions of windrower (safely driving the stems to the drum teeth and evacuating them) determines the drum driving parameters as follows:

$$2\pi V_{\text{com}} m \leq z\omega_{\text{ant}} \leq 2\pi V_{\text{com}} / d$$ \hspace{1cm} (11)

For efficiently driving the stems requires that the drum teeth pitch (fig.1) be:

$$p = \frac{2\pi (R - r)}{z}$$ and circular speed of drum

$$V = \omega_{\text{ant}} (R - r)$$ assures the displacement period from a tooth to another contacting the stem within a greater period of time than the necessary for cutting a stem:

$$\frac{2\pi (R - r)}{z} / \omega_{\text{ant}} (R - r) \geq \frac{d}{V_{\text{com}}}, \text{ from here}$$

$$z\omega_{\text{ant}} \leq 2\pi V_{\text{com}} / d$$ \hspace{1cm} (12)

where $R, r$ represents the drum radius and respectively the stem radius ($r = d/2$).

The last inequality (12) confirms the correctness of formula (11) and allows to set the dimensions of driving space of drum disc.

**Stems evacuation and driving.** As mentioned before, during the working process, the drum teeth perform a complex movement: they rotate along with the drum with angular speed $\omega_{\text{ant}}$ and moves with the combine with linear speed $V_{\text{com}}$ (fig.2).

Taking into account the recommendations [2], [3], from the scheme shown (fig. 2) can be obtained the equations of displacement of different points of evacuating disc:

- the tooth AB: $Y_a = V_{\text{com}} \tau_1 + R \sin \omega_{\text{ant}} \tau_1, \hspace{0.5cm} X_a = R \cos \omega_{\text{ant}} \tau_1, \hspace{1cm} (13)$

- the tooth CD: $Y_c = V_{\text{com}} \tau_2 + (R - b) \sin \omega_{\text{ant}} \tau_2, \hspace{0.5cm} X_c = (R - b) \cos \omega_{\text{ant}} \tau_2, \hspace{1cm} (15)$

where $R$ is the drum radius; $b$ – tooth working width.

Scheme analysis (fig. 2) demonstrates that *efficient and complete evacuation of stems* can be reached when $Y_a \geq Y_c$. Taking into consideration the necessity of unde $\omega_{\text{ant}}$ este viteza unghiulară a tamburului de antrenare.

Evacuarea operativă a tulpinilor din rând necesită ca tamburul să parcurgă unghiul $\varphi$ într-o perioadă de timp mai mică, decât cea necesară comblinei pentru a traversa distanța de 1 metru linear, adică:

unde $\omega_{\text{ant}}$ este viteza unghiulară a tamburului de antrenare.

Evacuarea operativă a tulpinilor din rând necesită ca tamburul să parcurgă unghiul $\varphi$ într-o perioadă de timp mai mică, decât cea necesară comblinei pentru a traversa distanța de 1 metru linear, adică:

$$2\pi n l \omega_{\text{ant}} \leq 1/V_{\text{com}}.$$  \hspace{1cm} (9)

Din inegalitatea (9) reiese, că pentru evacuarea operativă a tulpinilor din rând raportul parametrilor constructivi și cinematici ai tamburului trebuie să fie:

$$z\omega_{\text{ant}} \geq 2\pi n V_{\text{com}}$$ \hspace{1cm} (10)

Respectarea ambelor condiții de funcționare eficientă a vindroverului (antrenarea sigură a tulpinilor de către dinții tamburului și evacuarea operativă a lor din rând) determină parametrii tamburului de antrenare în felul următor:

$$2\pi V_{\text{com}} m \leq z\omega_{\text{ant}} \leq 2\pi V_{\text{com}} / d$$ \hspace{1cm} (11)

Condiția antrenării eficiente a tulpinilor impune ca pasul dinților din tambur (fig.1)

$$p = \frac{2\pi (R - r)}{z}$$ și viteza circulară a tamburului

$$V = \omega_{\text{ant}} (R - r)$$ să asigure durata deplasării de la un dintă până la altul din contact cu tulpina într-o perioadă de timp mai mare decât cea necesară pentru tăierea unei tulpini:

$$\frac{2\pi (R - r)}{z} / \omega_{\text{ant}} (R - r) \geq \frac{d}{V_{\text{com}}}, \text{ de aici}$$

$$z\omega_{\text{ant}} \leq 2\pi V_{\text{com}} / d$$ \hspace{1cm} (12)

unde $R, r$ reprezintă raza tamburului și respectiv a tulpinii ($r = d/2$).

Ultima inegalitate confirmă corectitudinea formulei (11) și permite precizarea dimensiunilor spațiului de antrenare a discului din tambur.

**Plenitudinea evacuării și antrenării tulpinilor.** După cum s-a menționat anterior, în procesul de lucru dinții tamburului efectuează o mișcare complexă: se rotesc împreună cu tamburul cu viteza unghiulară $\omega_{\text{ant}}$ și se mișcă consecvent împreună cu combina cu viteza liniară $V_{\text{com}}$ (fig.2).

Înțând cont de recomandări [2], [3], din schema prezentată (fig. 2) pot fi obținute ecuațiile deplasării diferitor puncte ale discului de evacuare:

unde $R$ este raza tamburului; $b$ – lățimea de lucru a dintelui.

Analiza schemei (fig. 2) demonstrează că *antrenarea și evacuarea eficientă și completă* a tulpinilor poate fi în cazul când $Y_a \geq Y_c$. Luând în considerație necesitatea
diminishing the energy consumption, the variant is optimum when \( Y_A = Y_{c1} \). In this case:

\[
\tau_1,\phi_1 / \omega_{ant} = \pi / 2\omega_{ant},
\]

\[
\tau_2 = \phi_2 / \omega_{ant} = (\frac{\pi}{2} + \frac{2\pi}{z}) / \omega_{ant} = \frac{\pi + 4\pi}{2z\omega_{ant}} = \frac{\pi(4 + z)}{2z\omega_{ant}}.
\]

From formulae (13, 15) it follows:

\[
Y_A = V_{com} \frac{\pi}{2\omega_{ant}} + R \sin \omega_{ant} \frac{\pi}{2\omega_{ant}} = \frac{\pi V_{com}}{2\omega_{ant}} + R,
\]

\[
Y_{c1} = V_{com} \frac{\pi(4 + z)}{2z\omega_{ant}} + (R - b) \sin \omega_{ant} \frac{\pi(4 + z)}{2z\omega_{ant}}
\]

\[
\frac{\pi V_{com}}{2\omega_{ant}} + R = \frac{\pi V_{com}(4 + z)}{2z\omega_{ant}} + (R - b) \sin \frac{\pi(4 + z)}{2z}
\]

Ecuation (19) describes the ratio between the constructive \((R,b,z)\) and kinematic \((V_{com},\omega_{ant})\) parameters of windrower in case of safe evacuation of stems in row. After modification the ecuation (19) has the following form:

\[
\frac{2\pi V_{com}}{z\omega_{ant}} = R - (R - b) \sin \frac{\pi(4 + z)}{2z}
\]

\[
= R - (R - b) \sin \left(\frac{2\pi}{z} + \frac{\pi}{2}\right).
\]

If we note the angular pitch between the drum disc teeth \( \frac{2\pi}{z} = \theta \), then:

\[
\frac{2\pi V_{com}}{z\omega_{ant}} = R - (R - b) \sin \left(\theta + \frac{\pi}{2}\right)
\]

\[
\text{sau} \quad \frac{2\pi V_{com}}{\omega_{ant}} = z \left[ R - (R - b) \sin \left(\theta + \frac{\pi}{2}\right) \right]
\]

\[
V_{com} = \frac{R - (R - b) \sin \left(\theta + \frac{\pi}{2}\right)}{\theta}.
\]

From the obtained equations (20) results, that increasing the combine displacement speed \( V_{com} \) requires, in case of fixed constructive parameters \((z, R, b)\) a relevant increment of drum angular frequency \( \omega_{ant} \). More rationally would be to determine values of parameters \( z, R, b \) and speed \( \omega_{ant} \), which assures the complete driving and evacuation of stems according to translation speed of combine \( V_{com} \).

**Degree of driving the stems in the drum lateral space.**

The windrower rotative disc below ensures the stems cutting according to rotation angle \( \varphi \) from 0 to \( \pi \) (fig.2). Rotative drum, placed above the cutting disc, can perform the efficient driving of stems when the angle is narrower \((0<\varphi<\pi)\). This range may be precised by analyzing the scheme of stems driving (fig.3). From the scheme mentioned it results that for driving a stem of diameter, at a certain moment, it is necessary that the distance between projections on x axis (perpendicular on vârfulor a doi dinţi vecini să fie mai mare decât diametrul
combine moving direction) of two close teeth tops be bigger than stem diameter:

\[ X_n - X_a = R \cos \left( \omega_{ant} \tau - \frac{2\pi}{z} \right) - R \cos \omega_{ant} \tau \cdot d, \quad \cos(\omega_{ant} \tau - \theta) = \cos \omega_{ant} \tau \cdot \frac{d}{R} \]

sau \[ \cos(\varphi - \theta) = \cos \varphi \cdot \frac{d}{R}. \]

(21)

Knowing the values of stems diameter \( d \), of drum constructive parameters (radius \( R \), angular pitch \( \theta \) of teeth), can be calculated the angle \( \varphi \) determining the minimum driving conditions of stems, position of lateral and central dividers.

Action of forces acting in stems driving and evacuating. Previous analysis of processes of cutting, driving and evacuating the stems in the windrower was based on kinematic and constructive parameters. For assuring the windrower efficient operation, it is necessary to analyze the forces acting on stems and respectively on windrower working parts (study of process dynamics).

As previously mentioned, during the working process the combine moves with the translation speed \( V_{com} \), and windrower working parts co-axially placed, rotate at different speed: lower cutting disc – by speed \( \omega_t \), upper drum with discs for stems evacuating – by speed \( \omega_{ant} \).

Previous calculations based on formula (11) demonstrate that drum linear rotation speed will be up to 5m/s \cite{5}. Therefore, cutting speed value \( V_t \geq 30 \) m/s \( \geq 30 \) m/s is much higher than driving speed value \( V_{ant} \).

The complex operating process of windrower consists in following stages:

a) cutting (stem is subjected to cutting disc action and, in certain cases, during a short period of time, to lower driving disc; in this stage, the stem remains connected to the root);

Cunoscând valorile diametrului tulpinilor \( d \), ale parametrilor constructive ai tamburului (raza \( R \), pasul unghiual \( \theta \) al dinţilor), se poate calcula unghiul \( \varphi \) care determină condiţiile minime de antrenare a tulpinilor, poziţia divizorilor laterali şi a celui central.

Acţiunea forţelor în procesul de antrenare şi evacuare a tulpinilor. Analiza precedentă a proceselor de tăiere, antrenare şi evacuare a tulpinilor în vindrover a fost bazată pe parametrii cinematici şi constructivi. Pentru asigurarea funcţionării eficiente a vindroverului este necesară analiza forţelor, care acţionează asupra tulpinii şi respectiv asupra organelor de lucru ale vindroverului (studiu dinamicii procesului).

După cum s-a menţionat anterior, în procesul de lucru combina se deplasează cu viteza de translaţie \( V_{com} \), iar organele de lucru ale vindroverului amplasate coaxial execută mişcare de rotaţie cu diferite vitezhe: discul inferior de tăiere – cu viteza \( \omega_t \), tamburul superior cu discuri pentru antrenarea şi evacuarea tulpinilor – cu viteza \( \omega_{ant} \).

Calculele prealabile în baza formulei (11) demonstrează, că viteza liniară de rotaţie a tamburului va fi de până la 5m/s \cite{5}. Prin urmare, valoarea vitezii de tăiere \( V_t \geq 30 \) m/s este mult mai mare decât cea a vitezei de antrenare \( V_{ant} \).

După cum reiese din descrierea modelului fizic, procesul complex de funcţionare a vindroverului constă din următoarele etape:

a) tăierea (tulpina este supusă acţiunii discului de tăiere şi, în unele cazuri pe o perioadă scurtă, dintelui discului inferior de antrenare; la etapa aceasta tulpina rămâne în legătură cu rădăcina).
b) driving (the cut stem is placed in the inner space between the drum teeth and is driven by cutting disc and drum teeth);

c) evacuation (the stem is in the same space as teeth and is subduced to drum teeth).

As the first stage, practically does not influence the driving-evacuating process, we shall analyze the forces applied to stem in the following two stages. The stem, immediately after the cutting is in vertical position within the space between the drum (fig.4) and is subjected to action of following forces: gravity force \( P(P = mg) \), force of stem friction on the cutting disc towards the rotation movement \( F_t(F_t = f_t P) \), force of inertia \( F_{ia}(F_{ia} = ma_{ia}) \), determined by combine translation movement by speed \( V_{cm} \). Under these forces action the stem begins a complex movement: simultaneously, towards the cutting disc rotation and rotation pin. As a result, the reactive forces appear: respectively, inertia forces \( F_{ia}(F_{ia} = ma_{ia}) \) and friction forces \( F_{ia}(F_{ia} = f_{ia} P) \). After initiating the stem movement, subjected to force \( F_t \) the centrifugal force appears \( F_{cf}(F_{cf} = ma_{cf} R) \). Angular speed \( \omega_{st} \) of stem foot is the same as the cutting disc speed (in terms of direction) \( \omega_t \), but \( \omega_{st} \) has a smaller value, which depends on the friction coefficient \( f_t \). Ratio of forces \( F_{cf} \) and \( F_{ia} \) determines the direction and value of friction force \( F_{ia} \) which is always inversely to the stem movement direction and maintains its position.

If projecting the forces above on axes \( X,Y \) the following results will be obtained:

\[
\begin{align*}
\text{axa } X \rightarrow F_{t} &= F_{t}, \quad f_t mg = ma_{ia}, \quad f_t g = a_{ia}, \\
axa Y \rightarrow \text{at first stage} & F_{i} = F_{ia} + F_{cf}, \quad ma_{z} = f_{z} mg + m\omega_{z}^{2} R, \quad a_{z} = f_{z} g + \omega_{z}^{2} R, \\
axa Y \rightarrow \text{at final stage may be (if)} & F_{i} = F_{ia} + F_{cf}, \quad ma_{z} + f_{z} mg = m\omega_{z}^{2} R, \quad a_{z} + f_{z} g = \omega_{z}^{2} R, \quad \omega_{z}^{2} R = a_{z} + a_{ia},
\end{align*}
\]
where \( m \) is stem mass, \( g \) – acceleration of natural fall; \( \alpha_1, \alpha_2 \) – acceleration of stem towards the circular direction and respectively to the combine direction; \( f_t \) – coefficient of friction of stem on cutting disc surface; \( \omega_{pt} \) – angular speed of stem foot on the cutting disc; \( R \) – radial coordinate of stem placement.

In the second driving stage the stem foot approaches the rear surface of tooth (fig. 4 b). In this case, the following forces act upon the stem: gravity force \( P \), centrifugal force \( F_{\text{cf}} \) (at first stage, when supporting the stem on cutting disc surface and respectively to the combine direction; \( f_t \) – coefficient of friction of stem foot on the cutting disc \( F_{\text{pt}} \), and tooth rear surface \( F_3 \). Where \( \omega_{ant} \) is the angular speed of stem and driving drum, \( f_2 \) – coefficient of friction, \( \alpha \) – angle between the tooth rear surface and centrifugal speed vector.

Because of friction force \( F_{\text{pt}} \) existing when acting the cutting disc, the energy consumed is of a power of:

\[
N = F_{\text{pt}} R (\omega_t - \omega_{ant}),
\]

unde \( m \) este masa tulpinii, \( g \) – accelerarea de cădere liberă; \( \alpha_1, \alpha_2 \) – accelerarea tulpinii în direcția circulară și respectiv în direcția deplasării combinei; \( f_t \) – coeficientul de frecare a materialului tulpinii pe suprafața discului de tăiere; \( \omega_{pt} \) – viteza unghiulară a piorului tulpinii pe discul de tăiere; \( R \) – coordonata radială de amplasare a tulpinii.

În faza a doua de antrenare piorului tulpinii se apropie de suprafața din spatele dintelui (fig. 4 b). În acest caz asupra tulpinii acționează următoarele forțe: gravitațională \( P \), centrifugală \( F_{\text{cf}}^{\text{ant}} \left( F_{\text{cf}}^{\text{ant}} = m \omega_{ant}^2 R \right) \), de frecare a piorului tulpinii pe discul de tăiere \( F_{\text{pt}} \), \( F_3 \) și pe suprafața din spatele dintelui \( F_3 \), reactivă \( R_t \), unde \( \omega_{ant} \) este viteza unghiulară a tulpinii și tamburului de antrenare, \( f_2 \) – coeficientul de frecare, \( \alpha \) – unghiul dintre suprafața a spate a dintelui și vectorul vitezei centrifugale.

Din cauza existenței forței de frecare \( F_{\text{pt}} \), la acționarea discului de tăiere se consumă energia a cărei putere este:

\[
N = F_{\text{pt}} R (\omega_t - \omega_{ant}),
\]

unde \( \omega_t, \omega_{ant} \) este viteza unghiulară a discului de tăiere și respectiv a tamburului de antrenare.

Reducerea consumului de energie este posibilă, dacă piorul tulpinii se va desprinde de la suprafața discului de tăiere și se va sprijini pe discul inferior de antrenare. În acest caz asupra tulpinii acționează forța centrifugală \( F_{\text{cf}}^{\text{ant}} \) și forțele de frecare \( F_3 \) ale piorului, părțile superioare ale tulpinii pe suprafețele de contact ale dinților tamburului de antrenare.

Din analiza schemelor (fig. 4) reiese, că pericolul expulzării înainte de vreme a tulpinii din spațiul de antrenare provine de la forțele centrifugale \( F_{\text{cf}}^{\text{ant}} \) (la prima etapă în cazul sprijinului tulpinii pe discul de tăiere) și \( F_{\text{ant}}^{\text{ant}} \) (la etapa a doua, când tulpina este sprijinită pe tamburul de antrenare). Forța \( F_{\text{cf}}^{\text{ant}} \) are posibilitatea de a avea valori mai înalte în raport cu forța \( F_{\text{cf}}^{\text{ant}} \) din cauza vitezei mai mari a discului de tăiere.

Minimizarea efectului negativ al forțelor centrifugale poate fi obținută prin următoarele metode:

- reducerea coeficientului de frecare \( f_t \) a piorului tulpinii pe discul de tăiere și respectiv a vitezei unghiulare \( \omega_{pt} \);
- majorarea vitezei de translație a combinei \( V_{\text{com}} \) și respectiv a forței de inerție \( F_{\text{ci}} \);
- menținerea în diapazonul optim a vitezei de rotație a tamburului de antrenare, care asigură antrenarea și evacuarea eficientă a masei vegetale fără expulzarea ei înainte de teren;
- utilizarea pe suprafața din spate a dinților discului inferior de antrenare profilului special, care frânează expulzarea piorului tulpinii [2];
- crearea condițiilor de urcare și sprijinire a piorului tulpinii pe suprafața din spate a dintelui prin asigurarea jocului minim dintre discul inferior de antrenare și discul de tăiere, tăierea fațetelor pe suprafața din spate [2];
- utilizarea tijelor de ghidare a tulpinilor în spațiul de antrenare și evacuare.
Driving the stem by means of guiding bar. During a drum rotation cycle, it is necessary to meet two different conditions (fig.5):

a) after cutting, as recently mentioned, in the upper sectors I, II have to be created the conditions appropriate for a safe driving and displacement of stems by drum teeth;

b) after the stems, vegetal wastes arriving in windrower feeding chamber (sector III), they have to leave the drum teeth to the feeding rollers.

From the scheme presented (fig.5) comes out that one of main conditions for the correct operating of windrower is to assure the stem driving within the inner space of tooth, when stem cross section diameter is on disc edge.

In this case, the forces acting on stem are perpendicularly on working surfaces of guiding bar (force $N_1$) and tooth (força $N_2$).

Displacement of stem in driving space results in friction forces appearing:

$$F_1=N_1 \cdot f_1,$$
$$F_2=N_2 \cdot f_2,$$
(25)

where $f_1, f_2$ are the friction coefficients of stem on working surface of guiding bar and respectively of drum tooth.

For determining the conditions of driving the stem between drum tooth and guiding bar, we project on axes $X, Y$ the forces applied:

axis $X$: $N_2 \cdot \sin \gamma = F_1 + F_2 \cdot \cos \gamma$
axis $Y$: $N_1 = N_2 \cdot \cos \gamma + F_2 \cdot \sin \gamma$ sau $N_1 = N_2 \cdot \cos \gamma + N_2 \cdot f_2 \cdot \sin \gamma$
(26)

Displacement of stem within the drum space imposes that: $N_2 \cdot \sin \gamma \geq N_1 \cdot f_1 + N_2 \cdot f_2 \cdot \cos \gamma$.

Using in the last inequality, the value $N_1$ from formula (27), we obtain after modification:

Deplasarea tulpinii în spațiul de antrenare are drept consecință apariția forțelor de frecare:

$$F_1=N_1 \cdot f_1,$$
$$F_2=N_2 \cdot f_2,$$
(25)

unde $f_1, f_2$ sunt coeficienții de frecare a tulpinii pe suprafața de lucru a tijei de ghidare și respectiv a dintelui tamburului.

Pentru determinarea condițiilor de antrenare a tulpinii între dientele tamburului și tija de ghidare, proiectăm pe axele $X, Y$ forțele aplicate:

axis $X$: $N_2 \cdot \sin \gamma = F_1 + F_2 \cdot \cos \gamma$
axis $Y$: $N_1 = N_2 \cdot \cos \gamma + F_2 \cdot \sin \gamma$ sau $N_1 = N_2 \cdot \cos \gamma + N_2 \cdot f_2 \cdot \sin \gamma$
(26)

Deplasarea tulpinii în interiorul spațiului tamburului impune ca: $N_2 \cdot \sin \gamma \geq N_1 \cdot f_1 + N_2 \cdot f_2 \cdot \cos \gamma$.

Utilizând în ultima inegalitate valoarea $N_1$ din formula (27), obținem după modificare:
\[
\sin \gamma \geq \cos \gamma \cdot f_1 + f_2 \cdot \sin \gamma \cdot f_1 + f_2 \cdot \cos \gamma
\]

\[
tg \gamma \geq f_1 + f_1 \cdot f_2 \cdot tg \gamma + f_2 \cdot \sin \gamma (1 - f_1 \cdot f_2) \geq f_1 + f_2, \quad tg \gamma \geq \frac{f_1 + f_2}{1 - f_1 \cdot f_2}
\] (27)

Because \( f_1 = tg \phi_1, \quad f_2 = tg \phi_2 \) (\( \phi_1, \phi_2 \) - friction angles), we obtain:

\[
tg \gamma (1 - f_1 \cdot f_2) \geq f_1 + f_2 \cdot tg \phi_1 \cdot f_1 \cdot f_2, \quad \gamma \geq \frac{f_1 + f_2}{1 - f_1 \cdot f_2}
\]

It results that, for safely driving and moving the stem within the drum with diminished energy consumption, it is necessary that the coefficients of friction \( f_1, f_2 \) should be reduced, and angle \( \gamma \) between the working surfaces of guiding bar and permanent dough tooth be higher than \( \phi_1 + \phi_2 \) sum. At the same time, the working width of driving space \( b_{\text{art}} \) (fig. 5) should meet the following condition:

\[
b_{\text{art}} \geq 2d_{\text{lab}} + d_{tg} \]

(29)

where \( d_{\text{lab}} \) is stem diameter; \( d_{tg} \) - diameter of guiding bar.

**Ejecting the stems from the drum.** Taking into account the forces and speed applied on the stem (fig. 5), as well as the condition that the minimum distance is on axis X, the ejecting plates upper part (cleaning) should be placed at the end of sector II.

We shall analyze the conditions of evacuating the stems from the drum in sector III (fig. 5). Forces \( N_1, N_2, F_1, F_2 \), applied on stem in this sector are identical with those from sectors I, II. Projecting the forces above on X,Y axes gives the results:

axis X \( - N_2 \cdot \sin \gamma = F_1 + F_2 \cdot \cos \gamma \),

axis Y \( - N_1 = N_2 \cdot \cos \gamma + F_2 \cdot \sin \gamma \).

Formule obtained are similar to formulae (26), (27), which allows to conclude: safe stems evacuation is performed if the angle \( \gamma \) between the working surfaces of drum teeth and ejecting plates is bigger than the sum of stem friction coefficients on respective working surfaces \( (\gamma \geq \phi_1 + \phi_2) \).

For increasing the probability of ejecting the stems and vegetal wastes, it is necessary that the length of area where teeth and plates interact be maximum.

Taking into consideration the fact that the angle between the working surfaces of driving teeth and vector of combine translation speed \( V_{\text{com}} \) changes from 90° when entering the sector III (fig. 5) up to 0° when leaving sector III, the ejecting plates along of area of teeth will be inclined towards the optimum speed vector \( V_{\text{com}} \). This will allow to maintain the optimum condition of evacuation (formula 28) and to increase the length of ejecting contact of stems in sector III (\( \phi_2 > \phi_1 \), fig.5 b). Plates may have right linear or curvilinear shape. For assuring the appropriate evacuation conditions of vegetal matter on the whole length of area where teeth interact with plates, the last ones should be convex.

For ensuring of favorable conditions for vegetal mass expulsion on the entire length of the interaction between the driving teeth and the expulsion plates, the plates shape must be convex. Based on the expulsion scheme of the stalks (fig. 5) can be calculated the duration of the expulsion:

\[
\text{unde } d_{\text{lab}} \text{ este diametrul tulpinii; } d_{tg} \text{ - diametrul tijei de ghidare.}
\]

**Expulsarea tulpinilor din tambur.** Luând în calcul forțele și vitezele aplicate asupra tulpinilor (fig. 5), precum și condiția că distanța minimă dintre două tambururi este pe axa X, începutul plăcilor de expulzare (curățare) trebuie să fie amplasat la terminarea sectorului II.

Vom analiza condițiile expulzării tulpinilor din tambur în sectorul III (fig.5). Forțele \( N_1, N_2, F_1, F_2 \), aplicate asupra tulpinii în acest sector, sunt identice celor din sectoarele I, II. Proiectarea forțelor menționate pe axele X,Y dă următoarele rezultate:

Formulele obținute coincid cu formulele (26), (27), ceea ce permite să se tragă următoarea concluzie: expulzarea sigură a tulpinilor se efectuează dacă unghiul \( \gamma \) dintre suprafețele de lucru ale diștilor tamburului și plăcilor de expulzare va fi mai mare decât suma coeficiențiilor de frecare a tulpinii pe suprafețele de lucru respective \( (\gamma \geq \phi_1 + \phi_2) \).

Pentru majorarea probabilității de expulzare a tulpinilor și resturilor vegetale este necesar ca lungimea zonei de interacțiune a diștilor și plăcilor să fie maximal posibilă.

Luând în considerație faptul că unghiul dintre suprafețele de lucru ale diștilor de antrenare și vectorul vitezei de translație a combinaie \( V_{\text{com}} \) se schimbă de la 90° la intrare în sectorul III (fig. 5) până la 0° la ieșire din sectorul III, plăcile de expulzare pe lungimea contactului cu diști de antrenare vor fi încinate spre vectorul vitezei \( V_{\text{com}} \). Aceasta a permite menținerea condiției optime de expulzare (formula 28) și majorarea lungimii contactului de expulzare a tulpinilor în sectorul III (\( \phi_2 > \phi_1 \), fig.5 b). Plăcile de expulzare pot să aibă forma dreptliniară sau curbunăriară.

Pentru asigurarea condițiilor favorabile de expulzare a masei vegetale pe toată lungimea interacțiunii diștilor de antrenare și plăcilor ultimele mai bine să fie de forma convexă. În baza schemei de expulzare a tulpinilor (fig. 5) se poate calcula durata expulzației:
from which results the ratio of the expulsion durations for the angles $\varpi_1, \varpi_2$: $\frac{r_1}{r_2} = \frac{\varpi_1}{\varpi_2}$.

Because $\varpi_2 > \varpi_1$, consequently $r_2 > r_1$. Stalks travel speed across the surface from the front of the driving tooth is equal to:

$$V_{\text{exp}} = \frac{b_{\text{ant}}}{r}$$  \hspace{1cm} (31)

It is obvious that $V_{\text{exp2}} < V_{\text{exp1}}$, which for $\varpi_2$ favors the expulsion of the stems.

The geometrical parameters of driving drum in the vertical plane also affect the conditions of evacuation of the stalks.

As mentioned, in the process of expulsion on the stalk act the frictional forces between the working surfaces of the expulsion plates and teeth. For the compensation of these forces on the stalk are applied the normal forces $N$. Under the action of forces $N$ (fig. 5c) occurs the bending of stalks, whose value can be determined from the strength of materials formula.

$$I = \frac{F S^2 (1 - S / I)^2}{3 E I}$$  \hspace{1cm} (32)

where $l$ – is the distance between the expulsion plates; $S$ – clearance between the plate and tooth in the vertical plane; $E$ – the elasticity modulus; $I$ – the moment of inertia of the cross-section of the stalk; $F$ – actuation force. Minimization of stalk bending is welcomed for its expulsion and it is possible, as demonstrated by the formula (32), first of all, by reducing the friction forces and respectively of driving forces $F$ (dependent on the normal forces), of the clearance $S$ and the increase the moment $I$, that depends on the geometrical parameters of the cross-section of the stalk (for example, for: the round shape $I = \frac{6D^3}{64}$, tubular shape $I = \frac{\pi}{64} (D^4 - d^4)$, where $D, d$ – the outer diameter and respectively inner of the cross-section of the stalk).

Deoarece $\varpi_2 > \varpi_1$, prin urmare $r_2 > r_1$. Viteza deplasării tulpinilor de-a lungul suprafeţei din faţa dintelui de antrenare este egală:

Este evident că $V_{\text{exp2}} < V_{\text{exp1}}$, ceea ce pentru $\varpi_2$ favorizează expulzarea tulpinilor.

Parametrii geometrici ai tamburului de antrenare în planul vertical de asemenea influenţează condiţiile de evacuare a tulpinilor.

După cum s-a mai menţionat, în procesul expulzării asupra tulpinii acţionează forţele de frecare cu suprafeţele de lucru a plăcilor de expulzare şi a dintelui. Pentru compensarea acestor forţe asupra tulpinii se aplică forţele normale $N$. Sub acţiunea forţelor $N$ (fig. 5c) se produce încovoierirea tulpinilor, a cărei valoare se poate determina din formula cunoscută în rezistenţa materialelor

unde $l$ – este distanţa dintre plăcile de expulzare; $S$ – jocul dintre placă şi dinte în planul vertical; $E$ – modul de elasticitate; $I$ – momentul de inerţie a secţiunii transversale a tulpinii; $F$ – forţa de acţionare.

Minimizarea încovoierii tulpinii este binevenită pentru expulzarea ei şi este posibilă, după cum demonstrează formula (32), în primul rând prin reducerea forţelor de frecare şi respectiv a forţelor de acţionare $F$ (dependente de forţele normale), jocului $S$ şi majorarea momentului $I$, care depinde de parametrii geometrici ai secţiunii transversale a tulpinii (de exemplu, pentru: forma rotundă $I = \frac{6D^3}{64}$, tubulară $I = \frac{\pi}{64} (D^4 - d^4)$, unde $D, d$ – diametrul exterior şi respectiv interior al secţiunii transversale a tulpinii).
The distance \( l \) between the plates influences less the bending of stalk, at the same time with the simultaneous reduction \( l \) and \( S \) takes place the essential decrease of bending \( l \). The minimum value of the clearance \( S \) is determined by the technological possibilities of windrower manufacturing. The distance \( l \) depends primarily on the thickness \( \delta \) of the driving plates, which in its turn is determined by the need to ensure the rigidity of the disk and the exclusion of cutting the stalk (\( \delta > \delta_{\text{t}} \) where \( \delta_{\text{t}} \) is the thickness of the tooth with which it starts cutting the of stalks). According to the data [6], the optimal thickness of the blade knife is 0.02 ... 0.04 mm, being allowed 0.1 mm. According to the preliminary results, in order to obtain enough rigidity the minimum thickness of the driving disk must be at least 3 ... 4 mm, that is 30 ... 40 times higher than allowable value for cutting. Therefore, the distance \( l \geq \delta_{\text{min}} + S_{\text{min}} \).

As mentioned, at the stage of stalks movement in the sector III (fig.5) it is necessary to concomitantly perform their expulsion from the drum and reorient from the vertical to the horizontal position. Therefore, distance \( l \) between the driving teeth (fig.4) must be enough to assure the change of the stalk position from vertical to the horizontal one. Angle \( \alpha \) of inclination of the stalk will depend on the drum geometrical parameters in the following way:

\[
tg \alpha = \frac{L - d}{h_{\text{int}}},
\]

where \( d \) is the diameter of the stalk, \( h_{\text{int}} \) the height of the stalk driving.

More favorable conditions for the reorientation of stalks provide inclination in the vertical plane of the drum teeth (the angle \( \alpha \), fig. 4b; 5c) and of the expansion plates (the angle \( \beta \), fig. 5d). In this case the foot of the stalk comes out faster from the drum and arrives by its lifting between the supplying rollers.

Inclination of surfaces referred improves not only the conditions for the reorientation of stalks, but also for their expulsion because size and the profile of cross section of the stalk in the plane of interaction and plates of the drum teeth and the expansion plates (fig. 5a,b) change. The round shape of the the cross section (fig. 5a) changes into ellipsoidal (fig. 5b). Therefore, it increases the area of the section and respectively the moment of inertia \( I \), the resistance to bending. Concomitantly changes the position of the points of application of the normal forces \( N_x, N_z \) (points B,C, fig. 3.13b), favoring the expulsion of stalks.

**CONCLUSIONS**

1) For ensuring the conditions for qualitative cutting, driving safely and operative evacuation of all of stalks into windrower with the vertical axis of rotation of the working bodies, was established the dependence between the agrotechnical parameters of the stalks (the diameter, the number \( m \) to 1 meter in the row), the constructive parameters (the number of teeth of the drum \( z \)) and kinematic parameters (combine speed \( V_{\text{com}} \), the speed of rotation of the driving drum \( \omega_{\text{drum}} \)). There have been determined the positions of the lateral dividers and of the central one in relation to the driving drum in order to obtain reliable driving of the stalks.

Distanța \( l \) dintre plăci influențează mai puțin asupra încovoierii tulpinilor, totodată cu reducerea simultană \( l \) și \( S \) are loc diminuarea esențială a încovoierii \( l \). Valoarea minimă a jocului \( S \) este determinată de posibilități tehnologice de confectionare a vindroverului. Distanța \( l \) depinde în primul rând de grosimea \( \delta \) a dinților de antrenare, care la rîndul său este determinată de necesitatea asigurării rigidității discului și excluzării tăierii tulpinii (\( \delta > \delta_{\text{t}} \) unde \( \delta_{\text{t}} \) este grosimea dintelui, cu care se începe tăierea tulpinilor). Conform datelor [6], grosimea optimă a lamei cuțitului este 0,02...0,04 mm, se admete 0,1 mm. Conform rezultatelor prealabile, pentru obținerea rigidității suficiente grosimea minimă a discului de antrenare trebuie să fie de cel puțin 3...4mm, adică de 30...40 ori mai mare decit valoarea admissible pentru tăiere. Prin urmare, distanța \( l \geq \delta_{\text{min}} + S_{\text{min}} \).

După cum s-a mai menționat, la etapa mișcării tulpinilor în sectorul III (fig.5) este necesară concomitent expulzarea lor din tambur și reorientarea din poziția verticală în cea orizontală. Pentru aceasta distanța \( l \) dintre dinții de antrenare (fig.4) trebuie să fie suficientă pentru asigurarea schimbării poziției tulpinii din verticală în cea orizontală. Unghiul \( \alpha \) de inclinare a tulpinii va depinde de parametrii geometrici ai tamburului în felul următor:

\[
tg \alpha = \frac{L - d}{h_{\text{int}}},
\]

unde \( d \) este diametrul tulpinii, \( h_{\text{int}} \) înălțimea antrenării tulpinii.

Condiții mai favorabile pentru reorientarea tulpinilor asigură încălțarea în plan vertical a dinților tamburului (unghiul \( \alpha \), fig. 4b; 5c) și plăcilor de expulzare (unghiul \( \beta \), fig. 5d). În acest caz piciorul tulpinii iese mai repede din tambur și nimeresețe prin ridicarea sa între tâvălui de alimentare.

Încălțarea suprafețelor menționate îmbunătățește nu numai condițiile pentru reorientarea tulpinilor, dar și pentru expulzarea lor, deoarece se schimbă mărimea și profilul secțiunii transversale a tulpinii în planul interacțiunării dinților tamburului și plăcilor de expulzare (fig. 5a,b). Forma rotundă a secțiunii transversale (fig. 5a) se schimbă în elipsoidală (fig. 5b). Prin urmare, se mărește suprafața secțiunii și respectiv momentul de inerție \( I \), rezistența la încovoierii. Concomitent se schimbă poziția punctelor de aplicare a forțelor normale \( N_x, N_z \) (puncte B,C, fig. 3.13b), favorizând expulzarea tulpinilor.

**CONCLUZII**

1) Pentru asigurarea condițiilor de tăiere calitativă, antrenare sigură și evacuare operativă a tulpinilor din rînd în vindrover cu axa verticală de rotație a organelor de lucru, s-a stabilit dependența dintre parametrii agrotehnici ai tulpinilor (diametrul, numărul \( m \) la 1 metru liniar în rînd), parametrii constructivi (numărul de dinți ai tamburului \( z \)) și cinematici (viteză combinaie \( V_{\text{com}} \), viteză de rotație a tamburului de antrenare \( \omega_{\text{tamb}} \)). Au fost determinate pozițiile divizorilor laterali și a celui central în raport cu tamburul de antrenare cu scopul obținerii antrenării sigure a tulpinilor.
2) The analysis of the forces acting on the stalk in the windrower has shown that the danger of untimely expulsion of the stalk from the area of driving comes from the centrifugal forces. Methods are proposed to minimize the negative influence of centrifugal forces. For safely driving and moving of the stalk inside the drum with low energy consumption is required that the coefficients of friction of the stalk on the surfaces of drum teeth $f_2$ and of guiding bars $f_1$ to be minimal, and the angle $\gamma$ between the working surfaces of the guiding bar and of the drum tooth to be permanently greater than the sum $\varphi_1 + \varphi_2$. Also the working width of the driving space (the working length of the driving tooth) must be greater than or equal to the sum of two diameters of stalk and a diameter of the guiding rod.

3) The reliable expulsion of the stalks in the reception chamber is performed if the angle $\gamma$ between the the working surfaces of the drum teeth and the expulsion plates is greater than the sum of the coefficients of friction of stalk on the respective working surfaces $(\varphi_2 + \varphi_2)$. For increasing the probability of expulsion of stalks and of vegetal remains it is necessary that the length of the zone of interaction of the teeth and plates to be the maximum possible. The convex shape of the expulsion plate provides favorable conditions for vegetal mass expulsion on the entire length of the interaction of the driving teeth and the plates.

4) The expulsion of stalks from the drum and their reorientation from the vertical to the horizontal position inside the reception chamber depend on the the constructive parameters not only in the horizontal plane but also in the vertical one (angles of inclination of the drum teeth $\alpha$ and of the expulsion plates $\beta$). The angles $\alpha$ and $\beta$ change the size and the profile of (from round in the ellipsoidal) of the cross section of the stalk in the plane of the drum teeth and plates interaction, changes the position of the points of application of the normal forces, favoring the expulsion of stalks from drum in the reception room of the windrower.

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2) Analiza forțelor care acționează asupra tulpinii în vindrover a demonstrat că pericolul expulzării înainte de vreme a tulpinii din spațiul de antrenare provine de la forțele centrifugale. Sunt propuse metode de minimizare a influenței negative forțelor centrifugale. Pentru antrenarea sigură și deplasarea tulpinii în interiorul tamburului cu consum redus de energie este necesar ca coeficienții de frecare a tulpinii pe suprafațele dinților tamburului $f_2$ și a tijelor de ghidare $f_1$ să fie mini, iar unghiul $\gamma$ dintre suprafețele de lucru tijei de ghidare și a dintelui tamburului să fie permanent mai mare decât suma $\varphi_1 + \varphi_2$. Totodată, lățimea de lucru a spațiului de antrenare (lungimea de lucru a dintelui de antrenare) trebuie să fie mai mare sau egală cu suma a două diametre ale tulpinii și un diametru al tijei de ghidare.

3) Expulzarea sigură a tulpinilor în camera de recepție se efectuează, dacă unghiul $\gamma$ dintre suprafețele de lucru ale dinților tamburului și plăcilor de expulzare va fi mai mare decât suma coeficienților de frecare a tulpinei pe suprafațele de lucru respective $(\varphi_2 + \varphi_2)$. Pentru majorarea probabilității de expulzare a tulpinilor și resturilor vegetate este necesar ca lungimea zonei de interacțiune a dinților și plăcilor să fie minimal posibilă. Forma convexă a plăcii de expulzare asigură condiții favorabile pentru expulzarea masei vegetale pe toată lungimea interacțiunii dinților de antrenare și plăcilor.

4) Expulzarea tulpinilor din tambur și reorientarea lor din poziția verticală in cea orizontală în camera de recepție depinde de parametrii constructive nu numai în plan orizontal, dar și în cel vertical (unghiuri de înclinare a dinților tamburului $\alpha$ și plăcilor de expulzare $\beta$). Unghiurile $\alpha$ și $\beta$ modifică mărimea și profilul (din rotund în elipsoidal) secțiunii transversale a tulpinii in planul interacțiunii dintii tamburului și plăcilor de expulzare, schimbă poziția punctelor de aplicare a forțelor normale, favorizând expulzarea tulpinilor din tambur în camera de recepție a vindrowerului.

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KINEMATIC ANALYSIS OF THE DRIVING MECHANISM OF ECCENTRIC SEPARATOR AS A COMPONENT PART OF MACHINE OF HARVESTING MISCANTHUS RHIZOMES

ANALIZA CINEMATICĂ A MECANISMULUI DE ACTIONARE A SEPARATORULUI CU EXCENTRIC AFLĂT IN COMPONENTA ECHIPAMENTULUI TEHNIC DE RECOLTARE A RIZOMILOR DE MISCANTHUS

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Abstract: The paper presents the kinematic analysis of mechanism which drives the eccentric separator comprised by the technical equipment of harvesting Miscanthus rhizomes, where the positions, speed and accelerations of component elements, are determined. The kinematic analysis of the mechanism which drives the eccentric separator allows to identify the functional and constructive parameters which have to be operated for improving the mechanism structure and performance.

Keywords: kinematic analysis, numerical study, eccentric separator, optimization, functional and constructive parameters

INTRODUCTION

Within the crop technology of Miscanthus energetic plant, rhizomes harvesting represents one of the most important operations, which greatly influences the quality of seeds, necessary to establish a new crop. Majority of technical equipment for harvesting the root vegetables generally, comprises extracting working parts and separating working parts. In case of technical equipment with fix inclined blade-type extracting working parts, the harvesting quality is mainly influenced by the separating parts.

Therefore, knowing the kinematic parameters of these separating parts, represents an objective necessary to be fulfilled for constructively and functionally optimize the respective equipment.

The technical equipment for harvesting Miscanthus rhizomes (fig. 1) comprises a separator with eccentric driven by a quadrilateral mechanism formed of handle, connecting rod and balance lever, represented by separator’s rods. Eccentric separator (fig. 2) is designed to clean by shaking and transport the extracted Miscanthus rhizomes towards the machine rear part. The machine comprises two oscillating grates which take over the soil dislocated mass together with the rhizomes and an oscillating mechanism with eccentric which performs an optimum vibratory effect so that the soil detaches from rhizomes and falls between the grate rods.

MATERIALS AND METHODS

Mechanism of driving the eccentric separator as a component of technical equipment for Miscanthus rhizomes harvesting, is a quadrilateral mechanism (fig. 3) made of handle 1, rod 2, balance lever 3 and four rotation couplings (R).

MATERIALE ŞI METODE

Mecanismul de acționare a separatorului cu excentric, parte componenta a echipamentului tehnic de recoltat rizomi de Miscanthus, este un mecanism patrulat cu intermediu unui mecanism patrulater format din manivela, biela şi balansier, reprezentat de vergele separatorului.

Separatorul cu excentric (fig. 2) este destinat pentru curăţirea de pământ, prin scuturare şi transport rizomilor de Miscanthus dislocaţi, spre spatele maşinii. Aceasta are în componenţă două grătare oscilante care preia masa de sol dislocată împreună cu rizomii şi un mecanism oscilant cu excentric care realizează un efect vibrato cu excentric astfel încât solul să se deprindă de rizomi şi să cadă pe sol printre vergele grătării.
Fig. 3 - Scheme of quadrilateral mechanism which drives the eccentric separator

Point B coordinates are:

\[
\begin{align*}
    x_b &= AB \cdot \cos \varphi_1 \\
    y_b &= AB \cdot \sin \varphi_1
\end{align*}
\]

(1)

Speed and accelerations of point B are obtained by differentiation related to time:

\[
\begin{align*}
    v_{bx} &= -AB \cdot \omega_1 \cdot \sin \varphi_1 \\
    v_{by} &= AB \cdot \omega_1 \cdot \cos \varphi_1 \\
    a_{bx} &= -AB \cdot \omega_1^2 \cdot \cos \varphi_1 \\
    a_{by} &= -AB \cdot \omega_1^2 \cdot \sin \varphi_1
\end{align*}
\]

(2)

For 3R modular group made of connecting rod 2, balance lever 3 and rotation couplings B,C and D, it can be written:

\[
AB + BC = AD + DC
\]

(3)

We are designing this vector equation on coordinates axes and obtain the equation system:

\[
\begin{align*}
    BC \cdot \cos \phi_2 - CD \cdot \cos \phi_3 - (x_d - x_b) &= 0 \\
    BC \cdot \sin \phi_2 - CD \cdot \sin \phi_3 - (y_d - y_b) &= 0
\end{align*}
\]

(4)

Linear equation system, in unknown \( \phi_2 \) and \( \phi_3 \), can be solved by eliminating the \( \phi_3 \) angle between the two equations of non linear system:

\[
\begin{align*}
    BC \cdot \cos \phi_2 - (x_d - x_b) &= CD \cdot \cos \phi_3 \\
    BC \cdot \sin \phi_2 - (y_d - y_b) &= CD \cdot \sin \phi_3
\end{align*}
\]

(5)

The following notations are made:

\[
\begin{align*}
    k &= x_d - x_b \\
    h &= y_d - y_b
\end{align*}
\]

(6)
The equation system will be:

\[
\begin{align*}
BC \cdot \cos \phi_2 - k &= CD \cdot \cos \phi_3 \\
BC \cdot \sin \phi_2 - h &= CD \cdot \sin \phi_3
\end{align*}
\]

(7)

We are raising to square the two equations:

\[
\begin{align*}
BC^2 \cdot \cos^2 \phi_2 + k^2 - 2 \cdot BC \cdot k \cdot \cos \phi_2 &= CD^2 \cdot \cos^2 \phi_3 \\
BC^2 \cdot \sin^2 \phi_2 + h^2 - 2 \cdot BC \cdot h \cdot \sin \phi_2 &= CD^2 \cdot \sin^2 \phi_3
\end{align*}
\]

(8)

We are summing up the two equations and obtain:

\[
BC^2 + k^2 + h^2 - 2 \cdot BC \cdot k \cdot \cos \phi_2 - 2 \cdot BC \cdot h \cdot \sin \phi_2 = CD^2
\]

(9)

The following notations are made:

\[
\begin{align*}
a &= 2 \cdot BC \cdot k \\
b &= 2 \cdot BC \cdot h \\
c &= BC^2 - CD^2 + k^2 + h^2
\end{align*}
\]

(10)

The circular function equation is obtained:

\[
b \cdot \sin \phi_2 + a \cdot \cos \phi_2 + c = 0
\]

(11)

Solution of circular function equation is

\[
\sin \phi_2 = \frac{b \cdot c - a \sqrt{a^2 + b^2 - c^2}}{a^2 + b^2}
\]

\[
\cos \phi_2 = \frac{a \cdot c + b \sqrt{a^2 + b^2 - c^2}}{a^2 + b^2}
\]

\[
\sin \phi_3 = \frac{BC \cdot \sin \phi_2 - h}{CD}
\]

\[
\cos \phi_3 = \frac{BC \cdot \cos \phi_2 - k}{CD}
\]

(12)

Rotation angles of connecting rod and balance lever are

\[
tg \phi_2 = \frac{\sin \phi_2}{\cos \phi_2} \quad \phi_2 = \arctg(\phi_2)
\]

(13)

\[
tg \phi_3 = \frac{\sin \phi_3}{\cos \phi_3} \quad \phi_3 = \arctg(\phi_3)
\]

(14)

For determining the angular speed of rod and balance lever, the equation system is derived from relation (4) in relation with time:

\[
\begin{align*}
- BC \cdot \dot{\phi}_2 \cdot \sin \phi_2 + CD \cdot \phi_3 \sin \phi_3 &= \dot{k} \\
BC \cdot \phi_2 \cdot \cos \phi_2 - CD \cdot \phi_3 \cos \phi_3 &= \dot{h}
\end{align*}
\]

(15)

Where:

\[
\begin{align*}
\dot{k} &= x_d - x_b \\
\dot{h} &= y_d - y_b
\end{align*}
\]

(16)

Matrix of unknowns coefficients is

\[
\omega = \begin{bmatrix}
- BC \cdot \sin \phi_2 \\
BC \cdot \cos \phi_2
\end{bmatrix} \quad \begin{bmatrix}
CD \cdot \sin \phi_3 \\
- CD \cdot \cos \phi_3
\end{bmatrix}
\]

(17)

The equations system (15) in unknowns \( \phi_2 \), and \( \phi_3 \) is solved by means of inverse matrix method and we obtain:

Sistemul de ecuații (15) în necunoscutele \( \varphi_2 \), și \( \varphi_3 \), se rezolvă folosind metoda mătricii inverse și se obține:
For determining the angular accelerations, the equations (15) are derived in relation with time and we obtain:

\[
\begin{align*}
- BC \cdot \varphi_2 \cdot \sin \varphi_2 - BC \cdot \varphi_2 \cos \varphi_2 + CD \cdot \varphi_3 \sin \varphi_3 + CD \cdot \varphi_3^2 \cos \varphi_3 &= \ddot{k} \\
BC \cdot \varphi_2 \cdot \cos \varphi_2 - BC \cdot \varphi_2 \sin \varphi_2 - CD \cdot \varphi_3 \sin \varphi_3 + CD \cdot \varphi_3^2 \sin \varphi_3 &= \ddot{h}
\end{align*}
\]  

(19)

Where:

\[
\begin{align*}
\ddot{k} &= x_d - x_h \\
\ddot{h} &= y_d - y_h
\end{align*}
\]  

(20)

The following notations are made:

\[
\begin{align*}
A_1 &= \ddot{k} + BC \cdot \varphi_2^2 - CD \cdot \varphi_3^2 \cos \varphi_3 \\
A_2 &= \ddot{h} + BC \cdot \varphi_2^2 \sin \varphi_2 - CD \cdot \varphi_3^2 \sin \varphi_3
\end{align*}
\]  

(21)

System of equations (19) becomes:

\[
\begin{align*}
- BC \cdot \sin \varphi_2 \cdot \varphi_2 + CD \cdot \sin \varphi_3 \cdot \varphi_3 &= A_1 \\
BC \cdot \cos \varphi_2 \cdot \varphi_2 - CD \cdot \cos \varphi_3 \cdot \varphi_3 &= A_2
\end{align*}
\]  

(22)

System of linear equations in unknowns $\ddot{\varphi}_2$ and $\ddot{\varphi}_3$ is solved by inverse matrix method:

\[
\begin{bmatrix}
\ddot{\varphi}_2 \\
\ddot{\varphi}_3
\end{bmatrix} = W^{-1} \begin{bmatrix}
A_1 \\
A_2
\end{bmatrix}
\]  

(23)

For C rotating torque, the position, velocity and angular speed are determined with relations:

\[
\begin{align*}
x_c &= x_d + CD \cdot \cos \varphi_3 \\
y_c &= y_d + CD \cdot \sin \varphi_3 \\
v_{cx} &= -CD \cdot \varphi_3 \cdot \sin \varphi_3 \\
v_{cy} &= CD \cdot \varphi_3 \cdot \cos \varphi_3 \\
a_{cx} &= -CD \cdot \varphi_3^2 \cdot \cos \varphi_3 - CD \cdot \varphi_3 \cdot \sin \varphi_3 \\
a_{cy} &= -CD \cdot \varphi_3^2 \cdot \sin \varphi_3 + CD \cdot \varphi_3 \cdot \cos \varphi_3
\end{align*}
\]  

(24)
RESULTS

Kinematic analysis is based on a series of values considered constant, representing the actual dimensions of the handle, connecting rod, balance lever, respectively A and D rotating torque positions. Considering the origin of the coordinate system XAY in point A, we will have the following constants:

\[ AB = 0.013 \text{ m}; \quad BC = 0.456 \text{ m}; \quad CD = 0.329 \text{ m}; \quad X_d = 0.135 \text{ m}; \quad Y_d = -0.43 \text{ m}. \]

Kinematic analysis for the quadrilateral mechanism was performed using a program developed in MathCad 14. In order to limit the data volume that would result by calculating the kinematic parameters in each crank position \((0...360^\circ)\) were considered 37 intermediate positions, in which position 1 and 37 are equivalent and correspond to 0 respectively 360\(^\circ\). Therefore, it will be determined the kinematic parameters in these intermediate points while kinematic analysis will be achieved by reference to the mentioned positions.

The AB handle separator of the acting mechanism is driven by hydraulic engine coupled to the tractor hydraulic system. For numerical simulation using the mentioned computer program, was considered an average hydraulic motor shaft speed of 250 rot/min. The variation of velocity components of point B on the axis of coordinates depending on the angle of rotation \(\varphi_1\) (crank position) is shown in Figure 4.

![Fig. 4 - Variation of component velocity at point B](image)

**Absolute velocity of point B has a value of 0.340 m/s.**

The connecting rod BC rotates with angle \(\varphi_2\). Changes in the rotating angle of the connecting rod on the crank position shown in Figure 5.

![Fig. 5 - Variation of the rod BC rotating angle](image)

**Maximum value of rotating angle \(\varphi_2 = -1.978 \text{ rad}\) is obtained for the position \(i = 19\) (rotation of the crank with \(\varphi_1 = 3.142 \text{ rad}\) when the crank is in the horizontal position at 180 degrees. The minimum value of the angle of rotation of the rod \(\varphi_2 = -2.04 \text{ rad}\) corresponds to position 1.**

REZULTATE

Analiza cinematica are la baza o serie de valori considerate constante, reprezentând dimensiunile reale ale manivelei, bielei, balansierului, respectiv pozițiile cupelor de rotație A și D. Considerând originea sistemului de coordonate XAY în punctul A, vom avea următoarele constante:

\[ AB = 0.013 \text{ m}; \quad BC = 0.456 \text{ m}; \quad CD = 0.329 \text{ m}; \quad X_d = 0.135 \text{ m}; \quad Y_d = -0.43 \text{ m}. \]

Analiza cinematică a mecanismului patrulater s-a efectuat cu ajutorul unui program realizat în MathCad 14. Pentru a limita volumul mare de date care ar fi rezultat prin calcularea parametrilor cinematici în fiecare poziție a manivelei \((0...360^\circ)\), s-au considerat 37 de poziții intermediare, în care poziția 1 și 37 sunt echivalente și corespund valorii de 0 respectiv 360\(^\circ\). Ca urmare, se vor determina parametrile cinematici în aceste puncte intermediare iar analiza cinematică se va realiza prin raportare la pozițiile amintite.

Manivela AB a mecanismului de acționare a separatorului este acționată prin intermediul motorului hidraulic cuplat la instalatia hidraulica a tractorului. Pentru simularea numerică utilizând programul de calcul amintit, s-a considerat o valoare medie a turatiei la axul motorului hidraulic de 250 rot/min. Variația componentelor vitezii punctului B pe axele de coordonate în funcție de unghiul de rotație \(\varphi_1\) (poziția manivelei) este prezentat în figura 4.

Viteza absoluta a punctului B are valoarea 0.340 m/s. Bieła BC se rotește cu unghiul \(\varphi_2\). Variația unghiului de rotație a bielei în funcție de poziția manivelei este prezentată în figură 5.

Valoarea maximă a unghiiului de rotație \(\varphi_2 = -1.978 \text{ rad}\) este obținută pentru poziția \(i=19\) (rotația manivelii cu \(\varphi_1 = 3.142 \text{ rad}\) atunci când manivelă se află în poziția orizontală, la 180 grade. Valoarea minimă a unghiiului de rotație a bielei \(\varphi_2 = -2.04 \text{ rad}\) corespunde poziției 37.
or 37 (crank rotation with $\varphi_1 = 0$ rad or 6283 rad) when the crank is in the horizontal position at 0 or 360 degrees. Changes in the angular velocity of the rod $\omega_2$ and $\varepsilon_2$ angular acceleration of the rod are shown in Figure 6.

![Graph of $\omega_2$ and $\varepsilon_2$ vs. i](image)

**Fig. 6 - Variation of rod angular velocity and acceleration / Variația vitezei și accelearației unghiulare a bielei**

Figure 7 shows the variation in the speed component of point C of on axes of the connecting rods and the speed variation point C in Figure 8 depending on the position of the crank.

![Graph of $v_{Cx}$ and $v_{Cy}$ vs. i](image)

**Fig. 7 - Variation of velocity components of point C**

It is observed that the extreme positions of point C correspond to position $i = 7$ and $i = 34$ of the crank, speed of point C having the minimum $v_c = 0.026$ m/s and maximum $v_c = 0.372$ m/s.

![Graph of $v_c$ vs. i](image)

**Fig. 8 - Variation of absolute velocity of point C**

Se observă că pozițiile extreme ale punctului C corespund pozițiilor $i = 7$ și $i = 34$ ale manivelii, viteză punctului C având valoarea minimă $v_c = 0.026$ m/s respectiv maxima $v_c = 0.372$ m/s.
Maximum rotation angle value is $\varphi_3 = 3.132\, \text{rad}$, the minimum value $\varphi_3 = 3.047\, \text{rad}$ and the variation of this angle is $0.085\, \text{rad}$. These values correspond to the extreme positions of the point C.

Variation in velocity and angular acceleration of balance lever is shown in Figure 10.

**Fig. 10 - Variation of angular velocity and acceleration balance lever**

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**CONCLUSIONS**

Through kinematic analysis program of mechanism operating the eccentric separator can be determined positions, velocities and accelerations components.

Velocities can be analytically determined by the two axes of the considered coordinate system as well as the absolute velocities of points B and C, in m/s.

Also, can be determined the maximum and minimum rotation angle $\varphi_2$, which can be correlated with the positions of the crank at a certain moment.

Variation of rotating angle $\varphi_3$ between the maximum and minimum, provide information regarding extreme positions of point C, respectively the amplitude and oscillation frequency of the balance lever, allowing the identification of functional and constructive parameters having to be adjust in order to optimize the construction and operation of the separator with eccentric.

**REFERENCES**


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**CONCLUZII**

Prin intermediul programului de analiză cinematică a mecanismului de acționare a separatorului cu excentric, se pot determina pozițiile, vitezete si accelelațiile elementelor componente.

Se pot determina analiic atat vitezele pe cele doua axe ale sistemului de coordonate considerat, cat si vitezele absolute ale punctelor B si C, in m/s.

De asemenea, se pot determina valorile maxime si minime a unghiului de rotație $\varphi_2$, putând fi corelate cu pozițiile manivelor la un anumit moment.

Variatia unghiului de rotație $\varphi_3$, intre valoarea maxima si minima, furnizeaza informatii privind pozițiile extreme ale punctului C, respectiv amplitudinii si frecventei de oscilație a balansierului, permitand identificarea parametrilor funcționali și constructivi asupra cărora se acționeze în scopul optimizării construcției și funcționării separatorului cu excentric.

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RESERCHES REGARDING THE SOLAR RADIATION USE AS HEATING SOURCE IN HAY VENTILATING INSTALLATIONS

CERCETĂRI PRIVIND UTILIZAREA RADIĂȚIEI SOLARE CA SURSĂ DE ÎNCĂlzIRE A AERULUI UTILIZAT DE INSTALAȚIILE DE VENTILARE A FĂNULUI

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Abstract: Solar radiation is a natural heat source with multiple uses on farms, for example, heating the air used in drying fruit technology and for domestic hot water or artificial drying of forage crops in order to obtain the hay. The paper presents the results of researches performed with a plane solar collector particular type, which is made of common materials and is designed to heat the air within special fodder ventilating installations for obtaining high quality hay and reducing conventional energy consumption. During this research, it has been measured and continuously monitored the following parameters: meteorological parameters (solar radiation, temperature, humidity), the temperature in the panel at various times of the day, TPS, air velocity in the panel, VPS, temperature variation during the panel ventilation, ΔT solar collector efficiency, η.

Keywords: hay, hot air ventilation, solar radiation, solar collectors

INTRODUCTION

Through harvesting, preparation and preserving various forms of fodder on grasslands and fodder crops it aims to achieve a final product with a nutritional value as close as possible to the original green fodder, starting from the premise that it fulfills a high quality feed, both in terms of botanical composition (balanced mix of perennial grasses with vegetables) and in the harvesting phenophase [2], [3], [5].

Harvesting, preparation and preserving as hay form represents the traditional method used in our country to capitalize the fields with feed and fodder crops, especially in the hilly and mountainous areas. In the plain regions, the hay is produced on agricultural land planted with annual or perennial forage crops, natural grasslands occupying smaller areas.

In order to reduce the drying time and implicitly the losses of nutritive substances, many harvesting, preparing and conserving methods of hay have been developed, drying representing an operation of great importance, with the biggest implications in the final quality of hay. The most known fodder drying methods are: traditional (natural) drying in stubble field; drying on supports; fodder drying by cold air ventilation; fodder drying by hot air ventilation; green fodder drying by thermal dehydration in special drying and briquetting stations, [4].

The biggest losses of nutritive substances are determined by hay traditional drying in stubble. These losses might reach, in bad weather conditions, even 50..60%, the drying period coming up to 6-8 days [7].

When hay of 35-45% moisture is gathered from the field, it is stored in hay stores or platforms endowed with drying installation, where is achieved cold or warm air ventilation up to conservation humidity (under 7%) and consequently, losses may be reduced up to

Rezumat: Radiația solară este o sursă de căldură naturală cu multiple utilizări în fermele agricole, spre exemplu încălzirea aerului utilizat în tehnologia de uscare a fructelor, pentru prepararea apei calde menajere sau pentru uscarea artificială a plantelor furajere în vederea obținerii fânului. Lucrarea prezintă rezultate ale cercetărilor efectuate cu un tip special de captatoare solare plane, construite din materiale uzuale, pentru încălzirea aerului utilizat de instalațiile speciale pentru ventilarea furajelor în vederea obținerii unui fân de calitate și reducerea consumului de energie convențională. În cadrul cercetărilor au fost monitorizate următoarele parametri: parametri meteorologici (radiație solară, temperatura, umiditate), temperatura aerului din panou la diverse ore ale zilei, \( T_{PS} \), viteza aerului în panou, \( V_{PS} \), variația temperaturii în panou în timpul procesului de ventilare, \( \Delta T \), randamentul captatorilor solari, η.

Cuvinte cheie: fân, ventilare cu aer cald, radiație solară, captatoare solare

INTRODUCERE

Prin recoltarea, pregătirea și conservarea sub diferite forme a furajelor de pe pajiști și din culturile furajere se urmărește realizarea unui produs final cu o valoare nutritivă cât mai apropiată de cea inițială a furajului verde, plecându-se de la premise că acesta îndeplinește condițiile unui furaj de foarte bună calitate, atât în ceea ce privește compoziția sa botanică (amestec echilibrat de graminee cu leguminoase perene), cât și în cea referitoare la fenofaza de recoltare [2], [3], [5].

Recoltarea, pregătirea și conservarea sub formă de fân reprezintă metoda tradițională folosită în ţara noastră pentru valorificarea furajelor de pe pajiștile și culturile furajere, în special de pe suprafețele din zona colinară și montana. În regiunile de câmpie, fânul se produce pe terenurile agricole cultivate cu plante furajere anuale sau perene, pajiștile naturale ocupând suprafețe mai mici.

Pentru reducerea timpului de uscare și implicit a pierderilor de substanțe nutritive s-au dezvoltat mai multe metode de recoltare, pregătire și conservare a fânului. Uscarea reprezintând o operatie de mare importanța, cu cele mai mari implicații în calitatea finală a fânului. Metodele de uscare a furajelor cunoscute sunt: uscarea tradițională (naturală) pe mirițe; uscarea pe suporturi; uscarea furajelor prin ventilare cu aer rece; uscarea furajelor prin ventilarea cu aer cald; uscarea furajelor verzi prin shidrătare termică în stații speciale de uscare și brichetare etc. [4].

Pierderile cele mai mari de substanțe nutritive se obțin la uscarea tradițională pe mirițe a fânului. Aceste pierderi ajung, în caz de vreme nefavorabilă (prin mușcarea fânului), chiar la 50…60 %, timpul de uscare crescând la peste 6…8 zile [7].

Atunci când fânul strâns din câmp în umiditatea de 35-45% este depozitat pe fânarele sau platformele prevăzute cu instalație de uscare, unde se face definitivarea uscarii fânului prin ventilare cu aer rece sau cald, până la umiditatea de păstrare (sub 17%), se pot

81
15-20% [8].

Installations for hay warm air drying based on conventional energy consumption: fossil fuels and electric energy are complex, expensive and difficult to redeem in small and medium-sized farms in unfavourable areas. Because of necessity to reduce conventional energy consumption, new solutions for non-polluting and cheap air heating solar installations have been sought [9], [10], [11].

MATERIALS AND METHODS

The hay drying installation tested comprises the solar collector (fig. 1), storage platform, technical equipment with axial fan and two circuits for air absorption humidity and temperature measuring sensors and a command board equipped with micro PLS, where the venting programs were set according to methodology elaborated for the installation testing.

The paper presents solutions designed to heat the air in solar collectors assembled as a panel placed on the ground, next to the drying platform.

The constructive solutions allow the users to move the drying installation from a store platform to another, on the spot, where hay final drying is needed. Also, the panel may be adapted for mounting on the roof deposits.

The solar panel (fig. 1) is a main assembly of air ventilation installation of bulk hay and because it is built as a modular structure, the users may adjust their installation according to the farm needs [6].

Panul solar al instalațiilor studiate, este format din cinci captatori solari de încălzire a aerului, montați în serie unul după celalalt pe un cadru din profil metalic. Captatori solari sunt de tipul ușor, în cazul de fața cu peretii din OSB. Peretele frontal de admiisie a radiatiei solare este din plexiglass transparent. În spațiul de încălzire al aerului, în captatori inseriați s-au montat pe lungime peretii longitudinali intermediari, creându-se trasee pentru dirijarea aerului în zig-zag, pe toată suprafața captatorilor, pentru obtinerea unui randament maxim de încălzire.

Aerul necesar ventilării este încălzit în captorii solari ai panoului prin efectul de seră. În timpul ventilării, se absoarbe aerului rece atmosferic prin orificiu - 4, acesta parcurge panoul solar pe traseul în zig - zag, se încălzește, și se evacuează prin orificiul special - 5 al panoului solar, continuând traseul prin tubulatura de aspirație flexibilă - 6, către orificiul de admiisie al ventilatorului până în camera de uniformizare a platformei de uscare.

Un indicator de performanță important pentru panoul solar plan este randamentul colectorilor solari, η, calculat cu relația (1), [1]:
where:
- $\eta_0$ - optical yield;
- $q_p$ - density of thermal flow dissipated in environment, from thermal agent, [W/m²];
- $I_g$ - density of global solar radiation, [W/m²];
- $\eta_0$ and $q_p$ are determined from relations (2) respectively (3):

\[
\eta_0 = \frac{q_p}{I_g}
\]

\[
q_p = k \cdot \Delta t
\]

where:
- $\tau$ - transmission factor of transparent material, $\tau = 0.8...0.87$ values recommended for glass, plexiglass;
- $\alpha$ - factor of absorption of absorbing material,
- $\alpha \approx 0.9$ value recommended for black enamel;
- $k$ - global coefficient of thermal transfer between collector and environment, [W/m² K];
- $\Delta t$ - difference between collector average temperature and environment, [°C].

Introducing relations (2) and (3) into (1), results the relation (4), used for determining the yield of installation plane collectors, results:

\[
\eta = \eta_0 - k \frac{\Delta t}{I_g}
\]

expressing:
- $\Delta T$ - growing indicator of panel air temperature [°C];
- $\Delta T_v$ - difference between panel air temperature before and after hot ventilation of hay stored for drying, [°C];

$\Delta T$ and $\Delta T_v$ depend on air temperature in environment, respectively on air temperature in the panel, after fodder venting, as one can see in relations (5) and (6):

\[
\Delta T = T_p - T_u
\]

\[
\Delta T_v = T_p - T_{pv}
\]

where:
- $T_p$ - air temperature in solar panel, [°C];
- $T_u$ - air temperature in the panel after hot air venting of fodder, [°C].

A digital thermometer with transducer measuring the panel temperature, INMA Bucharest professional agrometeorological station designed to control meteo parameters and a TESTOVENT 4000 type anemometer for determining wind speed in the panel when ventilating, were all used for tests.

La experimentări s-au utilizat: un termometru digital cu traductor pentru măsurarea temperaturii în panou solar, staţia meteo profesională agro-meteoreologică pentru monitorizarea parametrilor meteo, termohigrometrul și anemometrul tip TESTOVENT 4000 pentru determinarea vitezii aerului în panou în momentul ventilării.
RESULTS

Equipment for converting solar radiation, solar collectors planar panel is covered with transparent materials that are being crossed by solar radiation on the road to conversion element represented by the absorbing surface made of OSB material painted in black enamel.

Transparent cover panel was made of Plexiglas known as acrylic glass or stiplex with high transparency such as glass and has a high impact resistance.

The measurements were performed between the hours 8 in the morning and 16 in the afternoon. The parameters of atmospheric air and inside the captors, determined by measurement or calculation, are presented in Table 1, values measured being specific to a cloudy day of June.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>UM</th>
<th>8</th>
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<th>14</th>
<th>15</th>
<th>16</th>
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</thead>
<tbody>
<tr>
<td>Solar radiation, $I_g$</td>
<td>kW/m$^2$</td>
<td>0.425</td>
<td>0.562</td>
<td>0.525</td>
<td>0.219</td>
<td>0.798</td>
<td>0.203</td>
<td>0.159</td>
<td>0.073</td>
<td>0.055</td>
</tr>
<tr>
<td>Atmospheric humidity, $U_a$</td>
<td>%</td>
<td>72.243</td>
<td>65.075</td>
<td>64</td>
<td>61.287</td>
<td>59.392</td>
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<tr>
<td>Atmospheric temperature, $T_a$, °C</td>
<td>23</td>
<td>24.89</td>
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<td>27.44</td>
<td>27.78</td>
<td>26.89</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>Temperature in the panel, $T_p$, °C</td>
<td>24.6</td>
<td>28</td>
<td>40</td>
<td>45</td>
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<td>56</td>
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</tr>
<tr>
<td>Indicator of panel temperature increasing, $\Delta T$</td>
<td>°C</td>
<td>1.6</td>
<td>3.11</td>
<td>13.69</td>
<td>18.5</td>
<td>38.64</td>
<td>37.56</td>
<td>28.22</td>
<td>28.11</td>
<td>32</td>
</tr>
<tr>
<td>Panel temperature after 15 ventilating min, $T_{vn}$ (°C)</td>
<td>°C</td>
<td>23</td>
<td>26</td>
<td>30</td>
<td>33</td>
<td>38</td>
<td>36</td>
<td>30</td>
<td>29</td>
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</tr>
<tr>
<td>Temperature variation during the ventilation, $\Delta T_v$, °C</td>
<td>°C</td>
<td>1.6</td>
<td>2</td>
<td>10</td>
<td>12</td>
<td>28</td>
<td>29</td>
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</table>

The absorption process of solar radiation on absorbing surface of solar collectors, is characterized by the absorption coefficient of the absorbing material. Thus, the black enamel in which the collector was painted has an absorption coefficient of $\alpha = 0.9$ which means that 90% of solar radiation that reaches this material is converted into heat [1].

For the average yield calculation of the solar collector it has been used the equations (1), (2), (3), (4) and the following coefficient values [1]:
- transmission factor for glass or Plexiglas: $\tau = 0.835$;
- absorption factor for black enamel: $\alpha = 0.9$;
- global heat transfer coefficient between collector and the environment $k = 2.5$ W/m$^2$ K.

From Table 1 it have resulted the recorded average values for the following parameters:
- difference between average temperature of the collector and the ambient temperature: $\Delta t = 22.27^\circ$C;
- Global solar radiation density flux during the experiments: $I_g = 335$ W/m$^2$.

From the calculation it has resulted:
- optical yield: $\eta_o = 75\%$;
- average yield of solar collectors on the experimenting day: $\eta = 58\%$.

REZULTEATE

Echipamentul de conversie a radiației solare, panoul cu captatori solari plani, este acoperit cu materiale transparente, care sunt traversate de radiația solară, în drumul spre elementul de conversie reprezentat de suprafață absorbantă realizată din OSB vopsită cu email negru. Capacul transparent al panoului a fost realizat din plexiglass cunoscut și sub denumirea de sticla acrilică sau stiplex, cu transparenta asemănătoare sticlei și rezistentă la impact mare.

Masuratorile s-au efectuat în intervalul orar 8...16. Parametrii aerului atmosferic și din interiorul captatorilor, determinați prin masurare, sau prin calcule, sunt prezentati in tabelul 1, valorile sunt specificate unei zile cu cer variabil din lună iunie.

Table 1

<table>
<thead>
<tr>
<th>Parameter</th>
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</table>
Fig. 3 – The air temperature variation in the atmosphere and solar sensors

The temperature and air humidity variation of the solar panel according to the atmospheric parameters are shown in Figures 3 and 4.

Fig. 4 – The atmospheric humidity variation and solar sensors

During fodder ventilation by air heated in solar collectors studied, the installation axial fan absorbs the air, leads it through tube system to the drying platform levelling chamber, from where air penetrates into the fodder mass through the grating of drying platform and ventilating channels designed for this purpose.

The solar panel air velocities at different times of ventilation are shown in Table 2.

<table>
<thead>
<tr>
<th>Parameter</th>
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<td>8</td>
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<td>14</td>
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</tr>
<tr>
<td>Air speed [m/s]</td>
<td>1.61</td>
<td>1.71</td>
<td>1.84</td>
<td>1.84</td>
<td></td>
</tr>
<tr>
<td>Air speed when entering the panel [m/s]</td>
<td>2.4</td>
<td>2.5</td>
<td>2.4</td>
<td>2.4</td>
<td></td>
</tr>
<tr>
<td>Air speed when leaving the panel [m/s]</td>
<td>2.5</td>
<td>2.5</td>
<td>2.4</td>
<td>2.5</td>
<td></td>
</tr>
</tbody>
</table>

CONCLUSIONS

After the researches, the following appreciations and conclusions can be formulated:

- In order to reduce hay qualitative and quantitative losses, determined by long time exposure to sun and atmospheric factors after mowing and leaves losses by shaking, the technology of gathering the fodder on field at 35-45% humidity, their storing in special dryers or hay special stores and the final drying up to appropriate conservation humidity (about 18%) by warm air ventilation, were assured;
For small farms has been achieved and studied the hay drying installation by ventilating the air heated
in panel comprising the solar collectors, for reducing the electric and mechanical energy consumption;

- Temperature in panel is influenced by solar radiation and atmospheric air temperature. Analyzing the
panel temperature increasing indicator, it has been found that between 8.9 hours the temperature
raises up to 3°C, and between 10…16 hours the temperature reaches up to 39°C. Maximum values
are registered within 14-16 hour interval;

- The solar panel construction and ventilation installation make the air speed in the panel to be
almost steady during ventilation process;

- The average yield of the solar panel, \( \eta = 58\% \), is within the values indicated in the literature;

- The solar panel studied assures the heated air necessary to achieve the hay dehydrating by ventilation

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CONTRIBUTIONS TO THE MODELING AND SIMULATION OF HYDRAULIC SERVOSYSTEMS FOR TRACTORS AND AGRICULTURAL MACHINERY

CONTRIBUȚII LA STUDIUL MODELĂRII ȘI SIMULĂRII SERVOMECANISMELOR HIDRAULICE PENTRU TRACTOARE ȘI MAȘINI AGRICOLE

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Abstract: The purpose of this study is to achieve, in general, modeling and simulation of hydraulic servosystems, encountered in tractors and agricultural machinery. Due to their compact design and good controllability, position-controlled hydraulic servo drives are used in the automation of a great number of agricultural machines. The analysis starts from the functional model and then the simulation model is built using a specialized software. The paper demonstrates that the simulation software SimulationX can be effectively used to investigate complex problems of hydraulic drive structures in relation to the mechanical elements and the control loop in early development stages of new hydraulic systems. The graphically-interactive and object-oriented concept of SimulationX facilitates a friendly modeling and quick analysis of technical systems for the user.

Keywords: hydraulic servo drive, closed - loop system, simulation software, piston stroke, pump, control valve, relief valve

INTRODUCTION

The theoretical and experimental research of the elements of hydraulic systems represents the fundamental components of their analysis and synthesis realised in order to know the performances of static and dynamic quality. Experimental analysis is preponderant especially, when the system is known, and the theoretical (analytical) analysis for the case where the synthesis is done (system design).

The direct study of a system is more difficult to be carried out because of high cost or because it does not exist, but that is to be designed and carried out. For this reason the modeling is used. The model of a real system is also a system that presents analogies with the system modeled, on which basis conclusions on some properties of the real system can be drawn.

The description of the instructions for behavioral data generation, as well as a description model of a system, assume the existence and the use of a certain language. It may be a natural language, a mathematical language or a programming language, depending on which the model described may be called informal model, mathematical model (formal) or simulation model.

Possessing a number of advantages, numerical simulation has established itself in recent years, especially after elaboration and implementation of simulation languages, which allow rapid simulation of the operation of any system whose mathematical model for the operation in dynamic regime is known [1]. The paper presents the mathematical models of some major components of hydraulic systems [6].

Hydraulic motor model

In developing mathematical model for linear hydraulic model, it starts from the shape in fig.1, comprising the loading scheme and multivariable model of fig.2.

Rezumat: Scopul acestui studiu este de a realiza, în general, modelarea și simularea unor servomecanisme hidraulice, întâlnite la tractoare și mașini agricole. Datorită configurației lor compacte și bunii maniabilități, servomecanisme hidraulice cu controlul poziției sunt utilizață în automatizarea unui mare număr de mașini din agricultura. Analiza pleacă de la modelul funcțional și se construiește apoi modelul de simulare cu ajutorul unui program specializat. Studiul demonstrează că programul de simulare SimulationX poate fi utilizat efectiv pentru a investiga problemele complexe ale structurilor transmisilor hidraulice în raport cu elementele mecanice și bucla de comandă în stagiile premergătoare de dezvoltare a unor noi sisteme hidraulice. Conceptul grafic-interactive și orientate pe obiect al lui SimulationX facilitează utilizatorului o modelare accesibilă și o analiză rapidă a sistemelor tehnice.

Cuvinte cheie: servomecanism hidraulic, sistem buclă închisă, program de simulare, cursa pistonului, pompă, distribuitor, supapă de siguranță,

INTRODUCERE

Cercetarea teoretică și experimentală a elementelor sistemelor hidraulice reprezintă componente fundamentale ale analizei și sintezei acestora realizată în scopul cunoașterii performanțelor de calitate statice și dinamice. Analiza experimentală este preponderentă în special atunci când sistemul este cunoscut, iar cea teoretică (analitică) pentru cazul când se face sinteza (proiectarea sistemului).

Studierea directă a unui sistem real este mai dificilă de realizat din cauza costului ridicat sau pe motiv că acesta nu există, că urmează a fi proiectat și realizat. Pentru acest motiv, se recurge la modelare. Modelul unui sistem real este la rândul lui un sistem ce prezintă analogii cu sistemul modelat, pe baza căreia se pot trage concluzii asupra unor proprietăți ale sistemului real.

Descrierea instrucțiunilor de generare a datelor comportamentale, precum și descrierea modelului unui sistem, presupune existența și utilizarea unui anume limbaj. Acesta poate fi un limbaj natural, limbaj matematic sau un limbaj de programare, în funcție de care modelul descris poate fi numenit model neformal, model matematic (formal) sau model de simulare.

Poseând o serie de avantaje, simularea numerică s-a impus în ultimii ani, mai ales după elaborarea și implementarea limbajelor de simulare, care permit simularea rapidă a funcționării oricărei sisteme la care este cunoscut modelul matematic de funcționare în regim dinamic [1]. În cele ce urmează sunt prezentate modelele matematice ale unor componente importante ale sistemelor hidraulice [6].

Modelul motorului hidraulic

În elaborarea modelului matematic pentru motorul hidraulic linear, se pornește de la schița din fig.1, cuprinzând schema de încarcare și modelul multivariable din fig.2.
In figures above, it is noted: \( F \) - strength force in [N]; \( A_1 \) and \( A_2 \) - active areas of the piston \([m^2]\); \( Q_1, Q_2 \) - output flow rates \([m^3/s]\); \( p \) and \( p_0 \) - the input instantaneous pressures, respectively output ones \([N/m^2]\); \( M \) - the mass (reduced to piston rod) \([kg]\).

Starting from the equation of rates and moments the mathematical model of linear motor operating in dynamic stage is written (without \( Q_2 \)'s equation) in the form:

\[
Q_1 = \frac{d^2 x}{dt^2} \cdot A_1 + a_M (p - p_0) + \frac{V_o}{x} \cdot \frac{dx}{dt}
\]

\[
M \cdot \frac{d^2 x}{dt^2} + b_M \cdot \frac{dx}{dt} + c_f \cdot p^2 \cdot \frac{x}{x_0} = \left( A_1 \cdot p - A_2 \cdot p_0 \right) + F = p \cdot A_1 - p_0 \cdot A_2
\]

Where \( a_M \) is the linearised coefficient of the loss of flow to the piston, proportional to the pressure \((m^3/s)/N/m^2)\); \( V_o \) - the initial volume of liquid in engine chamber under the pressure \( p \) \([m^3]\); \( b_M \) - the linearised coefficient of losses of forces proportional to speed \([N/(m/s)])\); \( c_f \) - coefficient of dry friction (adimensional).

To avoid the nonlinearity originating from the product of two variables, namely the factor \( \frac{dx}{dt} \cdot p \cdot \frac{dx}{dt} \), the following replacement is made:

\[
\frac{dx}{dt} \cdot p \cdot \frac{dx}{dt} = \frac{V_o}{p} \cdot \frac{dx}{dt}
\]

where \( L \) is the piston stroke.

In view of the new notations, substituting then \( dx/dt = V \) and by applying transformed Laplace, in null initial conditions, the relationship (1) and (2) become:

\[
Q_1(s) = V(s) \cdot A_1 + a_M \cdot [p(s) - p_0(s)] + \frac{V_o}{p} \cdot p(s) \cdot s
\]

\[
M \cdot V(s) \cdot s + b_M \cdot V(s) + c_f \cdot p^2 \cdot \frac{x(s)}{x_0} \cdot [A_1 \cdot p(s) - A_2 \cdot p_0(s)] + F(s) = p(s) \cdot A_1 - p_0(s) \cdot A_2
\]

Control valve model

Being widespread in hydraulic drive systems, discrete manifolds provide connections of the body pressure source to mobile component, or various combinations and connections between pipes, by relative displacement between the spool and the valve body (fig.3) [2].

Modelul distribuitorului hidraulic

Având o largă răspândire în sistemele hidraulice de acționare, distribuitoroarele discrete asigură conexiunile sursei de presiune cu organul motor, sau diverse combinații și legaturi între conducte, prin deplasarea relativă dintre sertar și corp (fig.3) [2].
Considerând un distribuitor cu trei poziţii cu acoperire pozitivă (blocaj în poziţie mediană) şi pierderi neglijabile, rezultă, pentru: $x = +1 (P_3 \rightarrow A, B \rightarrow T)$; $Q_3 = Q_A$; $Q_T = Q_T$.

$iţii$, reiese că se poate analiza orice sistem hidraulic, pornind de la părţile componente

The simulation software used for hydraulic systems is based on functional models of these systems, connecting components to each other and establishing parameters for each component. Modeling can be called as object oriented.

A virtual instrument for modeling and simulation of hydrostatic systems called SimulationX, has been used. The fluid power models in SimulationX consider extreme nonlinearities such as pressure, temperature, nonlinear valve properties and cavitation, as well as volumetric and mechanical yields.

The fluid power libraries interact with models from Mechanics, Power Transmission and Controls. This permits the simulation of complex multi-physics models [7].

I chose this simulation software for its performance and the existence of a large number of libraries and numerous mechanic elements, control signals, transfer functions etc.

It is true that not all pumps, valves or other devices of hydrostatic category, will be represented by the same mathematical models and consequently the same virtual instruments, but hydrostatic elements with constructive-functional features, in one category or another, will be analyzed with special virtual instruments tailored for the respective particularities. Each virtual instrument of dynamic analysis of a hydrostatic drive, comes with its functional, constructive parameters as input size and the characteristic size as outputs.

Under these circumstances, it appears that it may consider any hydraulic system, based on common

Programele de simulare utilizate pentru sisteme hidraulice se bazează pe scheemele funcţionale ale sistemelor respective, conectarea componentelor unui cu celălalt şi stabilirea parametrilor pentru fiecare component.

Modelarea poate fi denumită ca fiind orientată pe obiect.

S-a utilizat în acest studiu un instrument virtual pentru modelarea şi simularea sistemelor hidrostatic ne numit SimulationX.

Modelele hidraulice în SimulationX iau în considerare nerăbdăt mâine extreme ale presiunii, temperaturii, proprietăţilor distribuitorului şi cavităţii, precum şi randamentele volumice şi mecanice.

Biblioteca de simboluri hidraulice interacţionează cu modelele din Mecanică, Transmitelui şi Control. Acest lucru permite simularea modelelor multizifice complexe [7].

Am ales acest soft de simulare pentru performanţe şi existenţa unui număr mare de bibilotece şi al unui număr mare de elemente mecanice, semnale de comandă, funcţii de transfer etc.

Este adevărat că nu toate pompele, supapele sau o altă categorie de aparatura hidrostatică, vor putea fi reprezentate prin aceleaşi modele matematice şi implicit aceleaşi instrumente virtuale, dar elementele hidrostatic care cu particularităţi constructive-construcţionale, dintr-o categorie sau alta, vor putea fi analizate cu instrumente virtuale speciale, adaptate particularităţilor respective. Fiecare instrument virtual de analiză dinamică a unui element hidrostatic de acţionare, este însotit de parametrii săi funcţional-construcţivi, ca mărimi de intrare şi de mărimele caracteristice corespunzătoare, ca mărimi de ieşire.

În aceste condiţii, reiese că se poate analiza orice sistem hidraulic, pornind de la părţile componente
component parts and entering the corresponding parameters for different types of pumps, control valves, valves, hydraulic cylinders etc.. Another approach may be that approach where it starts from a certain hydraulic scheme, at which index features will be analyzed, modifying afterwards the structure by adding new elements and analyzing index features obtained [3].

MATERIALS AND METHODS
The hydraulic drive system, as shown in figure 5, consists of a hydraulic cylinder and a 4/3 control valve (control element of the control circuit) in a closed position control loop.

For the position control loop in this example, a P-controller is used.

For the modeling of the hydraulic components such as, hydraulic cylinder, 4/3 proportional directional control valve, pressure supply, and reservoir, the corresponding model objects of the Hydraulics library of SimulationX are selected and positioned on the worksheet.

The mechanical mass considers the mass of the piston rod (with rigidly coupled load mass). The weight force of the piston rod and the load mass is performed by an external force.

The position of the rod is measured by a sensor block that takes over the mechanical state values and the mechanical connections. The absolute position of the rod is detected and compared to the command value. The subtraction yields the error signal.

The signal for controlling the valve is obtained in the P controller (proportional amplification of the error signal with the gain factor “kp”).

Once created the model structure shown in figure, we can enter parameters and activate elements of protocol attributes of the variables which we want to plot after simulation (table 1).

MATERIALE ŞI METODE
Sistemul de acționare hidraulică, așa cum se arată în figura 5, constă dintr-un cilindru hidraulic și un distribuitor proportional (element de control al circuitului de comandă), într-o buclă închisă de control al poziției.

Pentru bucla de control de poziție in acest exemplu, este utilizat un controler de tip P (proporțional).

Pentru modelarea componentelor hidraulice, cum ar fi, cilindru hidraulic, distribuitor proportional 4/3, sursă de presiune, și rezervor, sunt selectate obiectele corespunzătoare modelului din biblioteca Hidraulică a lui SimulationX și poziționate pe foaia de lucru.

Masa mecanică consideră masa tijei pistonului (cu masa de încărcare cuplate rigid). Forța de greutate a tijei pistonului și încărcarea sunt realizate de forța externă.

Poziția tijei este mesurată de un senzor care preia valorile parametrilor de stare mecanici și conexiunile mecanice. Poziția absolută a tijei este detectată și comparată cu valoarea de comandă. Diferența dă semnalul de eroare.

Semnalul pentru comanda distribuitorului proportional este obținut în controllerul de tip P (amplificare proporțională a semnalului de eroare cu factorul “kp”).

Odată creată structura modelului conform figurii , se pot introduce parametrii elementelor și se activează atributele de protocol ale variabilelor pe care dorim să le reprezentăm grafic după simulare (tabelul 1).
<table>
<thead>
<tr>
<th>Elements</th>
<th>Input parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cilindru</td>
<td><strong>Cylinder Dimensions</strong></td>
</tr>
<tr>
<td></td>
<td>Maximum Stroke: 94 mm</td>
</tr>
<tr>
<td></td>
<td>Piston Diameter: 90 mm</td>
</tr>
<tr>
<td></td>
<td>Rod Diameter: 30 mm</td>
</tr>
<tr>
<td></td>
<td>Transfer of Coordinates: -17 mm</td>
</tr>
<tr>
<td></td>
<td><strong>Friction Description cylFriction</strong>: No Friction Losses</td>
</tr>
<tr>
<td></td>
<td>Pressure Chamber A: pA: bar</td>
</tr>
<tr>
<td></td>
<td>Pressure Chamber B: pB: bar</td>
</tr>
<tr>
<td></td>
<td>Pressure Drop A→B: pAB: bar</td>
</tr>
<tr>
<td></td>
<td>Volume Flow Port A (Meter-in Flow): QA: V/min</td>
</tr>
<tr>
<td></td>
<td>Volume Flow Port B (Meter-in Flow): QB: V/min</td>
</tr>
<tr>
<td></td>
<td><strong>Displacement Volume Vd</strong>: 12.6 cm²</td>
</tr>
<tr>
<td>Pompă</td>
<td><strong>Friction Description ffrKind</strong>: No Friction Losses</td>
</tr>
<tr>
<td>Pump</td>
<td>Leakage Description Kind: No Leakage</td>
</tr>
<tr>
<td></td>
<td>Volume at Port A: VA: cm²</td>
</tr>
<tr>
<td>Relief Valve</td>
<td><strong>Pressure Drop P→T</strong>: pPT: bar</td>
</tr>
<tr>
<td></td>
<td><strong>Volume Flow (Meter-In Side)</strong>: Q: l/min</td>
</tr>
<tr>
<td></td>
<td><strong>Mass Flow</strong>: mdot: kg/s</td>
</tr>
<tr>
<td></td>
<td><strong>Power Dissipation</strong>: Pdiss: kW</td>
</tr>
<tr>
<td>Motor</td>
<td><strong>Kind</strong>: Rotational Speed</td>
</tr>
<tr>
<td></td>
<td><strong>Rotational Speed</strong>: 2200 rpm</td>
</tr>
<tr>
<td></td>
<td><strong>Torque</strong>: T: Nm</td>
</tr>
<tr>
<td></td>
<td><strong>Power</strong>: Pw: Nm/s</td>
</tr>
<tr>
<td>Proportional Control Valve</td>
<td><strong>Stroke Signal strokeDescr</strong>: Normalized Signal (-1 ... 1)</td>
</tr>
<tr>
<td></td>
<td><strong>Type of Edges</strong>: Identical Edges</td>
</tr>
</tbody>
</table>
For this simulation we have used the technical characteristics of U-650 M tractor power steering [8]; [9].
RESULTS

Once we have introduced the model parameters, the simulation may be started and the results can be observed, and, at the same time the type of oil may be changed by double-clicking on the connection and selecting a liquid [5].

The control signal shows the specified characteristics. If the stroke signal for the valve is negative, the pump is connected to port A of the cylinder and the piston is moved to the right.

The flow at port A and B of the valve is somehow proportional to the stroke signal (fig.6):

![Fig.6 - Shape of the control signal](image)

Because we have a differential cylinder, the flow shows an unsymmetrical behavior. The maximum positive flow can not exceed 10 l/min, which is the flow of the pump (fig.7).

![Fig.7 - Variation of proportional directional control valve flow](image)

The pressure can not exceed 100 bar (at the pressure set for the relief valve), and at full negative opening of the control valve, the pump pressure will drop up to 32 bar, since the pump cannot deliver enough flow (fig.8):

![Fig.8 - Variation of pressure in relief valve](image)

REZULTATE

Odată ce s-au introdus parametrii modelului, se poate porni simularea și se pot observa rezultatele, se poate schimba tipul uleiului prin comanda „dublu click” pe conductă și selectarea uleiului [5].

Semnalul de comandă arată caracterele specifice. Dacă cursa distribuitorului este negativă, pompa este conectată la orificiul A al cilindrului și pistonul este deplasat spre dreapta.

Debitul la orificiile A și B ale distribuitorului este într-o oarecare measură proportional cu alura semnalului (fig.6):

![Fig.6 - Shape of the control signal](image)

Din cauza faptului că avem un cilindru diferențial, debitul prezintă un comportament asimetric. Dacă s-a stabilit debitul pompei la 10 l/min, atunci debitul maxim pozitiv nu poate depăși această valoare (fig.7).

![Fig.7 - Variation of proportional directional control valve flow](image)

Presiunea nu poate să depășească 100 bar (la presiunea setată pentru supapa de siguranță), la deschiderea maximă negativă a distribuitorului, presiunea va scădea la 32 bar, deoarece pompa nu poate furniza suficient debit (fig.8):

![Fig.8 - Variation of pressure in relief valve](image)
The velocity of the piston is proportional to the flow in the valve, and if the pump pressure drops from 100 bar to 32 bar, the velocity also decreases slightly. When the control valve is closed, the piston oscillates because of the oil compressibility noticing that the piston velocity begins to oscillate with high frequency after 0.2 s (fig.9).

From the simulation study made, it was observed that the transitional time ranges between approximately 0.12 s and 4 s. It was noted that the hydrostatic execution elements that provide a translational movement of the load present higher transient periods.

For simulation of the pressure it was chosen a longer time (5 s) to view the corresponding pressure variation for a certain period of operation. If we examine the variation of the pressure in the hydraulic cylinder, we find an oscillation of the front of the stroke due to the oil compressibility.

Likewise, the pressure does not exceed 80 bar which is the maximum pressure of pump (fig.10).

\[ \text{Fig. 9. - Piston speed variation} \]

\[ \text{Fig.10 - Variation of pressure in the hydraulic actuator} \]

In this model, the dynamic behavior of the proportional directional control valve has been neglected. It is, therefore desirable to include parameters corresponding to the proportional control valve (fig.11) [4].

If we restart the simulation with the inclusion of dynamic behavior of the proportional control valve, it will be observed that the system shows a stable state (fig.12 and fig.13).

\[ \text{Fig.11 - Consider the dynamic behavior of hydraulic proportional control valve} \]
CONCLUSIONS

In the case of the hydraulic system studied, it was observed an instability of the piston speed, which starts to oscillate with high frequency after 0.2 s, due to oil compressibility.

It has also been observed that in the range 0 to 0.2 s, when the maximum negative opening of the proportional control valve pressure drops to 32 bar, the piston speed also decreases.

Following the hydraulic actuator pressure variation it has been observed, that in the time interval from 0 to 1 the pressure has large oscillations which occur with greater frequency. This is because the hydrostatic elements that provide a translational movement of the load (such as hydraulic cylinders), show greater transient periods; after about 1 second the varying of the pressure becoming uniform.

If one takes into account the dynamic behavior of the proportional control valve, then the piston speed and cylinder pressure become stable and present an steady variation.

Comparing modern study opportunities with traditional treatment, we can make the following observations:
- Loading elements can be performed in various conditions, operations and requirements being determined as evolution in time as compared with traditional research using static models based on the maximum strength;
- Use of modeling and simulation software offers a simple answer to mathematical issues involved in research.
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RESEARCHES REGARDING APPLES SORTING PROCESS BY THEIR SIZE

CERCETĂRI PRIVIND PROCESUL DE SORTARE A MERELOR DUPĂ DIMENSIUNI

INMA Bucharest, Romania

Abstract: Article comprises the results of theoretical and experimental researches related to apple sorting process by size. Apple calibration allows to sell them at an appropriate price by dimensional groups, according to standards which define fruits by categories. Apples may be designed to direct consumption (Extra category, I-st Category, II-nd Category) and consumption after being industrially processed (apple jus, apple vinegar, jams etc.). Experimental researches have been performed by means of a sorting equipment with spiral profiling rolls, which operates according to principle of longitudinal movement of fruit under action of rolls and apples falling within the correspondence area between apple size and sorting slot size between the two rolls.

Keywords: apples sorting, calibration

INTRODUCTION

Romania’s accession to E.U. has imposed certain responsibilities, among which the compliance to specific norms regarding fresh fruits and vegetables sale, if the producer wants to capitalize his merchandise on a common market [7]. Products traded on these markets should meet certain conditions related to: minimum quality requirements (be whole, sain, without lesions, foreign odour and/or taste, etc.), minimum characteristics of maturity, tolerance (±10% out of products number or weight), origin marking.

As for the calibration the European regulations provide for apples sold for direct consumption a minimum size of 60 mm. In order to guarantee the fruit size homogeneity, it is necessary that the diameter difference between fruits belonging to the same parcel should be limited to ±5 mm for fruits from «Extra» category and for those from I-st and II-nd category presented by rows and superposed layers and to ±10 mm for fruits from I-st category-as bulk, parcel or selling package [8].

The market harsh competition has led to the necessity of sorting the fruits according to European regulations. Romania has complied with these regulations and, therefore, the apples sold in stores should fulfil the requirements of regulation [8].

At world level, numerous researches on fruit sorting were achieved [1]…[6], which represent a permanent concern, sorting resulting in homogenous products with greater marketability.

In the context of ones previously mentioned, INMA Bucharest has designed and achieved a sorting equipment for apples by size, designed to subsistence fruit growing farms, namely a profiling rolls equipment.

MATERIALS AND METHODS

Equipment was designed in 3D, by means of SolidWorks program, which allowed the modelling and theoretically determining the rolls position, in order to determine the sorting slots dimensions (fig.1).

Rezumat: Articolul cuprinde rezultate ale cercetărilor teoretice și experimentale privind procesul de sortare a merelor după dimensiuni. Calibrarea merelor permite vânzarea acestora la un preț adecvat pe grupe dimensionale, cunoscându-se faptul că există standarde care defineșc fructele pe categorii. Merele pot fi pentru consum direct (categoria Extra, Categorii I, Categorii II) și pentru consum după industrializare (suc de mere, oțet de mere, gemuri și a.) Cercetările experimentale s-au realizat cu ajutorul unui echipament de sortare cu valuri profilate tip spirală, care funcționează pe principiul avansului longitudinal al fructelor sub acțiunea valurilor și căderii libere a merelor în zona de corespondență dintre dimensiunea mărului și dimensiunea fantei de sortare dintre cele două valuri.

Cuvinte cheie: sortare-calibrație mere

INTRODUCERE

În ceea ce privește calibrarea, reglementările europene prevăd pentru merele care se vând pentru consumul direct, un calibru minim de 60 mm. Pentru a garanta omogenitatea de calibru a fructelor se impune ca diferența de diametru dintre fructele din același colet să fie limitată la: ±5 mm pentru fructele din categoria «Extra» și pentru fructele din categoria I și II prezentate pe rânduri și în straturi suprapuse și ±10 mm pentru fructele din categoria I prezentate în vrac, în colet sau în ambalajul de vânzare [8].

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MATERIALELE SI METODE

Echipamentul a fost proiectat în 3D, cu ajutorul programului SolidWorks, ceea ce a permis modelarea și determinarea teoretică a poziției valturilor, pentru definirea dimensiunilor fantei de sortare (fig.1).
Certain constructive and functional characteristics were determined since the design phase, which were subsequently checked during the testing stages of equipment. Equipment has been tested both in laboratory and exploitation conditions.

**Theoretical determination of sorting capacity**

Determination was made by taking into account the main sorts of apples in Romania: Ionathan, Golden Delicious and Idared. Calculation was made during an ideal feed flow with apples, which is continuous and uniform. In reality, feeding breaks or auxiliary times necessary to load the apples tray, may appear, which determine a smaller real working capacity of this equipment than its theoretical capacity.

Sorting is made from small diameters to bigger ones per 7 sorting groups:

- Dimensional sorting groups
  - < 60 mm;
  - 60...65 mm
  - 65...70 mm;
  - 70...75 mm;
  - 75...80 mm;
  - 80...85 mm;
  - > 85 mm.

Apples fall on rolls in primary area where sorting of apples which size is less than 60 mm, takes place (fig.1 and fig.2). Then, they are displaced towards central area, by opposite rotation of rolls until they reach the area where the apple dimension is similar to dimension of slot between rolls and they fall on collecting trays. Rolls are disposed at a certain angle, which can be adjusted by changing the supporting bearings position. The apples designed to direct consumption are gathered both on a central and a final tray, where apples over 85 mm size are collected, but which have a smaller share in the apple mass sorted.

Apples with sizes less than 60 mm are intended to be consumed after processing as juice, vinegar, jam etc. In faza de proiectare, s-au determinat anumite características constructive și funcționale, care au fost verificate ulterior în etapele de testare a echipamentului. Echipamentul a fost testat atât în condiții de laborator cât și în condiții de exploatare.

**Determinarea teoretică a capacității de sortare**

Determinarea s-a făcut luând în considerare principalele soiuri de mere din România: Ionathan, Golden Delicios și Idared. Calculul s-a făcut în condițiile unui flux ideal de alimentare cu mere, continuu și uniform. În realitate, au loc întreruperi ale alimentării, apar timp de auxiliari necesitați de încărcarea masei de alimentare cu mere, ceea ce face ca, pentru aceste echipamente, capacitatea de lucru reală să fie mai mică decât cea teoretică.

Sortarea se face de la diametre mici spre diametre mari, pe 7 grupe de sortare:

- Grupe dimensionale de sortare:
  - < 60 mm;
  - 60...65 mm
  - 65...70 mm;
  - 70...75 mm;
  - 75...80 mm;
  - 80...85 mm;
  - > 85 mm.

Merele cad pe valțuri în zona primară, unde are loc sortarea merelor cu dimensiuni mai mici de 60 mm (fig.1 și fig.2). Apoi sunt deplasate spre zona centrală, prin rotația valțurilor în sensuri opuse, până ce ajung în zona în care dimensiunea mărului coincide cu fanta dintre valțuri și merele cad pe tăvile de colectare. Valțurile sunt dispuse la un anumit unghi ce se poate regla, prin modificarea poziției lagărelor de sprijin. Colectarea merelor pentru consumul direct se face pe masa centrală cât și pe masa finală, unde sunt colectate merele cu dimensiuni de peste 85 mm dar care au o pondere mai mică în volumul de mere sortat. Merele cu dimensiuni mai mici de 60 mm sunt destinate a fi consumate după procesare sub formă de suc, oțet de mere, gem etc.
RESULTS

Apple specific mass is determined according to structure, texture and chemical composition, elements which at their turn depend on other factors, such as: soil and climate conditions, agro-technique applied, apple ripening level.

From specialty literature it has been found that apples have a specific weight ranged between 0.6512...0.9583 kg/cm$^3$, their state being able to be variable, an average specific mass of fresh apples being taken into account for calculations.

\[ \gamma_{\text{fresh apples}} \approx 830 \text{ kg/m}^3 \]

where \( \gamma_m \) = apples specific mass

In order to calculate an apple mass, it has been considered the apples shape, which is not spherical, but there is a ratio \( K \), between apple dimension on two perpendicular directions (height and equatorial diameter):

\[ K = \frac{H}{D} \]

where:

- \( K \) is the ratio between the apple dimensions on two perpendicular directions;
- \( H \) = apple height, mm
- \( D \) = apple equatorial diameter, mm.

For the three sorts of apple this ratio has the following values:

<table>
<thead>
<tr>
<th>Sort</th>
<th>( K )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iona()n</td>
<td>0.82…0.86</td>
</tr>
<tr>
<td>Golden</td>
<td>0.90…0.96</td>
</tr>
<tr>
<td>Idared</td>
<td>0.78…0.80</td>
</tr>
</tbody>
</table>

Following the determinations performed, it has been found that for Golden Delicious sort the ratio between height and diameter is almost unitary, while for the other two sorts, the apple diameter is bigger than its height.

Average mass of an apple was calculated by formula

\[ m = \gamma_m \cdot V_{\text{mar}} = \gamma_m \cdot \frac{4}{3} \cdot \pi \cdot \left( \frac{D}{2} \right)^3 \cdot K \]

where:

- \( \gamma_m \) is specific mass
- \( V_{\text{mar}} \) = apple volume;

Following the determinations performed and taking into account an average value of \( K \) ratio, mass \( m \) for 1 apple resulted, depending on apple sort and size, according to table 1:

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Theoretical mass of an apple according to apple sort and equatorial diameter, ( D )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( D ) (mm)</td>
<td>Iona()n</td>
</tr>
<tr>
<td>60</td>
<td>0.079</td>
</tr>
<tr>
<td>65</td>
<td>0.100</td>
</tr>
<tr>
<td>70</td>
<td>0.125</td>
</tr>
<tr>
<td>75</td>
<td>0.154</td>
</tr>
<tr>
<td>80</td>
<td>0.187</td>
</tr>
<tr>
<td>85</td>
<td>0.224</td>
</tr>
</tbody>
</table>

Friction between apples and coils surface is neglectable, as the displacement is made by apples rolling between rolls coils, fig.2, coefficient of rolling friction being almost 0; therefore the apple displacement speed on rolls is equal to axial displacement speed, which depends on rolls rotate speed and coil pitch, according to relation:

\[ \gamma_{\text{m fresh}} \approx 830 \text{ kg/m}^3 \]

unde \( \gamma_m \) = masa specifică a merelor

For the three sorts of apple, s-a luat in considerare faptul că formă merelor nu este sferică, ci există un raport, \( K \), între dimensiunea mărului pe două direcții perpendicularice (înălțime și diametru ecuatorial):

\[ K = \frac{H}{D} \]

unde:

- \( K \) este raportul dintre dimensiunile mărului pe cele două direcții;
- \( H \) = înălțimea mărului, mm
- \( D \) = diametrul ecuatorial al mărului, mm.

Pentru cele trei soiuri de măr, acest raport are valorile:

<table>
<thead>
<tr>
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Din determinările efectuate s-a constatat că la soiul Golden Delicious raportul între înălțime și diametru este aproape unitar, pe când la celelalte două soiuri, diametrul mărului este mai mare decât înălțimea.

Media măsă a unui măr s-a calculat cu formula:

\[ m = \gamma_m \cdot V_{\text{mar}} = \gamma_m \cdot \frac{4}{3} \cdot \pi \cdot \left( \frac{D}{2} \right)^3 \cdot K \]

unde:

- \( \gamma_m \) este masa specifică a merelor
- \( V_{\text{mar}} \) = volumul mărului;

Din determinările efectuate, luând în calcul o valoare medie a raportului \( K \), a rezultat măsă \( m \) pentru 1 măr, funcție de soi și dimensiuni, conform tabelului 1:

\[ \text{Friction between apples and coils surface is neglectable, as the displacement is made by apples rolling between rolls coils, fig.2, coefficient of rolling friction being almost 0; therefore the apple displacement speed on rolls is equal to axial displacement speed, which depends on rolls rotate speed and coil pitch, according to relation:} \]

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Frecarea dintre mere și suprafața spirelor este neglijabilă, deoarece deplasarea se face prin rostogolirea merelor între spirele valțurilor, fig.2, coeficientul de frecare de rostogolire fiind aproape 0, de aceea viteză de deplasare a mărului pe valțuri este egală cu viteză de deplasare axială, care este funcție de turația valțurilor și de pasul spirei, conform relației:
\[ v = \frac{p \cdot n}{60} \text{ [mm/s]} \]  

where:  
\( v \) is axial speed, mm/s  
\( p \) = pitch of coil, mm, \( p = 120 \text{ mm} \)  
\( n \) = rolls rotative speed, rot/min, \( n = 88.7 \text{ rot/min} \)

Calculations were performed based on certain simplifying hypotheses:  
- the apples are considered to be homogenous as size;  
- the apples feeding is continuous so that the rolls should be uniformly loaded, an apple being put in each cell.  

Time of displacement of an apple on rolls was calculated by formula:

\[ t = \frac{L}{v} \text{ [s]} \]

where:  
\( t \) is apple displacement time to the falling area, [s];  
\( L \) = space covered by apple from fall on rolls till the sorting area, [mm];  
\( v \) = axial displacement speed of apple [mm/s]

Calibration tolerance  
Tolerance of calibration is determined for each dimensional group, as a ratio between the number of products from the plot considered, which have not fulfilled the respective group requirements and the total number of apples collected per dimensional group analyzed, from plots considered, expressed in percentages.

\[ c = \frac{N_c}{N_g} \cdot 100 \text{ [%]} \]

where:  
\( N_c \) is the number of apples from considered plot, which do not meet the requirements of dimensional group size;  
\( N_g \) – total number of apples collected per dimensional group analyzed, from the considered plot.

At the same time, among the apples which do not meet the size requirements of dimensional group analyzed, the number of apples with maximum diameter of equatorial section smaller by, at least 5 mm, comparing to lower limit of respective group, will be noted.

Apples displacement speed on rolls is constant, whatever the apple size is, depending only on rolls rotative speed and coil pitch:

\[ v = \frac{p \cdot n}{60} \]

Replacing the speed value \( v \) from relation (6) in relation (4), we shall obtain:

\[ t = \frac{60 \cdot L}{p \cdot n} = \frac{L}{177.4} \text{ [s]} \]

Calculations were performed luând în considerare anumite ipoteze simplificatoare:  
- se consideră că merele sunt omogene ca dimensiune;  
- alimentarea cu mere se face continuu, astfel că valţurile sunt încărcate uniform, în fiecare alveolă fiind câte un măr.

Timpul de deplasare a unui măr pe valţi s-a calculat cu formula:

\[ t = \frac{L}{v} \]

unde:  
\( t \) este timpul de deplasare a mărului până lâ zona de cădere, [s];  
\( L \) = spaţiul parcurs de măr de la căderea pe valţi şi până la zona în care este sortat, [mm];  
\( v \) = viteză de deplasare axială a mărului, [mm/s]

**Toleranţa de calibrare**  
Toleranţa de calibrare se determină pe fiecare grupă dimensională, ca raport între numărul de exemplare din lotul considerat, care nu îndeplinesc cerinţele privind calibrul grupei dimensionale respective şi numărul total de exemplare colectate pe grupa dimensională analizată, din loturile considerate, exprimat în procente.

\[ c = \frac{N_c}{N_g} \cdot 100 \text{ [%]} \]

unde:  
\( N_c \) este numărul de mere din lotul considerat, care nu îndeplinesc cerinţele privind calibrul grupei dimensionale respective;  
\( N_g \) – numărul total de mere colectate pe grupa dimensională analizată, din lotul considerat.

De asemenea, dintre exemplarele care nu îndeplinesc cerinţele privind calibrul grupei dimensionale analizate, se va nota numărul de exemplare cu diametru maxim al secţiunii ecuatoriale mai mic cu cel puţin 5 mm faţă de limita inferioară a grupei dimensionale respective.  

Viteză de deplasare a merelor pe valţi este constantă, nefiind dependentă de dimensiunile mărului ci doar de turaţia valţurilor şi de pasul spirei:
If all apples were over 85 mm, they would cross all the rolls length and be gathered on the final tray.

Time necessary for an apple to cover the whole length of rolls would be \( t_t \) and for covering the distance appropriate to a coil pitch- would be \( t_{1p} \):

\[
\begin{align*}
\frac{2080}{1774} & = 11.73 \text{ s} \\
\frac{120}{1774} & = 0.68 \text{ s}
\end{align*}
\]

To determine \( t_t \), it was taken into account the total length of the rolls, \( L_t = 2080 \text{ mm} \), and for the time \( t_{1p} \) it was considered \( L_{1p} = 120 \text{ mm} \) as time crossed by a coil pitch.

Taking into consideration the average mass of an apple depending on its sort and the results of \( t_t \) and \( t_{1p} \), after calculations, the conclusion reached was that the equipment has a theoretical sorting capacity according to table 2, if in each slot of every dimensional group one apple falls.

### Theoretical sorting capacity related to apple sort and equatorial diameter, D

<table>
<thead>
<tr>
<th>Sort</th>
<th>Theoretical sorting capacity (kg/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jonathan Sort</td>
<td>655</td>
</tr>
<tr>
<td>Golden Delicious Sort</td>
<td>682</td>
</tr>
<tr>
<td>Ida red Sort</td>
<td>580</td>
</tr>
</tbody>
</table>

Values in table 2 are ideal values, which is not in compliance with reality, the apple share within the total volume to be sorted not being uniform.

Experimental researches made with 3 apple sorts, the same which were previously taken into account, have led to results closer to reality.

First, the sorting rolls were adjusted by adjusting the median distance related to dimensional group, the setting being made at the beginning and the end of rolls.

An aspect during the experimental researches is shown in fig.3.

---

The experimental researches found by measurements that the equipment has a real capacity sorting cca.450 kg/h.

As for the calibration tolerance, after having performed the measurements, taking into consideration the equatorial diameter of the apples, the following average results were obtained:

\[
\text{Valoriile din tabelul 2 sunt niște valori ideale, ceea ce în practică nu este real, proporția merelor în volumul total ce necesită a fi sortat nefiind uniform.}
\]

Cercetările experimentale efectuate cu 3 soiuri de mere, aceleași cu cele luate în calcul anterior au condus la niște rezultate mai apropiate de realitate. În prealabil s-a făcut reglajul valțurilor de sortare, reglându-se distanța mediană, aferentă grupei dimensionale, reglajul făcându-se la începutul și la sfârșitul valțurilor.

În fig.3 se observă un aspect din timpul cercetărilor experimentale.

---

In urma cercetărilor experimentale s-a constatat prin măsurători că echipamentul are o capacitate reală de sortare de cca.450 kg/h.

În ceea ce privește toleranța de calibrare, în urma efectuării măsurătorilor după diametrul ecuatorial al merelor, s-au obținut următoarele rezultate medii:
**CONCLUSIONS**

After experimental research have drawn the following conclusions:

- It has been found that sorting is not always made by diameter, but by the smallest size between height and diameter, also depending on the apple position in respective area, the manner in which it rotates, so that the sorting should be performed either by diameter or by height, according to their value, or ratio between the two values, H/D.
- A more precise adjustment of rolls slots, as well as an increment of sorting limits should be achieved, having in view the fact that the difference between the maximum limit and minimum limit is of only 5 mm and apples have a random behaviour, which determine a non-eloquent tolerance to calibration.
- Equipment will be useful if the sorting limits are modified, the dimensional groups diminishing up to max.3: <60 mm; 60-85 mm; >85 mm.

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[7]. *** - Regulamentul (CE) nr.1221/2008 al CE în sectorul fructelor și legumelor privind standardele de comercializare;

**Tabel 3**

<table>
<thead>
<tr>
<th>Dimensional group [mm]</th>
<th>Quantity [buc]</th>
<th>Quantity from quality category [pcs]</th>
<th>$D_{max}$- $D_{min}$ from quality category</th>
<th>Quantity not framing within dimensional group [pcs] / [%]</th>
<th>Quantity for which $D_s$ (Lower limit-5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>60…85</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>65…70</td>
<td>5</td>
<td>5</td>
<td>9</td>
<td>3 / 60,0</td>
<td>0</td>
</tr>
<tr>
<td>70…75</td>
<td>13</td>
<td>13</td>
<td>6</td>
<td>2 / 15,3</td>
<td>0</td>
</tr>
<tr>
<td>75…80</td>
<td>12</td>
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<td>7 / 58,3</td>
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<td>80…85</td>
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<td>&gt;85</td>
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<td>1 / 25,0</td>
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HIGH –SPEED CONVEYOR PARAMETERS OPTIMIZATION

ОПТИМІЗАЦІЯ ПАРАМЕТРІВ ШВІДКОХІДНИХ ТРАНСПОРТЕРІВ

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Abstract: The procedure of high-speed conveyors optimization based on nonlinear problem where the minimization of materials consumption of high-speed spiral conveyors is achieved at initial absolute choice of kinematic and dynamic parameters minimizing the conveyor power capacity is developed. The parameters change is restricted by range of definition, represented by generalized function. The calculation procedure of rational constructional parameters and conveyors-mixers operating regimes is developed. It consists of ten main stages including derived analytical dependences.

Key words: vertical screw (spiral) conveyor, optimization, objective (target function), constraints function.

INTRODUCTION

Screw conveyors are getting more and more widespread in manufacturing processes dealing with granular material transporting as they are characterized by simple construction, and correspondingly, high reliability, easy use and adjustment when applied in automated systems, environmental friendliness due to their tightness [1],[3],[4],[10]. High-speed conveyors are applied for versatile unloading-loading units aimed at load transporting both on horizontal, inclining and vertical paths. The existing methods of their calculations are based on a number of theoretical and experimental investigations [1],[3],[4],[10], and also on statistical data analysis of their operating results. [1],[2],[3],[4],[9],[10]. The statement and solution of the problem to choose optimal parameters of flexible conveyor providing its material [4],[5] and power [6, 7] consumption minimizing are well known. But this statement doesn’t allow to get a solution of optimization problem of screw conveyors as interconnected system.

The problems of different machine parts optimization are considered in the research of A. Hryhorjev [3], B. Hevkо, R. Rohatynska [4], V. Loveikin [6], O. Rohatynska [7], I. Hevkо [8] and others. Nevertheless, taking into consideration variety of technological processes and design of screw transporting-technological mechanisms, the problem of optimization needs further study and specification of various parameters having theoretical and practical value.

The purpose of the paper is to develop a complex task of parameter optimization where minimization of material consumption of high-speed screw conveyor is achieved at initial absolute choice of kinematic and dynamic parameters, minimizing the conveyor power capacity.

MATERIALS AND METHODS

The important factor while choosing conveyors for versatile transfer complexes is to determine the sphere of their usage, namely dealing with transportation of certain granular materials. As, according to [7], minimal limit of energy intensity of screw conveyor is defined by coefficient of load friction to spiral surface, then the main

Резюме: Розроблено методику оптимізації швидкохідних транспортерів на основі нелінійної задачі в якій мінімізація матеріаломісткості швидкохідного гвинтового конвеєра досягається при попередньому безумовному виборі кінематичних та динамічних параметрів, що мінімізують енергоємність конвеєра.

На зміну параметрів накладено обмеження які задають область визначення, яка представлена узагальненою функцією. Розроблено методику розрахунку рациональних конструктивних параметрів і режимів роботи конвеєрів змінюючи у вигляді десяти основних етапів з введенням аналітичними залежностями.

Key words: вертикальний гвинтовий конвеєр , оптимізація, цільова функція, функція обмеження.

ПЕРЕДМОВА

Для технологічних операцій переміщення сипкого вантажу велике розповсюдження набули гвинтові конвеєри, які характеристуються простою конструкції та, відповідно, високою надійністю, простотою в користуванні та льотістю адаптування при використанні в автоматизованих системах, екологічно використанням.... їх герметичністю [1],[3],[4],[10]. Для універсальних розвантажувально-завантажувальних комплексів, які призначені для транспортування вантажу, як по горизонтальних, підйомних, так і вертикальних траєцях, використовують швидкохідні гвинтові конвеєри. Існуючі методи їх розрахунку ще не мають на рівні теоретичних та експериментальних досліджень [1],[3],[4],[10], а також аналізу статистичних даних за результатами їх експлуатації [1],[2],[3],[4],[9],[10]. Відомі постановка та розв'язок задачі вибору оптичних параметрів ГК з умов оптимизащиті його матеріаломісткості [4],[5] та енергоємності [6, 7]. Проте така постановка не дозволяє отримати розв'язок оптимальної задачі гвинтових конвеєрів, як взаємопов'язаної системи.

Питанням оптимізації різних механізмів машин присвячено праці Григор'єва А.М. [3], Гевко Б.М., Рогатинської Р.М. [4], Ловіййіна В.С. [6], Рогатинської О.Р. [7], Гевко І.Б. [8] та інших. Однак, враховуючи різноманітність технологічних процесів і конструктивного виконання ГТТМ, питання оптимізації потребує подальшого дослідження і уточнення різних параметрів теоретичного й практичного значення.

Мета роботи є розроблення комплексної задачі параметричної оптимізації в якій мінімізація матеріаломісткості швидкохідного гвинтового конвеєра досягається при попередньому безумовному виборі кінематичних та динамічних параметрів, що мінімізують енергоємність конвеєра.

МАТЕРІАЛ І МЕТОДИКА

Важливою умовою при виборі конвеєрів для універсальних перевантажувальних комплексів є встановлення області їх використання, зокрема щодо транспортування певного діапазону сипких вантажів. Оскільки, згідно [7], мінімальна межа енергоємності гвинтових конвеєрів визначається коефіцієнтом тертя вантажу до поверхні спіралі,
requirement of conveyor design is its ability to transport load under unfavorable conditions. In such a case we'll consider the most unfavorable, for power consumption purpose, is vertical position of screw conveyor.

Efficiency of load transportation by screw conveyors, according to [1], [3], [10], is determined by the dependence $N = p_n g Q(W_l + H)$, either for vertical screw $N = p_n g Q W_o$ where $p_n$ - volume mass (bulk density) of load in flow; $g$ - gravity acceleration; $Q$ - conveyor volume output; $W_o$ and $W_H$ - coefficient of resistance of load transportation; $L$ and $H$ - transportation length and height of load lifting accordingly, for vertical conveyors $L = H$.

The energy intensity $w$ is given, which determines energy consumption to transport a unit of load mass per unit of length accordingly, for vertical screw conveyors:

$$w = N/(Q\cdot L) = p_n g W_n$$  \hspace{1cm} (1)

In expanded form the energy intensity factor for vertical screw conveyors the formula is:

$$W_n = \frac{\mu P_1 (t g \alpha + t g\beta_1) \cos \beta_1}{t g \alpha \cdot t g\beta_1}$$  \hspace{1cm} (2)

de $\beta_1$ - the flow angle of arrival under gravity influence; $P_1 = D e o_1^2 h/(2 g)$ - flow specific speed, determined by load rotational speed in flow $o_1$, against screw axle of diameter $D$. The above-mentioned factor is connected with conveyor specific speed coefficient $P_1 = D e o_1^2 h/(2 g)$ by the dependence $P_1 = P C_{11}^2 / (1 + C_1^2)$. Here $C_{11}$ - the coefficient (number) of kinematic similitude of screw transportation $C_{11} = t g \alpha \cdot t g(\alpha + \phi_1)$, where $\phi_1$ - angle of friction of cargo to the screw surface.

The paper [7] shows that the minimal possible theoretical level of power capacity factor $W_n$ depends only on the load friction factor on the screw surface $\mu_1$ and for its change interval $0.3 \leq 0.5 \leq 1$ is approximated by the dependence.

Such a minimal value is achieved under condition when dimensionless criterion of dynamic similitude $S_{c_1} = o_1 / \omega$, where $o_1$ - conveyor critical angle speed and screw lifting angle with external diameter $\alpha$ are [7]:

$$S_{c_1}(\mu) = 0.3 + 0.1 \mu_1$$

Accordingly, all other dimensionless criteria of screw transportation, namely the coefficient (number) of kinematic similitude $C_{11}$, minimizing the conveyor power capacity, will also definitely be determined by the friction factor $\mu_1 = t g\phi_1$. Taking into consideration all above mentioned we'll optimize vertical screw conveyors according to their material consumption under condition of minimal power consumption of load screw transportation.

The energy intensity factor for vertical screw conveyors is determined by the theoretical level of power capacity factor $W_n$ and friction factor $\mu_1$.

$$W_n = 2.30 + 6.6\mu_1 + 19.16\mu_1^2$$  \hspace{1cm} (3)

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To minimize the energy intensity of screw conveyors, the coefficient of friction $\mu_1 = t g\phi_1$. Taking into consideration all above mentioned we'll optimize vertical screw conveyors according to their material consumption under condition of minimal power consumption of load screw transportation.

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As material consumption factor of screw transporting-technological system, similarly to [4], [5], we'll take the ratio value of conveyor-mixer mass to the unit length of the given efficiency $Q$. Material consumption factor at the given efficiency is used for the case when this criterion is one of the principal (for mobile systems) and the transportation function is the basic one. In this case the problem of conveyor material consumption minimization is determined according to the criterion

$$F_n = \alpha_1 V_1 + \alpha_2 V_2 + \alpha_3 V_3 \rightarrow \min,$$  

where $V_1, V_2, V_3$ - volumes of mixer sleeve, helical spiral and center shaft correspondingly; $\rho_s$ - material density (or their prime cost) of which $\alpha_s$ - sleeve, $\alpha_d$ - helical spiral and $\alpha_c$ - center shaft are made. Volumes of sleeve, helical spiral and mixer center shaft of unit length are found according to [4]:

$$V_i = \pi S_k D(1 + 2k_i + S_k / D); \quad V_c = HD(1 - k_c) \sqrt{1 + 1/k_c} ; \quad V_z = \pi S_d D(k_z - S_z / D),$$  

where $S_k$ - sleeve wall thickness; $S_d$ - hollow shaft wall thickness; $H$ - spiral thickness; $k$ - gap (between spiral and kuxykom) factor, according to load characteristics is assumed that $k = 2z / D = 0.21 - 0.23$; $k_k$ - helix lead factor $T$, $k_s = T / D = \pi \tan \alpha$; $k_c$ - coefficient estimated by the ratio of internal $d$ and external $D$ diameters of helical spiral $k_c = d / D$.

The following technological, constructional and license limitations are in the form of inequations $f_i \leq 0$ and equations $g_i = 0$ to determine the optimal parameters of vertical high-speed screw conveyors. In particular, technological constraints are described in [4], [5] in detail, so we use main of them without any change:

1. The necessary condition for the efficiency we need $Q$ is found from the known dependence:

$$f_1 = -D^{1.5} (1 - k_j^2) + \frac{8Q}{k_j \varphi \alpha \omega} \leq 0,$$  

de $\varphi$ - коефіцієнт продуктивності, в першому наближенні наповнення простору конвеера-змішувача, що враховує також збільшення діаметра кожуха, порівняно із діаметром спіралі, $\omega$ - кутова швидкість шnek.

2. Технологічна умова формулювання спіралі із полосової заготовки, [4], [5]:

$$f_2 = -k_j + \sqrt{\pi^2 + (1 - \phi_{max}^2) / \pi \phi_{max}} \leq 0,$$  

de $\phi$ - коефіцієнт нерівномірності видовження металу, що визначається коефіцієнтом видовження $\phi_{max} = (1 + 2\delta)^2$.  

3. Технологічна умова забезпечення стійкості смуги при виготовлені спіралі є відомою [4], [5]:
where \( \delta \) - permissible specific thickness of a helical spiral workpiece after rolling \( \delta = 0.02...0.03 \) after winding \( \delta = 0.05...0.07 \).

4. For long conveyors the condition is introduced to provide hollow sleeve endurance at rotation by torsional moment on stiff shaft \( T_2 = N/\omega \):

\[
f_s = -S_1(k_x D)^2(1 + k_x S_x / D) + \frac{T_2}{\pi [r_w]} \leq 0,
\]

where \([r_w]\) - permissible torsional stress of shaft material.

5. Providing condition of helical spiral endurance while in operation:

\[
f_s = K_{CT} D H^3 E(1 - k_x) \frac{k_r}{1 + k_r} - T_2 \leq 0,
\]

where \(K_{ct}\) – trial coefficient; \(E\) – Young’s modulus.

6. Condition for the calculated friction factor \( \mu_1 \) choice, taking into account the most unfavorable conditions:

\[
f_s = \mu_1 - \mu_{\max} \leq 0.
\]

Constraints \( g_j = 0 \), imposed on design and technological parameters of screw conveyors are:

Compatibility of screw surface lead angle and minimal power consumption condition (4).

Compatibility of dynamic similitude factor and minimal power consumption condition

\[
g_j = \mu_1 P_1 S_{ii}^2 - k_r \tan(\alpha + \varphi) = 0.
\]

After transformations the given condition looks like

\[
g_j = \mu_1 D \omega^2 (0.3 + 0.1 \mu_1)^2 (1 - 0.25 \mu_1 + 0.1 \mu_2^2) - 2g_k (0.25 + 0.9 \mu_1) = 0.
\]

where \(k_p\) - flow reduction coefficient, is observed and in the first approximation is adopted \( k_p = 1 \).

As basic design and technological parameters of screw conveyors, i.e. as independent changeable components in screw conveyors optimization we’ll take those as in the known optimization models: \( x_1 = D \) - sleeve external parameters; \( x_2 = \omega \) - angular rate of rotation of helical spiral \( \omega = \tan(\alpha) = T/(\pi D) \) - helix angle \( \tan \omega \) determined by helical spiral pitch \( T \); \( x_3 = k_x = d / D \) - coefficient estimated by correlation of internal \( d \) and external \( D \) diameters of helix spiral; \( x_4 = H \) - helix spiral thickness. Besides, we’ll introduce the parameter determining the characteristics of screw transporting schedule \( x_5 = \mu_1 = 1/g_k \), calculated value of load friction factor to spiral surface.

Search of parameters \( x_i \) optimizing the objective function \( F_0 \) at constraints \( f_i \leq 0, \quad g_j = 0 \) is similarly to

\[
f_s = D(1 - k_x) - \frac{2H}{\delta} \leq 0,
\]

de \( \delta \) - допустима товщина заготовки гвинтової спіралі, отриманої прокатуванням \( \delta = 0.02...0.03 \), отриманої навиванням \( \delta = 0.05...0.07 \).

4. Для довгих конвеєрів вводять умову забезпечення міцності пустотілого вала при крученні крутним моментом \( T_2 = N/\omega \) на валу:

\[
f_s = K_{CT} D H^3 E(1 - k_x) \frac{k_r}{1 + k_r} - T_2 \leq 0,
\]

de \([r_w]\) - допустиме напруження кручення матеріалу вала.

5. Умова забезпечення стійкості гвинтової спіралі в процесі роботи:

\[
f_s = \mu_1 - \mu_{\max} \leq 0.
\]

Обмеження \( g_j = 0 \), що накладаються конструктивні та технологічні параметри гвинтового конвеєра мають такий вигляд.

Відповідність куту підійому гвинтової поверхні умові мінімальної енергозносності згідно (4). Відповідність критерію динамічної подібності умові мінімальної енергозносності

\[
g_j = \mu_1 P_1 S_{ii}^2 - k_r \tan(\alpha + \varphi) = 0.
\]

Після перетворень дана умова набуває вигляду

\[
g_j = \mu_1 D \omega^2 (0.3 + 0.1 \mu_1)^2 (1 - 0.25 \mu_1 + 0.1 \mu_2^2) - 2g_k (0.25 + 0.9 \mu_1) = 0.
\]

de \( k_r \) - коефіцієнт приведення до потоку, визначається експериментально і в першому наближенні приймається \( k_r = 1 \).

За основні конструктивні і технологічні параметри гвинтових конвеєрів, тобто за незалежні змінні при оптимізації гвинтових конвеєрів приймемо такі, як і у відомих оптимізаційних моделях: \( x_1 = D \) - зовнішній діаметр кожуха; \( x_2 = \omega \) - кутова швидкість обертання гвинтової спіралі \( \omega = \tan(\alpha) = T/(\pi D) \) - тангенс кута підійому витка, що визначається кроком гвинтової спіралі \( T \); \( x_3 = k_x = d / D \) - коефіцієнт, що оцінюється відношением внутрішнього \( d \) і зовнішнього \( D \) діаметрів гвинтової спіралі; \( x_4 = H \) - товщина гвинтової спіралі. Крім цього, введемо параметр, що визначає характеристики режиму гвинтового транспортування \( x_5 = \mu_1 = 1/g_k \) - розрахункове значення коефіцієнта тertia вантажу до поверхні спіралі.
[4, 5], using Kuhn-Tucker conditions, when for the nonlinear programming problem in the given setting there are the following multipliers \( u_i \geq 0 \), \( i = 1, 2, \ldots n \), that \( u_i f_j = 0 \) and \( \partial \phi(x, u_j) / \partial x_j = 0 \), where \( \phi(x, u) = F_s + \sum u_i f_j \).

Constraints \( g_j = 0 \) are used for the problem order reduction, i.e. for the independent parameters number reduction.

Objective function (factor of quality) in the given nonlinear programming problem, taking into account (5) and (6), is put down in this way:

\[
F_s = \pi \alpha [\sigma_s (1 + k + S_k / x_k) + \alpha_x (1-x_k) \sqrt{1+1/x_k} + \pi \alpha S x_k (x_k - S_k / x_k)] .
\]

RESULTS AND DISCUSSION

New conditions introduction \( g_i = 0 \), providing low energy-consuming operating modes of conveyor, which allow to have a new parameter \( x_2 = \omega \) out the linear programming problem solution, so it doesn’t change the solution structure of the very optimization model and calculation schemes for determining the optimal parameters, shown in [4], [5], but only makes them more specific. Accordingly, we are finding the solution of the optimization problem similar to [4], according to two calculation schemes with primal constraints on conveyor capacity and additional constraints on technology of spiral making and on the shaft strength (for long conveyors). Accordingly, we define the following order of searching of optimal design values and technological parameters of high-speed screw conveyor: 1. According to technical specifications of transportation to provide all load nomenclature processing \( f_i = 0 \), therefore.

From situation \( g_i = 0 \) angle of screw ascent is determined \( \alpha = 0.25 \) on external diameter, minimizing the power parameters of transportation and lead coefficient.

In case, when \( k \leq k_{\text{min}} \), we adopt that \( \tan \alpha = k_l / \pi \). If purpose-built conveyor is designed for transportation of only one kind of load with friction factor \( \mu_l \), then \( \tan \alpha = 0.25 - 0.1 \mu_l \) is adopted. 2. From situation \( g_2 = g_3 = 0 \) conveyor power speed coefficient is determined:

\[
\mu_l = \mu_{\text{max}} .
\]

Визначаються із умов \( g_1 = 0 \) кут підійому гвинта \( \alpha = 0.25 \) по зовнішньому діаметру, що мінімізує енергосилові параметри транспортування та коефіцієнт кроку

\[
\tan \alpha = 0.25 - 0.1 \mu_{\text{max}} .
\]

\[
k_l = T / D = \pi \tan \alpha .
\]

У випадку, коли \( k \leq k_{\text{min}} \), приймаємо \( \tan \alpha = k_l / \pi \). Якщо проектується спеціалізований конвеєр для транспортування тільки одного виду вантажу з коефіцієнтом тертя \( \mu_l \), то приймають \( \tan \alpha = 0.25 - 0.1 \mu_l \).

2. Із умови \( g_2 = g_3 = 0 \) визначають коефіцієнт швидкохідності конвеєра:

\[
\mu_l = \mu_{\text{max}} .
\]
\[ P_t = \frac{k_3 \tan(\alpha + \varphi)}{\mu_t \frac{C_r}{v}} = \frac{k_3 (0.25 + 0.9 \mu_t)}{\mu_t (0.3 + 0.1 \mu_t) (1 - 0.25 \mu_t + 0.1 \mu_t^2)}. \]  

3. From technological situation \( f_1 = 0 \) the ratio \( k_d \) of screw internal and external diameters is found

\[ k_d = \sqrt{\frac{\pi^2 + 1 - \frac{\phi_n}{\pi \phi_{\text{in}}}}{\pi^2 + 1 - \frac{\phi_{\text{out}}}{\pi \phi_{\text{in}}}}}, \]  

4. From the equation set solution \( f_1 = 0 \) and \( g_2 = 0 \) at the given efficiency rotating speed is found:

\[ \omega = \left[ \frac{\pi g \alpha \cdot P_t \left(1 - k_d^2\right) (1 - Sc_H)}{Q (1 + C_r)} \right]^{\frac{1}{2}} = \frac{\sqrt{g} \left(1 - k_d^2\right)}{\mu_2 Q} K_w(\mu_t), \]  

where \( K_w(\mu_t) \) - depends only on \( \mu_t \) and is found by simplification of the previous one taking into account the values \( P_t, Sc_H, \) and \( C_r \).

5. Screw internal and external diameters are found

\[ D = \sqrt{2 P_t g / \omega^2} = \left(\frac{g^{1/3} Q^{1/10} K_w(\mu_t)}{\mu_2^{1/5} \phi_n^{3/10} (1 - k_d^2)^{1/10}}\right). \]  

6. Lead of a helix is determined by the dependence

\[ T = k_t D. \]  

7. Spiral internal diameter (shaft diameter), as such

\[ d = k_s D = D \sqrt{\frac{\pi^2 + 1 - \frac{\phi_n}{\pi \phi_{\text{in}}}}{\pi^2 + 1 - \frac{\phi_{\text{out}}}{\pi \phi_{\text{in}}}}}. \]  

8. Spiral thickness from the situation \( f_1 = 0 \)

\[ H = \delta (D - d)/2. \]  

For specific spirals, namely for elastic spirals, values \( H = \delta (D - d)/2 \) are inspected on the conformance to situation \( f_1 \leq 0 \).

9. Axial velocity of load transportation according to [6], [7] is determined by the dependence

\[ v = \frac{T \omega}{2 \pi} \frac{1 - Sc_H}{1 + C_r}. \]  

10. Vertical conveyor transportation capacity, providing the efficiency \( Q \) of length \( L \) at load transporting, by bulk density \( \rho_r \)

\[ N = \rho_1 g Q L W = \frac{\rho_1 g Q L C_r \left(Sc_H + C_r\right)^3}{Sc_H (1 + C_r)(1 - Sc_H) \tan^2 \alpha \sqrt{(Sc_H + C_r)^2 + (1 - Sc_H)^2 \tan^2 \alpha}}. \]  

Behavior of vertical screw conveyor angular velocity and its spiral diameter, minimizing the conveyor power capacity at different rheological properties of load, is shown on fig.1.
In case of long screw conveyors their shafts bear heavy torsion load, hence the received values $d$ are tested on limits.

At its violation the internal diameter is determined by the approximating dependence

$$d = \frac{2k_{\mu}M_{\mu}}{S_{\text{c}}[G]}.$$ 

(27)

Further the spiral external diameter is specified

$$D_i = \sqrt{D_{i-1}^2 + \frac{8Q}{k_{\phi,\omega}i_1}},$$

(28)

where values $D_1$ and $\omega_1$ are taken from the previous calculations.

At significant difference of values $D_i$ and $D$, the coefficient $k_0 = d/D$ is specified and calculated value of angular velocity $\omega$ is specified according to dependence (20).

For horizontal and low falling high-speed screw conveyors there is no critical angular speed, hence the parameter $Sc=0$, and a rational angle of helical screw spiral opposite to friction factor is determined graphically, e.g. according to [8].

In case of loading-unloading transporting screw systems, having two screw conveyors – loading and unloading, the normal working condition is to provide more efficient unloading conveyor $Q_2$ than a loading one $Q_1$ at any conditions, that is

where $\lambda \cdot \text{safety margin } \lambda = 1.2...1.3$ depending on the working conditions.

$Q_{\text{max}}$ - is reached at horizontal position of loading conveyor, and $Q_{\text{min}}$ - at vertical one of unloading conveyor.

Situation (29) in the first approximating is:

$$Q_{\text{min}} \geq \lambda Q_{\text{max}},$$

(29)

where

- $\lambda$ - кофіцієнт запасу $\lambda = 1.2...1.3$ залежно від умов роботи.

$Q_{\text{max}}$ - досягається при горизонтальному розміщенні забірного конвеєра, а $Q_{\text{min}}$ - при вертикальному вивантажувальному.

Умова (29) в першому наближенні буде

$$D(\mu_1) = DD(\mu_1),$$

(20)

1. Fig. 1. Change of rational value of angular velocity $\omega(\mu_1) = wQ(m_1)$, c-1 (a) and spiral external screw diameter $D(\mu_1) = DD(m_1)$, m (b) from load friction ratio to the spiral (sleeve) surface, $\mu_1 = \mu_2$ for the given conveyor efficiency

Для довгих гвинтових конвеєрів їх вали несуть значні крути навантаження, а тому отримані значення $d$ перевіряють на відповідність обмеженню .

При його порушенні внутрішній діаметр визначають по наближенні залежності

$$d = \frac{2k_{\mu}M_{\mu}}{S_{\text{c}}[G]}.$$ 

(27)

В подальшому уточнюють зовнішній діаметр спіралі

$$D_i = \sqrt{D_{i-1}^2 + \frac{8Q}{k_{\phi,\omega}i_1}},$$

(28)
The ratio we received allow to calculate with high accuracy the optimal constructional and technological parameters of screw conveyors (SC), providing the necessary mixture quality at high efficiency of transportation process.

CONCLUSION

Theoretical basis of optimization of high-speed conveyors for granular materials transportation is developed. The nonlinear programming problem is solved using Kuhn-Tucker conditions.

The procedure of calculations of rational constructional parameters and conveyors-mixers operating regimes is developed. It consists of ten main stages with derived analytical dependences.

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\[
\phi_1 D^2/\alpha_1 \tan \alpha_1 (1 - \tan \alpha_1/\tan \alpha_2) \geq \lambda \phi_1 D^2/\alpha_1 \tan \alpha_1 (1 + \tan \alpha_1/\tan \alpha_2)
\]

(30)

Отримані співвідношення дозволяють з високою точністю обчислити оптимальні конструктивні й технологічні параметри гвинтових конвеєрів (ГК), при яких забезпечується потрібна якість суміші при високій ефективності процесу транспортування.

ВИСНОВКИ

Розроблено теоретичні основи оптимізації швидкодійних транспортерів для транспортування сипких матеріалів. Роз'язано задачу нелінійного програмування з використанням умов Куна-Таккера.

Розроблено методику розрахунку раціональних конструктивних параметрів і режимів роботи гвинтових конвеєрів у вигляді десяти основних еталів з виведеними аналітичними залежностями.

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THEORETICAL ASPECTS RELATED TO THE AIR FLOW THROUGH THE SEED LAYER ON THE PNEUMATIC-VIBRATING MACHINE SURFACE

Abstract: The thesis presents the main theoretical elements related to the air flow going through granular bed under vibrating motion. It draws the hypothesis of analogy between the vibrating granular layer and the stationary layer, having in view that the seeds speed on the machine table are relatively low and consequently their influence upon air flow through layer can be neglected. It is emphasized that in this case can be utilized with good results, the Ergun equation as a link between pressure downfall (ΔP) on the thickness of the seed layer and air speed for a global laminar turbulent way through layer. On this basis have been presented theoretical studies for two different machines used in the concrete work practice for wheat and barley seeds. Experimental results obtained regarding the pressure downfall (ΔP) subject to the fans air flow of these machines have been compared to those evaluated by calculation and there is reasonable difference (errors ±5%).

Keywords: pressure downfall (ΔP), stratification, global laminar- flow, minimum fluidization speed

INTRODUCTION

One of the necessary operations for sorting seeds, often used, is sorting seeds by their density. The pneumatic vibrating machines [6, 7] are used for sorting seeds by density. The flat working surfaces of such machine which carry out segregation are represented schematically in fig.1.

By means of this method the selection is realized as an effect of a combined action of a continuous air flow which is homogeneous, upward, of constant pressure and goes through the seed layer situated on a cobweb or wire net surface and due to the vibrations at which this surface is subject. [2,3,4].

As a result of air flow together with the agitation caused by vibrations of the surface, the particle mixture on the sorting surface will get loose the particles arriving in the air flow in suspension condition and a stratification by density of the seeds is obtained, fig.2.

The stratification effect is favored if during the air circulation through seed layer, such layer will get loose up to fluidization limit, an increasing of the porosity of the seed layer, respectively. [6].

As proved by experimental researches [2, 4] the air circulation through seed layer situated on the flat surface of the pneumatic vibrating machine plays an important role in seeds stratification.

Rezumat: În lucrare se prezintă principalele elemente teoretice legate de curgerea aerului prin mediul granular în stare de mişcare vibratorie. Se formulează ipoteza analogiei între stratul granular vibrator cu stratul în stare stationară, având în vedere că vitezele de deplasare a semințelor pe masa mașinii sunt relativ mici și în consecință influența acestora asupra curgerii aerului prin strat se poate neglija. Se evidențiază faptul că în această situație se poate utiliza, cu bune rezultate, ecuația lui Ergun, de legătură între căderea de presiune (ΔP) pe grosimea stratului de semințe și viteză curentului de aer, pentru o curgere globală laminar-turbulentă prin strat. Pe această bază s-au prezentat studii de caz pentru două mașini diferite existente în practică, în condiții concrete de lucru pentru semințele de grâu și orz.

Datele experimentale obținute, referitoare la căderea de presiune (ΔP) în funcție de debitul de aer al ventilațoarelor existente la aceste mașini au fost comparate cu cele evaluate prin calcul, diferențele încadrându-se în limite rezonabile (în domeniul erorilor ±5%).

Cuvinte cheie: căderea de presiune (ΔP), stratificare, curgere globală laminar-turbulentă, viteză minimă de fluidizare

INTRODUCERE

Una din operațiile necesare de sortare a semințelor, este adesea și separarea acestora după densitatea lor.

Prin separarea după densitate a semințelor se utilizează mașinile pneumo-vibratoare, [6, 7]. Schematic, suprafețele plane de lucru ale acestor mașini care efectuează separarea sunt reprezentate în fig.1.

Prin această metodă separarea se realizează ca efect al acțiunii combinate a unui curent de aer continuu, uniform, ascendent, de presiune constantă, care străbate stratul de semințe ce se află pe o suprafață din țesătură fină sau plasă de sârmă și a vibrățiilor la care aceasta este supusă, [2, 3, 4].

Sub acțiunea curentului de aer și a agitației provocate de oscilațiile suprafeței, amestecul granular de semințe de pe suprafața de separare se afânează, particulele acestuiu ajungând în stare de suspensie în curentul de aer, având loc și o stratificare după densitate a semințelor, fig.2.

Efectul de stratificare este favorizat dacă la curgerea curentului de aer prin stratul de semințe se produce o afanare a acestuia până la starea limită de fluidizare, respectiv o creștere a porozației stratului de semințe. [6].

Așa cum au arătat și cercetările experimentale, [2, 4] un rol esențial în fenomenul stratificării îl joacă circulația curentului de aer prin stratul de semințe de pe suprafața plană a mașinii pneumo-vibratoare.
The information furnished by specialty literature regarding the relevant theoretical aspects is quite poor. Therefore, in this thesis, appropriate mathematical models regarding the air circulation through seed layer under vibrations effect, were developed, the model with experimental data obtained on a machine in working process was tested and on this basis a theoretical study with concrete data was performed.

**Fig. 1 - Scheme of surfaces for pneumatic vibrating segregation by seeds density**
a) - scheme of wheat machine doubled inclined table  
b) - scheme of barely seeds machine double inclined table

MATERIALS AND METHODS
According to specialty literature, in order to assure the air circulation through seed layer, a pressure downfall (\( \Delta P \)) on the thickness of seed layer is evaluated, as presented in fig. 2 and fig. 3.

The theoretical basis of the seed stratification due to air circulation through layer by analogy with air circulation through granular, porous, stationary bed, [6], to which is assimilated, is hereby presented.

As a consequence of stratification there is a differentiation as regards the seeds friction coefficient on the relevant supporting surfaces. Thus, the interaction between seeds is reduced and decreases towards zero, which makes motion possible within the mixing layer, on its thickness.

The heavy particles, with high density, fall to the base of the mixing layer (getting in contact with the segregation surface) and the lighter particles, with lower density, rise to the top of the mixing layer.

**Fig. 2 - Diagram of vibrating surface with one seed layer segregated by particles’ density**

**MATERIALE ŞI METODE**
Potrivit literaturii de specialitate pentru asigurarea circulaţiei aerului prin stratul de seminţe se apreciază necesitatea unei anumite căderi de presiune (\( \Delta P \)) pe grosimea stratului, aşa cum este prezentat schematic în fig. 2 şi fig. 3.


Consecinţa stratificării este o diferenţiere a coeficientului de frecare a seminţelor pe suprafeţele corespunzătoare de sprijin. În acest fel se va micşora interacţiunea între particule până la anulare, ceea ce le asigură posibilitatea deplasării în interiorul stratului de amestec, pe grosimea sa.

Particulele grele, de densitate mare, covoară la baza stratului de amestec (ajungând în contact cu suprafaţa de separare), iar particulele mai ușoare, de densitate mai mică, scapă de acolo.
density, move to the upper part of the layer, getting loose, with a more reduced interaction with the lower layers comparing to the one of heavy particles with segregation surface, see fig.3.

The presence of air layers between segregated lines, causes, probably, a decrease in friction coefficient value, lower values for those in the upper layer, together with particle density decrease, as in fig.3.

We will consider applicable the fluid flow theory through solid particles bed, which does not change its characteristics during process, thus representing an approximation of real case when seeds move with relative low speeds on the vibrating surface.

Therefore, we will analyze, only the fluid (air) flow through seed layer (solid particles) in stationary condition. The seed bed is considered as stationary when its characteristics remain unchanged.

During air circulation through seed layer are considered to be plausible three flow type: laminar flow, turbulent flow and global laminar turbulent flow, [5].

Out of these, the last flow is most probable. We shall present synthesized the three flow modes.

**Laminar flow**

The flow is laminar if air flow through existing channels within seeds bed is laminar. After making several considerations and calculations, which are to be presented in details in item [6], Fanning equation for each channel can be written as follows:

$$\frac{(-\Delta P)}{\rho_a} = \frac{64 \cdot h' \cdot v_c^2}{Re \cdot 2 \cdot D_e}$$

where Reynolds number, i.e. $v_c$ is presented in the formulae:

$$Re = \frac{\rho_a \cdot v_c \cdot D_e}{\eta}$$

The symbols used in these equations are as follows: $\rho_a$ - air density; $v_c$ - air speed through channel; $v$ - conventional air speed through cross section equal with table surface covered with seeds; $D_e$ - channel equivalent diameter; $h'$ - channel length (as a rule, lower than seed layer thickness $h$); $\varepsilon$ - seed layer porosity.

After making several considerations and calculations presented detailed in [1], we get final form of eq. (1):

$$v = \frac{(-\Delta P)}{\eta \cdot h} \cdot \frac{\varepsilon^3}{K''(1-\varepsilon)(a_{so})}$$

The equation (4) is known as Kozeny-Carman equation, where: $K''$ - Kozeny constant which depends on porosity and specific surface and was experimentally established, $K'' = 5\pm0.5$; $a_{so}$ - specific surface of the particle, defined by $a_{so}$ - (particle surface) / (particle volume); $\eta$ - air dynamic viscosity; (-ΔP) pressure downfall on thickness layer.

**Turbulent flow**

If air flow through channels is the turbulent one, the Fanning equation can be applied, [5].

mică, se deplasează spre partea superioară a stratului și ies la suprafața acestuia, găsindu-se în stare afănată, cu o interacțiune mai redusă cu păturile inferioare în raport cu aceea a particulelor grele cu suprafața de separare, vezi fig.3. Existența păturilor de aer între straturile stratificate determină, probabil o scădere a coeficientului de frecare de la baza stratului spre partea lui superioară, odată cu scăderea densității particulelor, ca în fig.3.

Se va considera aplicabilă teoria curgerii fluidelor prin patul de particule solide care nu-și schimbă caracteristicile în timpul procesului, ceea ce reprezintă o aproximare a cazului real în care semințele se deplasează cu viteză relativ mici, pe suprafața vibratoare. De aceea se va analiza numai curgerea fazei fluidului (aerului) prin stratul de semințe (particule solide) în stare staționară. Patul de semințe este considerat staționar, când caracteristicile acestuia nu variază.

La curgerea aerului prin stratul de semințe sunt plauzibile trei regimuri de curgere: curgere laminară, curgere turbulentă și curgere globală laminar-turbulentă, [5]. Dintre acestea, ultimul regim de curgere este cel mai probabil. Vom prezenta în sinteză cele trei regimuri de curgere.

**Curgerea laminară**

Curgerea este laminară dacă fluxul de aer prin canalele existente în patul de semințe este laminar. După o serie de considerații și calcule, prezentate în detaliu în [6], ecuația lui Fanning pentru fiecare canal poate fi pusă sub forma:

unde numărul lui Reynolds, respectiv $v_c$ sunt prezente în formulele:

$$Re = \frac{\rho_a \cdot v_c \cdot D_e}{\eta}$$

Semnificația mărimilor din aceste ecuații este: $\rho_a$ - densitatea aerului; $v_c$ - viteză aerului prin canal; $v$ - viteză convențională a aerului prin secțiunea egală cu suprafața mesei acoperită cu semințe. $D_e$ - diametrul echivalent al canalului; $h'$ - lungimea canalului (de regulă mai mic decât grosimea h a stratului de semințe); $\varepsilon$ - porozitatea stratului de semințe.

După o serie de considerații și calcule, prezentate în detaliu în [1], ec. (1) devine în forma finală:

$$v = \frac{(-\Delta P)}{\eta \cdot h} \cdot \frac{\varepsilon^3}{K''(1-\varepsilon)(a_{so})}$$

Ecuată (4) este cunoscută sub numele de ecuația Kozeny-Carman. unde: $K''$ - constanta lui Kozeny care depinde de porozitate și suprafața specifică și a fost găsită experimental, $K'' = 5\pm0.5$; $a_{so}$ - aria specifică a particulei, definită prin $a_{so}$ - (suprafața particulei) / (volumul particulei); $\eta$ - este vâscozitatea dinamică a aerului; (-ΔP) căderea de presiune pe grosimea stratului.

**Curgerea turbulentă**

Dacă circulația aerului prin canale este turbulentă, se poate aplica ecuația lui Fanning, [5].
\[
\frac{(-\Delta P)}{\rho_e} = 4 f \frac{h^2 \cdot v^2}{2 \cdot D_e}
\]

(5)

where: \( f \) is the friction coefficient.

In conformity with item, [5] above:

\[
D_e = 4 \cdot \frac{\epsilon}{a_m (1-\epsilon)} a_m = \frac{6}{d_e}
\]

(6)

Having in view the item (3), (6) above, which are included in item (5) and after making calculation, the result is:

\[
\frac{(-\Delta P)}{h} = 3(K')^3 \cdot f \cdot \frac{\rho_s \cdot v^2 (1-\epsilon)}{d_e \cdot \epsilon}
\]

(7)

where: \( K' = h'/h \) is so called bed tortuosity coefficient and \( d_e \) is particle equivalent diameter.

If we make notation \( f' = f \cdot (K')^3 \), a modified friction coefficient, then the equation (7) becomes:

\[
\frac{(-\Delta P)}{h} = 3f' \frac{\rho_s \cdot v^2 (1-\epsilon)}{d_e \cdot \epsilon}
\]

(8)

This equation is known as Burke-Plummer equation and value of \( f' \) to be obtained experimentally and depends on Reynolds number, [5].

**Global laminar- turbulent flow**

This is the real case, most plausible, in which both flow types through seed layer exist simultaneously. The characterization of air flow is defined by Reynolds number modified for particle:

\[
Re_p = \frac{\rho_e \cdot v \cdot d_e}{\eta}
\]

(9)

where \( v \) is not the real speed but conventional speed.

As per item [5] data, if: \( Re_p < 40 \) then flow mode is laminar and for \( Re_p > 40 \) the flow mode is turbulent or global-turbulent. In accordance with certain considerations, detailed in item [5], it is recommended for estimations, in case of solid granular materials (seeds) the following equation to be applied:

\[
\frac{(-\Delta P)}{h} = 150 \cdot \frac{(1-\epsilon)^2 \cdot \rho_s \cdot v^2 + 1.75 \cdot (1-\epsilon) \rho_s \cdot v \cdot d_e}{\rho_e \cdot \epsilon \cdot d_e}
\]

(10)

This equation can be used to estimate not only pressure downfall \((-\Delta P)\), at the air circulation through seed layer, independent of flow type, if all parameters on the right side of the equation can be evaluated, but also conventional speed \( v \) when pressure downfall \((-\Delta P)\) is estimated.

**Minimum speed at fluidization**

It is important to know the point when fluidization takes place, defined by minimum speed of fluidization. In this point takes place the dynamic equilibrium between weight forces (\( F_0 \)) and those exerted by air (\( F_F \)) upon particles:

\[
F_0 = (\rho_p - \rho_e) S \cdot h (1-\epsilon) g
\]

(11)

where: \( \rho_p \) - particles density; \( S \) - vibrating surface (equal to cross surface of the column having same surface); \( g \) - gravity acceleration. The force due to air pressure on the particles from layer of cross section, is:

unde: \( f \) este factorul de frecare:

În conformitate cu considerațiile din, [5]:

\[
D_e = 4 \cdot \frac{\epsilon}{a_m (1-\epsilon)} a_m = \frac{6}{d_e}
\]

Având în vedere relațiile (3), (6) care se includ în (5) și după efectuarea calculelor se obține:

\[
\frac{(-\Delta P)}{h} = 3(K')^3 \cdot f \cdot \frac{\rho_s \cdot v^2 (1-\epsilon)}{d_e \cdot \epsilon}
\]

unde: \( K' = h'/h \) este așa numitul coeficient de tortuozitate a patului și \( d_e \) este diametrul equivalent al particulei,. Dacă se notează: \( f' = f \cdot (K')^3 \), un factor de frecare modificat atunci ecuația (7), devine:

\[
\frac{(-\Delta P)}{h} = 3f' \frac{\rho_s \cdot v^2 (1-\epsilon)}{d_e \cdot \epsilon}
\]

Această ecuație este cunoscută sub numele de ecuația lui Burke-Plummer, iar valoarea lui \( f' \) se obține experimental și depinde de numărul lui Reynolds, [5].

**Curgerea globală laminar - turbulentă**

Acesta este cazul real, cel mai plauzibil, în care sunt prezentate simultan ambele regimuri de curgere al aerului prin stratul de semințe. Caracterizarea regimului de curgere se face prin numărul lui Reynolds modificat pentru particule:

\[
Re_p = \frac{\rho_e \cdot v \cdot d_e}{\eta}
\]

unde \( v \) nu este viteza reală ci viteza convențională.

Conform datelor din [5], dacă: \( Re_p < 40 \) atunci regimul de curgere este laminar și pentru \( Re_p > 40 \) regimul de curgere este turbulent sau global laminar-turbulent. După unele considerații, prezentate în detaliu în [5], se recomandă pentru estimări, în cazul materialelor granulare solide (semințele) utilizarea ecuației:

\[
\frac{(-\Delta P)}{h} = 150 \cdot \frac{(1-\epsilon)^2 \cdot \rho_s \cdot v^2 + 1.75 \cdot (1-\epsilon) \rho_s \cdot v \cdot d_e}{\rho_e \cdot \epsilon \cdot d_e}
\]

cunoscută sub numele de ecuația lui Ergun.

Această ecuație poate fi folosită la estimarea, atât a căderii de presiune \((-\Delta P)\), la curgerea curventului de aer prin stratul de semințe, independent de tipul curgerii, dacă toți parametrilor din dreapta ecuației pot fi evaluații, cât și a vitezii convenționale \( v \) când se estimatează căderea de presiune \((-\Delta P)\).
Theoretical study

Theoretical study will make reference to the estimation of conventional air speed under seed layer not only for wheat seeds but for barley seeds, in the segregation process by density and compare them to the customary values utilized in practice for Cimbria Gravity Separator GA71 machine, for wheat seeds, and Jubus MJ-S 120 machine, for barley seeds.

In order to evaluate the pressure downfall and air speed under different working conditions we will refer to the Glosa species of native wheat seeds, crop of year 2011 and 2012 selected by densitometry machine Gravity Separator with an active vibrating surface of \( S = 1.5 \text{ m}^2 \), [1].

During our experimental studies, the wheat seeds layer during the machine working process had a height, experimentally measured by us, \( h = 25 \text{ mm} \) in a loose condition having a porosity greater than the one when air does not circulate through system. In repose condition, the wheat seeds porosity was \( \varepsilon = 0.35 \cdot 0.4 \).

It was taken into account the sphericity coefficient (for shape), \( \psi = 0.85 \), [5]. On the basis of the known formula, the equivalent diameter of wheat seeds is, [1]:

\[
d_s = \frac{6\pi}{\psi} \left( \frac{m_p - \text{seeds mass}}{0.04 \text{ g}} \right)^{1/3} \cdot \frac{1}{\varepsilon} \cdot \left( \frac{1.25 \text{ g/cm}^3 - \text{average value}}{\text{density of wheat seed}} \right)
\]

Also, it was taken into account for pressure downfall (\( \Delta P \)) the average value experimentally determined, [4] of:

\[
(\Delta P) = 7.5 \text{ mm} \text{Hg} \cdot 73.5 \text{ Pa}, \text{ for air density and dynamic viscosity under normal conditions (} t = 20 \text{ C and atmospheric pressure} \ 760 \text{ mm} \text{Hg}). \text{ col.}) \text{, } \rho_a = 1.21 \text{ kg/m}^3 \text{ and } \eta = 2.12 \cdot 10^{-2} \text{ Pa} \cdot \text{s}, [2].
\]

Substituting above data in Ergun equation (10) and making calculation, we obtain the second order equation in \( v \): \( v^2 + 0.269v - 0.496 = 0 \), valid for a positive result of equation only, for air speed under seed layer \( v \) would be \( 0.58 \text{ m/s} \). The regime of air circulation against particles is checked and Reynolds number modified with eq.(9) is calculated. The result is, \( \text{Re}_p = 111 \), \( \text{Re}_p > 40 \), thus

where: \((\Delta P)\) - is pressure downfall of the air when goes through the seed layer, which depends on its flow. The minimum speed on which fluidization takes place, corresponds to the equality between the two forces, \( F_S = F_A \), and resulting:

\[
\frac{(\Delta P)}{h} = (\rho_p - \rho_a)(1 - \varepsilon)g
\]

and for pressure downfall Ergun equation to be applied (10), resulting the below equation:

\[
(\rho_p - \rho_a)(1 - \varepsilon)g = 150 \frac{(1 - \varepsilon)^2 \eta}{\varepsilon^3 d^2} v^m + 1.75 \cdot (1 - \varepsilon) \rho_a \cdot \frac{v^2}{\varepsilon^3 d^2}
\]

where: \( v_m \) - minimum speed at fluidization.

It is correct to apply the equation (14) if the particles Reynolds number from equation (9) meet the requirement of turbulent flow, \( \text{Re}_p > 40 \), [5]. On the basis of these equations, with practical data for wheat and barley seeds, the values of pressure downfall and air speed under different working conditions will be evaluated, on theoretical studies, applicable to the two types of machines existing in practice.

RESULTS

Theoretical study

Studiu de caz

Studiul de caz se va referi la evaluările vitezelor convenționale ale aerului sub stratul de semințe, atât pentru semințele de grâu cât și pentru semințele de orz, în cazul procesului de separare după densitate și compararea acestora cu valorile uzuale utilizate în practică în cazul mașinii Cimbria Gravity Separator GA71, utilizată pentru semințele de grâu, iar pentru semințele de orz mașina Jubus MJ-S 120.

Pentru evaluarea căderii de presiune și a vitezelor curentului de aer în diferite condiții de lucrare ne vom referi la semințele de grâu din soiul autohton Glosa, din producția anului 2011 și 2012 sortate cu mașina Cimbria Gravity Separator având o suprafață vibrațioare activă \( S = 1.5 \text{ m}^2 \), [1].

La experimentările noastre stratul de semințe de grâu în timpul lucrului mașinii avea o înălțime măsurată experimental de \( h = 25 \text{ mm} \) între stația de inel și straturi de mai jos, iar pentru căderile de presiune se folosește ecuația lui Ergun (10), obținându-se:

\[
F_p = (\Delta P) \cdot S
\]

unde: \((\Delta P)\) - este căderea de presiune a aerului la trecrea prin stratul de semințe, care depinde de curgerea acestuia. Viteza minimă la care are loc fluidizarea, corespunzând egalității între cele două forțe, \( F_S = F_A \), de unde rezultă:

\[
\frac{(\Delta P)}{h} = (\rho_p - \rho_a)(1 - \varepsilon)g
\]

iar pentru căderea de presiune se folosește ecuația lui Ergun (10), obținându-se:

\[
(\rho_p - \rho_a)(1 - \varepsilon)g = 150 \frac{(1 - \varepsilon)^2 \eta}{\varepsilon^3 d^2} v^m + 1.75 \cdot (1 - \varepsilon) \rho_a \cdot \frac{v^2}{\varepsilon^3 d^2}
\]

unde: \( v_m \) - este viteza minimă la fluidizare.

Utilizarea ecuației (14) este corectă dacă numărul lui Reynolds pentru particule din ecuația (9) satisface cerința curgerii turbulente, \( \text{Re}_p > 40 \), [5]. Pe baza acestor ecuații, cu date practice pentru semințele de grâu și orz, vor fi evaluate, pe studii de caz, cu aplicație la două tipuri de mașini existente în practică, valorile căderilor de presiune și vitezelor curentului de aer în diferite condiții de lucrare.

REZULTATE

Studiul de caz

Studiul de caz se va referi la evaluările vitezelor convenționale ale aerului sub stratul de semințe, atât pentru semințele de grâu cât și pentru semințele de orz, în cazul procesului de separare după densitate și compararea acestora cu valorile uzuale utilizate în practică în cazul mașinii Cimbria Gravity Separator GA71, utilizată pentru semințele de grâu, iar pentru semințele de orz mașina Jubus MJ-S 120.

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unde: \((\Delta P)\) - este căderea de presiune a aerului la trecrea prin stratul de semințe, care depinde de curgerea acestuia. Viteza minimă la care are loc fluidizarea, corespunzând egalității între cele două forțe, \( F_S = F_A \), de unde rezultă:
means that the air flow is turbulent, and the utilization of Ergun equation is completely justified.

In conformity with technical description of the machine \( Q = 1 \) m\(^3\)/s, \( S_o = 1.5 \) m\(^2\) the conventional speed used during machine working process is \( v = Q/S_o = 0.67 \) m/s, which means a deviation from estimated speed of Ergun equation (0.58 m/s), of (-13.4%), such value being accepted in technical conditions.

Also, during machine working process the pressure downfall was measured by piezometric method by means of a glass pipe, connected to machine, as shown in [1], resulting the value \((\Delta P=10 \) mm col. H\(_2\)O\). The pipe was filled with distilled water at the environment temperature and the pressure downfall represents the gauge difference after reading on the paper, attached to the latch plate, [1]. The value experimentally determined is 10 mm col. H\(_2\)O as against those evaluated by calculation 9.51 mm col. H\(_2\)O.

Using Ergun equation (10) for value of air flow speed during machine working process \((v = 0.67 \) m/s) and for the values of the above mentioned parameters for wheat, after making calculation we obtain \((\Delta P)=93.2\) Pa. In this case, the estimated error between calculated value and measured value is 4.9 %, such deviation justifies the validity of Ergun equation.

Also, the pressure downfall and air flow speed were evaluated for barley seeds, separated by gravity machine Jubus MJS 120, with an active surface \( S_o = 3.36\) m\(^2\) [6], this machine is used in practice in Constanța county. During experimental studies, have been used Maresal species of native barley seeds, from Constanța country, from 2011 crop.

During experimental studies, the barley layer had a height experimentally measured by us \( h = 25 \) mm, at a porosity \( \varepsilon = 0.45\), [1], seeds average dimensions being \( l = 10 \) mm, \( b = 3.5\) mm, \( c = 3\) mm where: \( l, b, c \) (length, width, and thickness of barley seed). For barley designed to sowing, it is necessary to sort seeds by their density in order to obtain the most vigorous material.

Drawing an analogy between the shape of barley seeds and an oblate spheroid, with length \( l \), big semi axis \( x=1/2-5\) mm and small semi axis \( y = (b+c)/4 = 1.625\) mm, and making relevant calculations we obtain a sphericity coefficient \( \psi = 0.839\) [1] and the equivalent diameter of barley seeds is, on the basis of the known formula. [1]: \( d_p = \frac{\psi}{(6/\pi)(m_p/p)^{1/3}} \) where: \( m_p \) - seed mass (0.05 g - average value); \( p_p \) - seed density (1.3 g/cm\(^3\) - average value),after making calculation: \( d_p = 3.51 \) mm, [1].

Input these data into Ergun equation (10), and considering pressure downfall \((\Delta P)=7.5\) mm H\(_2\)O=73.5Pa, and for air density and dynamic viscosity under normal conditions \((t=20\) C and atmospheric pressure 760 mm. Hg col\), \( \rho_p=1.21\) kg/m\(^3\) and \( \eta=2.12\times10^{-2} \) \( \text{Pa.s} \), [2], after making calculations we obtain the second order equation in \( v: v^2+0.235v-0.807=0 \), valid for the positive result for air speed under the seed layer, only \( v>0.79\) m/s. The regime of air flow against particles is checked and Reynolds number modified with eq.(9) can be calculated. The result is, \( R_e=158 \) (\( R_e > 40\) ) that means the air flow is turbulent, the utilization of Ergun equation is completely justified.

This value of the speed allows to estimate the flow of machine’s fan during working process, \( Q=V \) S\(_o\), obtaining \( Q=0.79\times3.36=2.654\) m\(^3\)/s, such value being used to make an initial adjustment of the machine.

40, circulația aerului fiind turbulentă, ceea ce justifică utilizarea ec. Ergun.

Din datele tehnice ale mașinii \( Q = 1 \) m\(^3\)/s, \( S_o = 1.5 \) m\(^2\) rezultă viteză convențională utilizată în timpul lucrului mașinii de \( v=Q/S_o=0.67 \) m/s, ceea ce înseamnă o abatere față de viteză estimată din ecuația lui Ergun \((0.58 \) m/s), de (-13.4%), valoare acceptată în condiții tehnice.

De asemenea a s-a procedat la măsurarea căderii de presiune în timpul lucrului mașinii, prin metoda piezometrică cu ajutorul unui tub din stică, conectat la mașină, așa cum se arată în [1], obținându-se valoarea \((\Delta P = 10 \) mm col. H\(_2\)O). În tub s-a introdus apă distilată la temperatura mediului iar căderea de presiune reprezintă diferența de nivel ce s-a citit pe hârtia milimetrică, atâșată plăcii de sprijin, [1]. Valoarea determinată experimental este de 10 mm col. H\(_2\)O față de cea evaluată prin calcul de 9.51 mm col. H\(_2\)O.

Utilizând ec. lui Ergun (10) pentru valoarea vitezii curentului de aer din timpul lucrului mașinii \((v = 0.67 \) m/s) și pentru valorile parametrilor specificați anterior în cazul grâului, după efectuarea calculurilor se obține \((\Delta P)=93.2 \) Pa. În acest caz eroarea estimată pentru calcul față de valoarea măsurată, obținută este de 4.9 %, eroare care justifică valabilitatea aplicabilității ec. lui Ergun în acest caz.

De asemenea a fost efectuată căderile de presiune și viteză curentului de aer, în cazul semințelor de orz, sortate cu mașina densimetrică Jubus MJ-S 120, având o suprafață activă \( S_o = 3.36\) m\(^2\) [6], utilizată în practică în cadrul jud. Constanța. La încercările experimentale s-au folosit semințe de orz soiul autohton Mareșal, din jud. Constanța din producția anului 2011.

În timpul experimentărilor stratul de semințe de orz avea o înălțime măsurată experimental de noi de \( h = 25 \) mm, la o porozitate \( \varepsilon = 0.45\), [1], dimensiunile mediile ale semințelor fiind \( l = 10 \) mm, \( b = 3.5\) mm, \( c = 3\) mm unde: \( l, b, c \) (lungimea, lățimea, grosimea seminței de orz).

Pentru orzul destinat însămânării este necesară o separare după densitate a semințelor pentru obținerea fracției cu semințele cele mai viguroase.

Așimilându-se forma reală a semințelor de orz cu un elipsoid de revolție, cu lungimea l, semiaxa mare \( x=1/2-5 \) mm și semiaxa mică: \( y = (b+c)/4 = 1.625\) mm, efectuând calculurile se obține un coeficient de sfericitate \( \psi = 0.839\) [1] și un coeficient equivalent al semințelor de orz este, pe baza relației cunoscute, [1]: \( d_p = \frac{(6/\pi)^{1/3}(m_p/p)^{1/3}}{\psi} \) unde: \( m_p \) - masa seminței (0.05 g - valoare medie); \( p_p \) - densitatea seminței (1.3 g/cm\(^3\) - valoare medie), după efectuarea calculurilor va fi: \( d_p = 3.51 \) mm, [1].

Cu aceste date introduse în ecuația lui Ergun (10), și considerând căderea de presiune \((\Delta P)=7.5\) mm H\(_2\)O=73.5Pa, iar pentru densitatea aerului și vâscozitatea dinamică în condiții normale \((t=20 \) C și presiunea atmosferică 760 mm.col. Hg), \( \rho_p=1.21\) kg/m\(^3\) și \( \eta=2.12\times10^{-2} \) \( \text{Pa.s} \), [2], după efectuarea calculurilor se obține ecuația numerică de gradul II în \( v^2+0.235v-0.807=0 \), valabilă numai soluția pozitivă a ecuației pentru viteză aerului sub stratul de semințe \( v=0.79\) m/s. Se verifică regimul de curgere al aerului față de particule, calculându-se numărul lui Reynolds modificat cu ec.(9). Se obține, \( R_e=158 \) (\( R_e > 40\) ) care arată că circulația aerului este turbulentă, deci ceea ce justifică utilizarea ec. Ergun.

Această valoare a vitezii permite, estimarea debitului ventilatorului mașinii, în timpul lucrului, \( Q=V \) S\(_o\), obținându-se \( Q=0.79\times3.36=2.654\) m\(^3\)/s, valoare utilizată pentru efectuarea unui reglaj inițial al mașinii.
CONCLUSIONS

This thesis states that stratification effect is enabled if during air flow circulation through seed layer, the seed layer will get loose up to fluidization level, respectively an increase of layer porosity and surface vibrations which are conveyed to the layer of seeds.

Also, it is emphasized the important part in elaborating the technological separation flow within the machine of pressure downfall (ΔP) on the layer thickness which allows the air flow circulation through porous bed , and, respectively the air speed circulation.

During seeds segregation process by density with pneumatic vibrating machines, the vibrating motion of the planned double inclined surface of the machine plays an important role together with vertical air flow circulation through seed layer on the surface which has a stratification effect.

It was developed a mathematical model of the air flow going through seeds vibrating layer on the basis of theory of analogy between this and flowing through bed of solid particles in stationary condition, considering that under real condition, the particles (seeds) movements take place with a speed, relatively low, on the vibrating surface.

Data are useful for the real case of air flow going through seed layer which is global laminar turbulent flow where the two flow modes exist simultaneously; thus allows Ergun’s equation (eq.10) to be applied in order to create a link between pressure downfall (ΔP) and the speed of air flow through layer seeds.

Mathematical model of the air flow circulation through vibrating seed layer, in the form of Ergun (ec.10) equation, was applied for concrete situation in two theoretical studies, and the estimated values for pressure downfall (ΔP), have been compared to experimental data obtained through measurements, and they were highly satisfactory.

Both values of conventional speed (v=0.58 m/s) obtained for air circulation under layer of wheat seed with thickness h=25 mm, porosity ε=0.4 which is plausible, and experimental confirmation of value of estimated pressure downfall (ΔP), allow us to appreciate that we can use the Ergun equation with good results not only to determine speed v and consequently the fan’s rate flow if the pressure downfall is known, but also for evaluate pressure downfall (ΔP) if speed v is known (from fan’s rate flow formula).

Also, the value of speed (v=0.79m/s) for air circulation under barley seed layer with thickness h=25mm and a porosity ε = 0.45 is plausible, being one more proof that Ergun equation can be utilized with good results, to evaluate not only the speed v but also the pressure downfall (ΔP) for various situation arisen during working process of machine in discussion.

These data are very useful for research and engineering activities in the field of pneumatic-vibrating machines for sorting seeds by density and also contribute to enrich the bank of scientific data in this domain.

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CONCLUZII

În această lucrare se constată că efectul de stratificare este favorizat dacă la curgerea curentului de aer prin stratul de semințe se produce o afânare a acestuia până la starea limită de fluidizare, respectiv o creștere a porozației stratului și de vibrația suprafeței transmisă și ea stratului de semințe.

De asemenea, se evidențiază rolul fundamental în elaborarea fluxului tehnic de separare optim în interiorul mașinii, a căderii de presiune (ΔP), în grosimea stratului de semințe care asigură circulația aerului prin patul poros cu care acesta este asimilat și respectiv a vitezei de circulație a aerului.

În procesul separării semințelor după densitate cu ajutorul mașinilor pneumo-vibratoare un rol însemnat îl are, pe lângă mișcarea vibratoare a suprafeței plane dublu înclinate a mașinii și circulația curentului de aer vertical ascendent prin stratul de semințe de pe suprafață, cu efect de stratificare.

S-a dezvoltat modelul matematic al curgerii aerului prin stratul de semințe vibrator pe baza ipotezei analogiei între aceasta și curgerea prin patul de particule solide în stare staționară, considerându-se că în starea reală deplasările particulelor (semințelor) au loc cu viteză relativ mici, pe suprafața vibratoare.

Curgerea globală laminar-turbulentă este cazul real de curgere a aerului prin stratul de semințe în care sunt prezente simultan ambele regimuri de curgere ceea ce a permis utilizarea ecuației lui Ergun (10) pentru legătura între căderea de presiune (ΔP) și viteză convingătoră a curentului de aer prin semințele din strat.

Modelul matematic al curgerii aerului prin stratul de semințe vibrator sub forma ecuației lui Ergun (ec.10) a fost utilizat în situații concrete în două studii de caz, comparându-se valorile estimate pentru căderea de presiune (ΔP), cu datele experimentale obținute la măsurători, care au dat deplină satisfacție.

Atât valoarea convențională (v=0.58 m/s) obținută pentru circulația aerului sub stratul de semințe de grâu de grosime h=25 mm și o porozație ε=0.4 care este plauzibilă, cât și confirmarea experimentală a valorii estimate a căderii de presiune (ΔP), ne permite să apreciem că se poate utiliza cu bune rezultate ecuația lui Ergun fie pentru determinarea vitezii v și de aici a debitului ventilatorului dacă se știe căderea de presiune (ΔP), fie pentru evaluarea căderii de presiune (ΔP), dar și pentru diferitele situații posibile în timpul lucrului mașinilor considerate.

Aceste date sunt utile în activitățile de cercetare și ingineriști din sfera mașinilor pneumo-vibratoare pentru separare densimetrică a semințelor contribuind la imbogățirea băncii de informații științifice din acest domeniu.

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INTRODUCTION

Manufacture of wheat flour involves repeated grinding and sieving operations, for endosperm to be separated from the bran. Grinding of wheat is made into two separated technological phases: crushing of wheat seeds (breakage phase) and grinding of semolina (reduction phase). In wheat milling plant, breakage / reduction and sifting are complementary operation forming together individual technological phases. After each grinding stage, a sorting on fractions (sifting) of the grist within a plansifter compartment, is performed.

According to several papers from the specialty literature [1, 7, 10, 11], sifting of intermediate products is affected by several factors, the most important being: size and shape of the grist particles, character of the relative motion of the particles on the sieve surface, characteristics of sieving fabric, revolution of plansifter, and the amount of material reaching the sieve.

To properly correlate the technical characteristics of equipment used in the milling process flow is particularly important to know the granulometric characteristics, as well as physical characteristics of grist intermediate products. Thus, operating parameters of equipment on the technological flow, and proper selection of fabrics from inside of plansifters or semolina machines, are influenced by the physical properties of grist.

Coefficient of static friction and angle of natural slope of grist intervene in the movement of grist particles on different types of surfaces, in the sorting on fractions and in the characterization of separation on fractions process, [3].

As described in the paper [5], it is important to know the physical properties of wheat seeds (size and shape, bulk density, density, and mechanical properties, among which hardness and elastic modulus) because they influence the processes of grinding and sifting, grist.
properties being correlated with those of the seeds from which it came. Among these, wheat seeds hardness imposes functional and constructive characteristics of the roller mills, as well as shape and size of grist particles which influence the choice of fabrics for sorting on fractions of grist.

Processes of drying, ventilation, heating and cooling of wheat seeds, efficient use of storage places (especially, at seeds and final products of the grinding process), but also process of modeling of air flow through the mass of material particles are affected by the porosity of the wheat seeds and intermediate grist products, [6]. Also, porosity of grist fractions and density of particles influence the stratification of grist on the frames inside of plansifter compartment.

Taking into account the importance of knowing the physical properties of grist products, obtained after each stage of sifting within a plansifter compartment, this paper presents the results of experimental research on the physical properties of the fractions separated at compartment of reduction roll 2 of a milling plant of 4.2 t/h.

MATERIALS AND METHODS

Samples used in the experimental measurement of the physical characteristics of grist were taken on the technological flow of unit S.C. Spicul S.A., Roşiorii de Vede, Teleorman, Romania. There were experimentally determined: coefficient of static friction, angle of slope, bulk density and density of particles of each fraction and were calculated the specific surface and porosity of grist fraction at plansifter compartment C2 for passage M1B from the reduction phase of the milling plant. In fig.1 is presented the flow diagram for reduction phase of semolina at the reminded milling plant.

mârunțire și cernere, proprietățile măcinășului fiind corelate cu cele ale seminței din care provine. Dintre acestea, duritatea semințelor de grâu impune caracteristicile funcționale și constructive ale cilindrilor de mârunțire, precum și forma și mărimea particulelor de măcină care influențează alegerea țesăturilor pentru sortarea fracțiilor de măcină.

Procesele de uscare, ventilare, încălzire și răcire a semințelor de grâu, ocuparea eficientă a locurilor de depozitare (în special, la semințe și produsele finite ale procesului de mârunțire), dar și procesul de modelare a fluxului de aer prin masa de particule de material sunt influențate de porozitatea semințelor de grâu și a produselor intermediare de măcină, [6]. De asemenea, porozitatea fracțiilor de măcină și densitatea particulelor influențează stratificarea măcinășului pe ramele compartimentelor de sită plană.

Dată fiind importanța cunoașterii proprietăților fizice a produselor de măcină, obținute după fiecare fază de cernere în cadrul unui compartiment de sită plană, în această lucrare se prezintă rezultatele unor cercetări experimentale asupra proprietăților fizice ale fracțiilor separate la compartimentul măcinătorului 2 al unei unități de morărit de 4,2 t/h.

MATERIALE ŞI METODE

Probele utilizate în determinările experimentale ale caracteristicilor fizice ale măcinășului au fost prelevate de pe fluxul tehnologic al unității S.C. Spicul S.A., Roșiorii de Vede, Teleorman, România. Au fost determinate experimentale: coeficientul de frecare static, unghiul de taluz natural, masa volumică și densitatea particulelor fiecărei fracții și au fost calculate suprafața specifică și porozitatea fracțiilor de măcină la compartimentul C2 de sită plană aferent pasajului M1B din faza de măcinare a morii. În fig.1 este prezentată diagrama fazei de măcinare a grişurilor la unitatea de morărit amintită.

Fig. 1 – The flow diagram of the wheat reduction phase in a milling plant with the capacity of 4.2 t/h / C1–C6 – plansifter compartments; Break 1–5 – break rolls; MG1, MG2 – semolina machines; M1A, M1B, M2–M6 – reduction rolls; F, F1, F2 – flour
For technological diagram of the analyzed mill, equivalence between number of mesh and mesh size, as are indicated in the diagram, is presented in table 1.

**Bulk density** of a granular mixture is defined as the mass of the material reported to the total volume that it occupies in its natural state.

This property is considered as one of base qualitative indices used in establishing of extraction flour, [4]. Yield of flour is closely related to the bulk density. To determine the bulk density was used the method of graduated cylinder.

**Density** represents the ratio between the mass of the sample and the volume occupied by the particles of it. In paper, determination of density of the grist fractions was made through pycnometric method using xylene as working fluid ($\rho_{p}=825.44$ kg/m$^3$).

Methodology for determining the bulk density and density used in this paper is given in detail in the papers [2, 8] and corresponds to the standard method.

In the paper was performed also particle size analysis of each grist fraction. Fineness of grist, assessed by the **mean diameter** $d_m$ of grinded particles, determined with sieve shaker, was calculated with relation:

$$d_m = \frac{\sum p_i \cdot d_i}{\sum p_i} \ [\text{mm}]$$  \hspace{1cm} (1)

where:

- $p_i$ represents percentage of material on the sieve of the sieve shaker ($i = 0, 1, 2, ..., 5$); $2p_i = 100$ – sum of the percentages of material on sieves; $d_i$ – average particle size of each intermediate fractions, considered as an arithmetic mean of sieve aperture sizes surrounding the respective fraction $d_i = (l_{i}+l_{i+1})/2$. Classifier sieves were chosen to meet the estimated relationship $l_{i+1} = \sqrt{2} \cdot l_i$ from the topper to the lower sieve.

Knowing the average diameter of newly formed particles, their **specific external surface** $S_{e,m}$ can be evaluated by the relation (2):

$$S_{e,m} = \frac{6}{\rho \cdot d_m} \ [\text{m}^2/\text{kg}]$$  \hspace{1cm} (2)

where:

- $\rho$ is the density of analyzed fraction, determined with the pycnometer.

**Porosity** represents the property of granular materials not to overlay the whole storage volume, existing a intergranular space. Knowing the values of bulk density and density of grist, porosity was determined by the relation (3), [2], [8]:

$$\rho_{e} = \frac{\rho_{m}}{\rho_{p}} \ \text{and} \ \rho_{m} = \frac{\rho_{p} \cdot d_m}{6} \ [\text{kg}/\text{m}^3]$$  \hspace{1cm} (3)

where:

- $\rho_{e}$ reprezintă procentul de material pe sita i a clasicatorului ($i = 0, 1, 2, ..., 5$); $2\rho_{e} = 100$ – suma procentelor de material pe pe sita; $d_i$ – dimensiunea medie a particulelor fiecărei fracții intermediare, considerată ca medie aritmetică a dimensiunii oricăror sitelor care încadrează fracția respectivă $d_i = (l_{i}+l_{i+1})/2$. Sitele clasicatorului au fost alese astfel încât să respecte cât mai bine cerința $l_{i+1} = \sqrt{2} \cdot l_i$, pornind de la sita de sus către sita cea mai de jos a clasificatorului.

Cunoscând diametrul mediu al particulelor nou formate, suprafața exterioră specifică $S_{e,m}$ a acestora se poate evalua cu relația (2):

Pentru diagrama tehnologică a morii analizate, echivalența dintre numărul sitelor și dimensiunea ochiurilor acesteia, așa cum sunt ele precisezate în diagramă, este prezentată în tabelul 1.

**Masa volumică** a unui amestec granular este definită ca fiind masa materialului raportată la volumul total pe care acesta îl ocupă acesta în starea sa naturală.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Equivalent between the mesh number and mesh size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mesh number</td>
<td>18</td>
</tr>
<tr>
<td>Mesh size [mm]</td>
<td>1.17</td>
</tr>
</tbody>
</table>

Această proprietate este considerată ca unul din indicii calitative de bază folosindu-se în stabilirea extracției de făină, [4]. Randamentul în făinuri este strâns legat de valoarea masei volumice. Pentru determinarea masei volumice s-a utilizat metoda cilindrilor gradat.

**Densitatea** reprezintă raportul dintre masa probei și volumul ocupat de particulele din aceasta. În lucrare, determinarea densității fracțiilor de măcină s-a făcut prin metoda picnometrică utilizând ca lichid de lucru xilenul ($\rho_{p}=825.44$ kg/m$^3$).

Metodologia de determinare a masei volumice și a densității utilizată în lucrarea de față este dată în detalii în lucrările [2, 8] și corespunde cu metoda standard.

În lucrare s-a efectuat și analiza granulometrică a fiecărei fracții de măcină. Finetea măcinăului, apreciată prin diametrul mediu $d_m$ al particulelor mărunțite, determinat cu clasicatorul cu site, s-a calculat cu relația:

$$d_m = \frac{\sum p_i \cdot d_i}{\sum p_i} \ [\text{mm}]$$  \hspace{1cm} (1)

unde:

- $p_i$ reprezintă procentul de material pe sita i a clasificatorului ($i = 0, 1, 2, ..., 5$); $2p_i = 100$ – suma procentelor de material pe pe sita; $d_i$ – dimensiunea medie a particulelor fiecărei fracții intermediare, considerată ca medie aritmetică a dimensiunii oricăror sitelor care încadrează fracția respectivă $d_i = (l_{i}+l_{i+1})/2$. Sitele clasicatorului au fost alese astfel încât să respecte cât mai bine cerința $l_{i+1} = \sqrt{2} \cdot l_i$, pornind de la sita de sus către sita cea mai de jos a clasificatorului.

Cunoscând diametrul mediu al particulelor nou formate, suprafata exteriora specifica $S_{e,m}$ a acestora se poate evalua cu relația (2):

$$S_{e,m} = \frac{6}{\rho \cdot d_m} \ [\text{m}^2/\text{kg}]$$  \hspace{1cm} (2)

unde:

- $\rho$ este densitatea particulelor fracției analizate, determinată cu picnometru.

**Porozitatea** reprezintă proprietatea materialelor granulare de a nu ocupă întregul volum de depozitare, existând un spațiu intergranular. Cunoscând valorile masei volumice și a densității măcinăului, porozitatea a fost determinată cu relația (3), [2], [8]:
The angle of the natural slope is the angle that is made by a free surface of a mass of granular material poured onto a surface, with the horizontal plane. To determine the angle of natural slope was used the material conic method, [2].

Coefficient of static friction, determined by the usual method of the inclined plane [9], was carried out on three types of surfaces: fiber glass, steel sheet and cotton canvas.

RESULTS

The experimental data which characterize the physical properties of the grist obtained at reduction roll M1B of the technological diagram of milling plant, and sorted on fraction in afferent plansifter compartment, are shown in table 2.

According to the technological diagram, wheat semolina ground in reduction roll M1B are sorted on fractions inside of plansifter compartment C2 (see fig.1), consisting of four frame packages with metallic fabric or from plastic material with mesh size in correlation with type of fabric and with number of wires per unit length (table 1).

From the analysis of fig. 1, it has been found that the first five sieves are disposed within a package, have no. 50 (i.e. mesh size of 0.35 mm) and transmit the packet refusal to reduction roll M3, while the sitting of the frames is directed to second package with eight sieve frames (flour sieves, having the fabric no. IX, ie mesh size 0.1 mm). Refusal of the second package feeds the frames of the third package that has seven sieve frames no. X, with mesh size of 0.15 mm (flour sieve). Sifting of sieve frames from packages 2 and 3 is evacuated from compartment sub formă de fire pe unitatea de lungime (table 1). From the analysis of fig. 1, it has been found that the first five sieves are disposed within a package, have no. 50 (i.e. mesh size of 0.35 mm) and transmit the packet refusal to reduction roll M3, while the sitting of the frames is directed to second package with eight sieve frames (flour sieves, having the fabric no. IX, ie mesh size 0.1 mm). Refusal of the second package feeds the frames of the third package that has seven sieve frames no. X, with mesh size of 0.15 mm (flour sieve). Sifting of sieve frames from packages 2 and 3 is evacuated from compartment sub formă de fire pe unitatea de lungime (table 1).

All fractions extracted at compartment C2 – afferent to reduction roll M1B were analyzed and the coefficient of static friction and angle of natural slope were determined (table 2).

\[
\varepsilon = \left(1 - \frac{\rho v}{\rho}\right) \times 100 \, [%]
\]  

(3)

Unghiul de taluz natural reprezintă unghiul pe care îl face suprafața liberă a unei mase de material granular turnat pe o suprafață, cu planul orizontal. Pentru determinarea unghiului de taluz natural a fost utilizată metoda conului de material, [2].

Coeficientul de frecare static, determinat prin metoda uzuală a planului inclinat [9], s-a efectuat pe trei tipuri de suprafețe: fibră de sticlă lucioasă, tablă din oțel și pânză din bumbac.

REZULTATE

Datele experimentale ce caracterizează proprietățile fizice ale măcinisului obținut la măcinătorul M1B al diagramei tehnologice a unității de morărit, sortat pe fracții în compartimentul de sită plană aferent, sunt prezentate în tabelul 2.

Conform diagramei tehnologice, grăsuri de grâu mărunțițe la măcinătorul M1B sunt clasificate pe fracții în interiorul compartimentului C2 (vezi fig. 1), alcătuit din patru pachete de rame cu ţesături metalice sau din material plastic cu dimensiunile orificiilor sitelor în corelație cu tipul ţesăturii și cu numărul de fire pe unitatea de lungime (tabelel 1). Din analiza figurii 1 se constată că primele cinci site, sunt dispuse în cadrul unui pachet, au nr. 50 (adică dimensiunile orificiilor 0,35 mm) și transmit refuzul pachetului către măcinătorul M3, în timp ce cernutul ramelor este dirijat către pachetul al doilea cu opt rame de sită (site de făină, având ţesătura nr. IX, adică orificii de dimensiune 0,1 mm). Refuzul pachetului al doilea alimentează ramele pachetului al treilea care are spațe rame de sită numărul X, cu orificiile ţesăturii de 0,15 mm (site de făină). Cernururile ramelor de sită de la pachetele 2 și 3 sunt evacuate din compartiment sub formă de fire de făină, iar refuzul acestora trece la pachetul al patrulea prevăzut cu 5 rame nr. VIII (de asemenea, site de făină), cu orificii de 0,18 mm. Cernutul acestor rame este o făină grificială și este evacuată ca atare, în timp ce refuzul pachetului este redirijat la măcinătorul M2.

Toate fracțiile de măcinin extrase la compartimentul C2 – aferent măcinătorului M1B au fost analizate și s-a determinat coeficientul de frecare și unghiul de taluz natural (tabelul 2).

### Table 2

<table>
<thead>
<tr>
<th>Grist fraction</th>
<th>Static friction coefficient, μ</th>
<th>Angle of natural slope, ψ</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Steel sheet</td>
<td>Cotton canvas</td>
</tr>
<tr>
<td>C2 Entrance</td>
<td>0.576±0.723</td>
<td>1.470±1.760</td>
</tr>
<tr>
<td>C2 M3</td>
<td>0.611±0.900</td>
<td>&gt;1.760±1.760</td>
</tr>
<tr>
<td>C2 M2</td>
<td>0.835±1.176</td>
<td>&gt;1.760±1.760</td>
</tr>
<tr>
<td>C2 Fgrif</td>
<td>0.688±1.035</td>
<td>&gt;1.760±1.760</td>
</tr>
<tr>
<td>C2 F2</td>
<td>0.653±0.941</td>
<td>&gt;1.760±1.760</td>
</tr>
<tr>
<td>C2 F</td>
<td>0.676±1.400</td>
<td>&gt;1.760±1.760</td>
</tr>
</tbody>
</table>

\[ ϕ = \left(1 - \frac{\rho v}{\rho}\right) \times 100 \, [%] \]
From Table 2 it can be seen that the values of the coefficient of static friction, on steel sheet and fiber glass, are within the limits described in the specialty literature. Values of friction coefficient obtained for cotton canvas also falls within the range of values presented in other papers, being somewhat higher, because of humidity, of equivalent average diameter of particles quite small, which makes them adhere to work surface used in experiments, and to high content of endosperm of grist fractions analyzed.

Using experimental values, presented in table 2, were drawn charts of variation of the average values for the coefficient of static friction and the angle of natural slope for the six grist fractions analyzed, using MS Excel program version 12 (fig.2).

Values of bulk density, specific surface, porosity and mean diameter of the grist fractions analyzed are presented in table 3.

Based on the data obtained and presented in table 3, were graphically drawn, the variations of bulk density, density, specific surface and porosity of grist intermediate products analyzed.

As can be seen from the analysis of data from table 3, and of charts in figure 3, bulk density of fractions resulted when sorting grist in planisifter compartment C2 has a random variation, depending on the type of sieve frame fabric, and the size of apertures of the working sieve, but also of the initial granulation of grist or of shell content, adhesive on the semolina particles subjected to grinding.

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![Fig. 2 - Variations of the average values of static friction coefficient for six grist fractions, on 3 types of surface (steel sheet, cotton canvas and fiber glass) and of natural slope angle](image)

<table>
<thead>
<tr>
<th>Grist fractions</th>
<th>Average diameter [mm]</th>
<th>Bulk density [g/dm³]</th>
<th>Density [g/dm³]</th>
<th>Specific surface [m²/kg]</th>
<th>Porosity [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>C2 Entrance</td>
<td>0.160</td>
<td>499.000</td>
<td>1371.970</td>
<td>27.333</td>
<td>63.629</td>
</tr>
<tr>
<td>C2 M3</td>
<td>0.420</td>
<td>463.000</td>
<td>1334.897</td>
<td>10.702</td>
<td>65.316</td>
</tr>
<tr>
<td>C2 M2</td>
<td>0.210</td>
<td>426.000</td>
<td>1389.644</td>
<td>20.560</td>
<td>69.345</td>
</tr>
<tr>
<td>C2 Fgrif</td>
<td>0.140</td>
<td>463.000</td>
<td>1371.312</td>
<td>31.253</td>
<td>66.237</td>
</tr>
<tr>
<td>C2 F2</td>
<td>0.130</td>
<td>460.000</td>
<td>1377.551</td>
<td>33.504</td>
<td>66.607</td>
</tr>
<tr>
<td>C2 F</td>
<td>0.090</td>
<td>440.000</td>
<td>1382.717</td>
<td>48.214</td>
<td>68.179</td>
</tr>
</tbody>
</table>

Table 3

Values of density, bulk density, specific surface, porosity and average diameter for grist fractions resulting at C1 compartment (from technological diagram)
Also, when grist is separated on fractions, the porosity of each fraction is changing, and this will influence the bulk density value of the resulting material.

However, it has been noticed that fractions C2-M3 and C2-Fgrif have the highest bulk density value (about 463 kg/m³ for both). Nevertheless, it appears, that porosity of flours has relatively high values, in the inverse relationship with bulk density (about 65.3% for C2-M3, respectively 66.2% for C1-Fgrif).

It has been also noted, that fraction which has the lowest bulk density (fraction C2-M2, which is a dunst) presents the higher porosity (having 426 kg/m³ bulk density and 69.3% porosity), in the same inverse ratio as the other fractions of compartment.

Related to the surface area of the grist fractions of compartment C2 of the second reduction roll, it is found that the flour fractions have the highest values (31.2 for m²/kg C2-Fgrif, 33.5 m²/kg for C2-F2 respectively 48.2 m²/kg).

It is found that fraction C2-M3 (with a high content of shell) has a lower specific surface (about 10.7 m²/kg), even if the porosity is high.

Regarding the fraction C2-M2 classified as dunst, it has a specific surface, with value of about 20.5 m²/kg, in linear relationship with the porosity of the material.

It has been also noticed that flours (consisting of the endosperm of the wheat seeds) have high values of density with values over 1371 kg/m³.

De asemenea, la separarea pe fracţii a măcinărilui, porozitatea fiecărei fracţii se modifică, iar aceasta va influenţa valoarea masei volumice a materialului rezultat.

Totuşi, se observă că fracţiile C2-M3 şi C2-Fgrif au cea mai mare valoare a masei volumice (circa 463 kg/m³ pentru ambele). Se constată, însă, că porozitatea făinurilor are valori relativ ridicate, în relaţie invers proporcională cu masa volumică (circa 65,3% pentru C2-M3, respectiv 66,2% pentru C1-Fgrif).

Este de remarcat, de asemenea, că fracţia care are cea mai mică masă volumică (fracţia C2-M2, care reprezintă un dunst), prezintă cea mai mare valoare a porozităţii (având 426 kg/m³ masa volumică şi 69,3% porozitatea), în aceeaşi relaţie invers proporţională ca şi celelalte fracţii ale compartimentului.

Legat de suprafaţa specifică a fracţiilor de măcinare sortate la compartimentul C2 al celui de-al doilea măcinător, se constată că fracţiile de făină au valori cele mai ridicate (31.2 m²/kg pentru C2-Fgrif, 33.5 m²/kg pentru C2-F2 respectiv 48.2 m²/kg pentru C2-F).

Se constată că fracţia C2-M3 (cu un conţinut ridicat de înveliş) are o suprafaţă specifică scăzută (circa 10,7 m²/kg), chiar dacă valoarea porozităţii este mare.

În ceea ce priveşte fracţia C2-M2, clasificată în categoria dunsturilor, aceasta are o suprafaţă specifică, cu valoarea aprox. 20.5 m²/kg, în relaţie direct proporţională cu porozitatea materialului.

Se remarcă, de asemenea, că făinurile (constituite din endospermul seminţelor de grâu) au valori ridicate ale densităţii cu valori de peste 1371 kg/m³.
CONCLUSIONS

The physical characteristics of grist intermediate products determine the functional characteristics of the passages technological equipment (breakage or reduction) from milling plant. The analysis and interpretation of data obtained for the 6 samples, coming from the input and 5 outputs of the plansifter compartment C2 (fig. 1), show the following:

- fraction C2-M2, having a high content of shell (bran), compared with the other analyzed fractions that have a high content of endosperm, has a lower bulk density (~426 g/dm³);
- semolina flour extracted at this compartment (C2-Fgrif) together with fraction C2-M3 have the highest bulk density (both ~463 g/dm³);
- also, it can be observed that, although the mass of grist mixture that feeds the plansifter compartment C2 has a porosity of 63.62 %, after sorting, the porosity changes considerably reaching 68.18 % for flour fraction C1-F and 69.35 % for dust that feeds reduction roll M2 (fraction C2-M2).

For all plansifter compartments of a milling plant, from the wheat reduction phase, it is important to know the average size of particles of separated fractions, because it re-enters into the grinding process, and structural characteristics of the roller mills and their operating parameters must be correlated with these.

At the analyzed mill, physical properties of grist, average size of particles of fractions at plansifter compartments and their particle size distribution fall within the limits shown in other specialty papers.

The data presented can be important for all specialists and workers in the milling and grinding of wheat, referring, firstly, to reduction phase of technological process.

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REFERENCES


CONCLUZII

Caracteristicile fizice ale produselor intermediare de măcinat determină caracteristicile funcționale ale echipamentelor din pasajele tehnologice (de glotare sau măcinare) din morile de grâu.

Din analiza și interpretarea datelor obținute pentru cele 6 probe, care provin de la intrarea și cele 5 ieșiri ale compartimentului de sită plană C2 (fig.1), se constată următoarele:

- fracția C2-M2, având un conținut mai ridicat de înveliș (tărăță), față de celelalte fracții analizate ce au un conținut mai ridicat de endosperm, are o masă volumică mai mică (~426 g/dm³);
- făina grifică extrasă la acest compartiment (C2-Fgrif) împreună cu fracția C2-M3 au masă volumică cea mai mare (ambele ~463 g/dm³);
- de asemenea, se poate observa că, deși masa amestecului de măcinat ce alimentează compartimentul de sită plană C2 are o porozitate de 63,62%, după sortarea pe fracții porozitatea se modifică considerabil ajungând până la 68,18% pentru fracția de făină C1-F și 69,35% pentru dunsul ce alimentează măcinătorul M2 (fracția C2-M2).

Pentru toate compartimentele de sită plană ale unei mori, din fața de măcinare a grâului este important a se cunoaște dimensiunile mediei ale particulelor fracțiilor separate, distribuția după dimensiune și compoziția fizică a acestora, deoarece ele reintră în procesul de mântuire, iar caracteristicile constructive ale cilindrilor de măcinar, precum și parametrii funcționali ai acestora trebuie să fie corelate cu acestea.

La moara analizată, proprietățile fizice ale măcinișurilor, dimensiunile medii ale particulelor fracțiilor la compartimentele sitei plane și distribuția după mărime a acestora se încadrează în limitele prezentate și în alte lucrări științifice de specialitate.

Datele prezentate pot fi importante pentru toți specialiștii și lucrătorii în domeniul morăritului și măcinării grâului, cu referire, în primul rând, la fața de măcinare a procesului tehnologic.

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THE EFFECT OF ULTRASOUND TREATMENT ON SELECTED MAIZE AND BUCKWHEAT EXTRUDATES PARAMETERS /

WPLYW ULTRADZWIêKÓW NA WYBRANE PARAMETRY EKRUSDATÓW KUKURYDZIANYCH I GRYCZANYCH


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Abstract: This study attempted to understand the influence of ultrasound pretreatment on quality of extrudates. The maize and buckwheat seeds were subjected to low power ultrasound at 40kHz frequency. The pretreated material was processed using extrusion cooking technology. The effect of the ultrasound waves on quality of extrudates produced from pretreated seeds and its grinds were investigated. Typical quality standard parameters like sectional expansion, volumetric expansion indices, water solubility index and water absorption index of extrudates were investigated by using central composition design. For all extrudates samples inner cells structure was also determined. The inner texture of extrudate as structure and configuration of pores were described using mean size of pores, their number on cross stedon unit, geometric orientation of pores. The extrudates produced from pretreatment materials were compared with extrudates obtained from non-treated material. Extrudates made from pretreated material showed different texture properties than produced from ultrasound untreated ones.

Keywords: ultrasound, food extrusion, buckwheat, maize

INTRODUCTION

Extrusion is one of the most extensively used and promising method for ready-to-eat cereals and other processed food production. It is a process where a mixture of food ingredients is forced to flow through a die. Moisture, high shear, mass temperature and pressure applied during extrusion make it possible to convert raw starchy material for variety end uses (Desrumaux et al., 1998, Chang et al., 2001, Ekielski et al., 2007a). The pretreatment of raw materials in conditioners used in extrusion line is able to reduce energy consumption and improve the final product quality (Ekielski et al., 2007b, Wójtowicz and Mościcki, 2008). One of the interesting pretreatment methods is the ultrasound radiation used for starch raw materials directly before extrusion process. Depending on the intensity and frequency of the ultrasonic waves it can be utilized for preparation of new and improved products as well as used to facilitate testing the quality of manufactured food products, especially in the on-line monitoring of the quality of extruded products (Owolabi et al., 2008, Awad et al., 2012).

Ultrasound waves are widely studied and used in variety of food processing operations and processes like freezing, drying, sticky products cutting, meat crumbling, wine and whiskey aging, cheeses ripening, sterilization, extraction, emulsification, and many more (Soria and Villamiel, 2010, Chang et al., 2012). Effect of ultrasound is used mainly for cavitation and improves mass and heat transfer. Using ultrasounds, food processing processes can be done several times faster, with high degree of reproducibility at reduced processing costs, simplifying the operations performed and yielding a higher purity of the final product, thereby eliminating the process of treating and purifying waste water (Hromádková et al., 2003; Chemat et al., 2011; Chandrapala et al., 2012; Karkani et al., 2013).

Abstrakt: W pracy przedstawiono wyniki badań procesu ekstruzji nasion gryki i kukurydzy, które poddano wcześniej wstępnej obróbce ultradźwiękowej w całości i po zmianie. Celem badań było określenie wpływu pola akustycznego o niskiej częstotliwości 40kHz na jakość wytworzonych produktów. Wyznaczono wskaźniki ekspandowania radialnego i objętościowego oraz wskaźniki wodoczynności WAI i rozpuszczalności wodnej WSI z zastosowaniem doświadczenia z centralnym planowaniem kompozytynym. Dla wszystkich prób wyznaczono również porównanie ekstrudatu. Rozkład porów został opisany poprzez średnią wielkość porów i ich liczbę na jednostkę powierzchni przekroju poprzecznego oraz orientację geometryczną porów. Ekstrudaty otrzymane z materiału poddanej ultradźwiękowym porównano z ekstrudatami z materiału nie poddanej żadnej obróbce, otrzymując odmienne właściwości teksturalne.

Słowa kluczowe: ultradźwięki, ekstruzja żywności, gryka, kukurydza
Some studies also support the use of ultrasound in the extrusion process to improve the flow and to reduce the resistance of highly viscous and sticky material transported from the inside of the extruder and the modification of its structure. To this end, the ultrasound source was located at right angles to the cylinder to impart a radial vibration (Akbari et al., 2007). From the standpoint of extrusion process used directly on grains important effect of sonication is the degradation of the polymers, including carbohydrates. Depolymerization occurring due to cavitation phenomenon may be related to the physical collapsing of cavitation bubbles or chemical changes produced by the action of radicals on the polymer chain. Ultrasounds were tested on the starch of many different plants. The first work in this area was established in 1933. Many studies demonstrated that ultrasounds alter the rheological properties of food: disturb the arrangement of crystalline grains of maize and potato starch, the starch gelatinization, increase the water absorption capacity and the solubility of the starch grains of corn and increase wheat proteins solubility, reduce viscosity, improve foaming properties (Vinatour et al., 1999; Jambrak and et al., 2010; Chemat et al., 2011; Zhu et al., 2012; Hernoux et al., 2013; Sujka and Jamroz, 2013).

The objective of the present investigation was to study the effect of ultrasound waves pre-treatment on extrudate properties obtained through the single screw extrusion cooking of maize and buckwheat seeds.

MATERIALS AND METHODS

Maize (Credo varieties) and buckwheat (Luba varieties) grains which were procured from the local market have been used in the investigation. For investigation of the ultrasound effect for maize and buckwheat, the two group of raw materials have been prepared: ultrasound treated and untreated. Treated samples have been prepared as suspension in the water.

Suspension has been prepared by stirring the appropriate amount of grain (grain sample mass=5 kg) and water in 1:1 mass ratio.

Ultrasound treatment

Separately maize-water and buckwheat-water suspension have been treated with ultrasonic waves. The ultrasound transducer has been located in the container filled with suspension. The ultrasound 40kHz generator (Inter Sonic 37P, Poland) was attached to the transducer, irradiated the 40kHz frequency waves with 60W power. Samples were treated for 20 minutes.

Determination of ultrasound power

Ultrasonic power transmit to suspension, which is considered as mechanical energy, is partly dissipated and converted on thermal energy. Since the suspension temperature grows up, the ultrasound power is able to estimate by measurement of suspension temperature changes. The equation (1) describes this functional relationship shown below (Margulis, 2003):

\[ P = m \cdot c_p \cdot \left( \frac{dT}{dt} \right) \]

where: \( m \) - the mass of the sonicated liquid (g), \( c_p \) - the specific heat of medium at a constant pressure dependent on composition and volume of medium (JgK\(^{-1}\)), dT/dt - the slope of the suspension temperature changes in observe time curve.

Ultrasound intensity is expressed in watts per unit volume suspension. In the experiment ultrasound intensity \( P=11.5 \text{ W cm}^{-2} \) was obtained.


Celem pracy było zbadanie wpływu działania fal ultradźwiękowych na parametry jakościowe ekstrudatów otrzymywanych z kukurydzy i gryki wytwarzanych na ekstruderze jednoślimakowym.

MATERIAŁ I METODYKA

Podstawowym materiałem wykorzystywanym w badaniach było ziemno kukurydzy odmiany Credo oraz ziemno gryki odmiany Luba. Materiał podzielono na dwie grupy: poddane obróbce i nie poddane obróbce. Obróbka wstępna ziaren przeznaczonych do przetwarzania w procesie ekstruzji polegała na poddawaniu ich działaniu fal ultradźwiękowych. Surowiec przed obróbką ultradźwiękową został zalany wodą w stosunku 1:1, tworząc zawiesinę. Jednorazowo działaniu ultradźwięków poddawano próbkę o masie 5 kg.

Obróbka ultradźwiękami

Ziemno kukurydzy i gryki poddano działaniu fal ultradźwiękowych o natężeniu 40 kHz za pomocą generatora ultradźwięków z przetwornikiem (Inter Sonic 37P, Poland) o mocy nominalnej 60 W umieszczonego w pojemniku z zawiesiną. Czas działania ultradźwięków wynosił 20 min.

Określenie mocy ultradźwięków

Moc ultradźwięków podawana do zawiesiny materiał z wodą, traktowana jako energia mechaniczna, jest częściowo rozpraszana i zamiennana na energię cieplną. Ponieważ temperatura zawiesiny wzrastała moc ultradźwięków mierzono poprzez zmiany temperatury zawiesiny. Równanie (1) opisujące tę zależność funkcjonalną przedstawiono poniżej (Margulis, 2003):

\[ P = m \cdot c_p \cdot \left( \frac{dT}{dt} \right) \]

gdzie: \( m \) - masa cieczy poddanej obróbce (g), \( c_p \) - ciepło właściwe czynnika przy stałym ciśnieniu w zależności od składu i ilości czynnika (JgK\(^{-1}\)), dT/dt - krzywa zmian temperatury zawiesiny w danym okresie czasu.

Nateżenie ultradźwięków wyrażone jest w watach na jednostkę objętości zawiesiny. W badaniach uzyskano natężenie równe \( P=11,5 \text{ W cm}^{-2} \).
Experiment

The single 5 kg mass of corn or buckwheat grain sample before experiment was placed in the glass container filled with water in 1:1 ratio. The samples were treated for 20 minutes by the ultrasonic generator and transducer. Figure 1 shows the experimental stand for ultrasound processing.

Grains after ultrasound treatment were dried to 15% w/w (buckwheat) and 25% w/w (maize) moisture content with a drum dryer. The final moisture content was measured in moisture analyser WPS 210 (Poland). Half of the ultrasound treated material was ground in grinder RUD-216 (Poland) equipped with 20 mesh screen.

A single screw extruder KZM-2 (modified Russian one), with outer diameter of the extruder screw of 100 mm, was used. The length to diameter (L/D) ratio of the extruder was 8:1, the screw speed - 200 rpm. The extruder was provided with a temperature control facility (in two separate zones), and digital display for measuring electrical power consumption developed during extrusion. The temperature of the extruder at sections (starting from the feed end) was maintained at 80, 125°C by fuzzy algorithm controller (Ekielski, 2006). Feeding of the raw material to the extruder was accomplished by using single screw volumetric feeder. The extrusion trials were repeated three times.

Quality indices

Water absorption and water solubility indices. Water absorption (WAI) and water solubility (WSI) indices were determined by the method of Anderson et al. (1969). The extrudates were first milled to a mean size of 180-250 µm. A 2.5g sample was dispersed in 25 ml of distilled water. The plastic stem had been used to break up any lumps, next start to stir for 20 minutes. Four dispersion samples were rinsed into centrifuge pockets and then centrifuged at 4500 rpm for 15 minutes. The supernatant was decanted for determination of its solid content and sediment was weighted. Collected supernatant had been dried in 105°C in laboratory dryer for 24 hours. The residues solids had been weighted on the precision electronic scale, mass determined with 0,001 g accuracy. WAI and WSI were calculated from the equations (2) and (3):

\[
WAI = \frac{m_n - m_o}{m_n} \times 100[-] \\
WSI = \frac{m_n}{m_o} \times 100[%]
\]

where: \(m_n\) - mass of sediment, \(m_o\) - mass of dry solids (mass of dry milled extrudate), \(m_n\) - mass of dissolved solids in supernatant.

The inner structure of extrudate

Porosity tests were performed on the test image analysis with a light chamber equipped with fluorescent light TL-D DeLuxe Pro 18 W/965 (Philips manufactured) with color emitted temperature 6500K, presented the color index Ra=90%. Images have been taken by CCD camera (model FD30, Hitachi) and grabber image software saved the pictures on computer HDD. The pictures saved in TIFF format were treated and analysed by National Instrument NI Vision 7.1.1 software. Porosity was determined for using the method described by Gosselin and Rodrigue (2005) where an irregular boundary for the analyzed group of air pores in cut view, was used.

Color cut views images obtained during experiment were then transposed to the monochrome color space. The resulting images 8-byte grayscale (256 levels) in next step were converted to binary bitmaps. The threshold T transformations were selected automatically as the result of the function (4):

Przebieg badań

Przed rozpoczęciem eksperymentu każdą próbę surowcowa o masie 5 kg kukurydzy lub grzyki umieszczano w szklanym pojemniku z wodą w stosunku 1:1. Następnie próbki poddawano obróbce ultradźwiękowej przez okres 20 minut.

Ziarna po obróbce ultradźwiękowej suszono w suszarce bębnowej do wilgotności 15% (kukurydza) i 25% (kukurydza). Wilgotność końcową mierzono w wagosuszarek WPS 210 (Polska). Połowa materiału po obróbce była mielona w rozdрабniaczu RUD-216 (Polska), i przesiewana na siecie o oczkach 20 mesh.

Następnie materiał ekstrudowano na ekstruderze jednoślimakowym KZM-2 (modyfikacja rosyjskiego ekstrudera), o średnicy zewnętrznej śliłnaka 100 mm. Stosunek długości do średnicy (L/D) wylotaczkami wynosił 8:1, prędkość obrotowa śliłnaka wynosiła 200 obr/min. Wylotaczarka była wyposażona w regulator temperatury (w dwóch oddzielnych strefach) oraz cyfrowy miernik z wyświetlaczem zużycia energii elektrycznej w trakcie wylatczania. Temperaturę wylotaczaków w sekcjach (licząc od końca zasilającego) utrzymywano na poziomie 80°C i 125°C z użyciem regulatora ustawionego za pomocą algorytmu rozmytowego (Ekielski, 2006). Podawanie surowca do wylotaczarki zachodziło przy użyciu jednoślimakowego podajnika objęciowego. Próbki wykonano w 3 powtórzeńach.

Wskazniki jakościowe

Wskazniki wodociągności WAI i rozpuszczalności WSI. Wodociągność i rozpuszczalność określa metodą Andersona i wsp. (1969). Metoda polegała na wymieszaniu 2,5 g rozdrobnionego ekstrudatu (wielkość cząsteczek 180-250 µm) w 25 ml destylowanej wody i oddzieleniu nadmiaru wody od osadu po upływie 20 minut poprzez odwirowanie w wirówce przez prędkości obrotowej 4500 obr/min przez 15 min. Uzyskany w ten sposób nasadczek zlawiono na płytce Petriego i suszono w temperaturze 105°C przez 24 godz. Odsączoną próbkę ważono na wadze elektronicznej z dokładnością 0,001g.

Współczynniki WAI i WSI obliczono z zastosowaniem poniższych równań (2) i (3):

\[
WAI = \frac{m_n - m_o}{m_n} \times 100[-] \\
WSI = \frac{m_n}{m_o} \times 100[%]
\]

gdzie: \(m_n\) - masa nasączonej próbki, \(m_o\) - masa suchej próbki (masa suchego rozdrobnionego ekstrudatu), \(m_n\) - masa wysuszzonego nasadczka.

Struktura wewnętrzna ekstrudatu


Otrzymane obrazy o 8-bitowej skali szarości (256 odcięć) przekształcano w dwuwartościowe mapy bitowe. Wartość progową T przekształcenia dobierano automatycznie jako wynik funkcji (4):
where: $A_T$ – presented the set values for the number of pore recognized, for the threshold values equal $T \in \{0-255\}$. After calculating the value of $T$, set the number of pore per unit area [cm$^2$] and the average pore size were counted.

### Physical extrudate properties

**Expansion indexes.** The sectional, volumetric indexes of the extrudates were assigned according to the methods developed by Alvarez Martinez et al. (1988).

The sectional expansion (SEI) was calculated by dividing the cross-sectional areas of the extrudates ($S_a$) by the cross sectional of the die opening ($S_d$). The volumetric expansion index (VEI) is the apparent raw material density ($\rho_m$) to apparent extrudate density after expansion ($\rho_e$). Expansion indexes were expressed as (5) and (6):

$$SEI = \frac{S_a}{S_d}$$

$$VEI = \frac{\rho_m (1 - MC_e)}{\rho_e (1 - MC_a)}$$

where:

- $MC_m$ and $MC_e$ are the moisture contents of the raw material before extrusion process, and moisture content of the extrudates, respectively.

**Apparent extrudate density.** The expanded extrudate density ($\rho_e$) was calculated as the mass of extrudate sample ($m_e$) divided by the equivalent volume of extrudates ($V_e$). The sample was weighted on the laboratory scale (RADWAG WPS 300) with an accuracy of 0.001g. The volume of extrudates ($V_e$) was determined with water displacement method developed by Ekielski and Osiak (2003). The extrudate sample was immersed in container filled with rapeseed oil to impregnate. After removing the samples from the oil container, the extrude was dried of excess oil and immersed into the tank filled with water. The water volume increase was read from the scale on the side of the vessel.

### Statistical analysis

The experiments were designed using standard design (SD) $2^{2(2-0)}$ with selectivity R=Full (three repetitions). Standard design comprising two independent processing parameters at two different levels. SD was chosen for designing the experiments, because it is a correct tool for optimization and it also reduces the number of experiments. Data were analysed using DOE module, SD design in the Statistica 10 program (table 1).

![Table 1](image)

### Treatment coded and the plan of experiments generated by standard design (SD) in Statistica 10

$T = su_T \{A_T \}$

where: $A_T$ – zbiór przedstawiający wartości liczby rozpoznawalnych por dla wartości progowej $T \in \{0-255\}$. Po obliczeniu wartości $T$ wyznaczono liczbę por na jednostkę powierzchni [cm$^2$] oraz średni rozmiar por.

### Właściwości fizyczne ekstrudatów


Wskaźnik ekspandowania radialnego (SEI) był obliczany jako stosunek przekroju ekstrudatu ($S_a$) do pola przekroju poprzecznego otworu matrycy ($S_d$). Wskaźnik ekspansji objętościowej (VEI) obliczono jak stosunek gęstości materiału wejściowego ($\rho_m$) do gęstości ekstrudatu ($\rho_e$). Indeksy ekspansji wyrażono jako (5) i (6):

$$SEI = \frac{S_a}{S_d}$$

$$VEI = \frac{\rho_m (1 - MC_e)}{\rho_e (1 - MC_a)}$$

gdzie:
- $MC_m$ i $MC_e$ to odpowiednio zawartość wilgoci w suchym materiale przed ekstruzją i zawartość wilgoci w ekstrudacie.

**Gęstość ekstrudatu.** Gęstość ekstrudatu ($\rho_e$) obliczono jako stosunek masy ekstrudatu ($m_e$) do objętości ekstrudatu ($V_e$). Próbki wczesniono na wadce laboratoryjnej firmy RADWAG WPS 300 z dokładnością 0,001g. Objętość ekstrudatu ($V_e$) określono metodą wypornościową opracowaną przez Ekielskiego (Ekielski i Osiak, 2003). Próbka ekstrudatu zanurzana była w pojemniku wypełnionym olejem rzepakowym do impregnacji. Po usunięciu próbki ze zbiornika oleju, ekstrudat odsączano z nadmiaru oleju i zanurzano w zbiorniku z wodą. Następnie odczytywano objętość wody. Różnica objętości wody odpowiadała mierzoną objętość ekstrudatu.

### Analiza statystyczna

W badaniach zastosowano plan standardowy $2^{2(2-0)}$ o rozdzielczości R=FULL z trzema powtorzeniami o oliczbie wielkości wejściowych dwa na dwóch różnych poziomach. W celu poprawnego przeprowadzenia eksperymentu (SD - standard design) wielkości wejściowe sprowadzono do wartości liczbowej. Dane poddano analizie w programie Statistica 10 z wykorzystaniem modułu planowania doświadczeń DOE (tab.1).
To determine the significance of the quality parameters extrudates ANOVA variance analysis was applied.

RESULTS

The influence of ultrasonic pretreatment on the quality parameters of corn and buckwheat extrudate indicates that ultrasonic treatment results in qualitative changes in the products obtained. This relationship was confirmed by the results of empirical research and statistical significance tests carried out for each of the extrude quality parameters (tab. 2). When one had looked on the results shown, it should be noted that in some cases the results of significance test for corn and buckwheat clearly differ, which might be primarily due to the different chemical composition of these materials, as well as the various physical characteristics of whole seeds undergoing a process of extrusion. Particular attention had been paid to the importance of changes in both the corn and buckwheat extrudate.

The obtained experiment results during testing of influence of ultrasonic treatment on the corn and buckwheat extrudate quality parameters are shown in Figures (1-6). Analyzing the graph (figure 1), it can be observed that the water absorption (WAI) extrudates varied depending on the method of pretreatment. The values of this index were the highest (5.60 - corn and 5.23 - buckwheat) for extrudates obtained from whole grains and treated with ultrasound. In the case of grounded grains and treated with ultrasound, the WAI values for extrudates obtained from whole grains. Extrudates obtained from untreated material were characterized by ultrasound and the lowest water absorption and WAI values ranged from 5.04 to 4.66 for buckwheat and corn. The values ranged from 5.04 to 4.66 for buckwheat and 5.23 - buckwheat) for extrudates obtained from whole grains. Extrudates obtained from untreated material were characterized by ultrasound and the lowest water absorption and WAI values ranged from 5.04 to 4.66 for buckwheat and corn.

Istotność parametrów jakościowych ekstrudatów określono z wykorzystaniem analizy wariancji ANOVA.

WYNIKI BADAN

Wyniki badań wpływului ultradźwiękowej na parametry jakościowe ekstrudatu kukurydzianego i gryczanego wskazują, że fale ultradźwiękowe powodują zmiany jakościowe uzyskiwanych produktów. Zależność tą potwierdzają zarówno wyniki badań empirycznych, jak i statystyczne testy istotności przeprowadzone dla poszczególnych parametrów jakościowych ekstrudowanych wyrobów (tab. 2). Należy zwrócić uwagę, że wyniki testu istotności dla kukurydzy i gryki w niektórych przypadkach wyraźnie się różnią, co może wynikać głównie z różnego składu chemicznego tych surowców, jak również z różnych cech fizycznych całych ziaren poddawanych procesowi ekstruzji. Szczególną uwagę zwraca parametr WAI, gdzie analiza statystyczna wyraźnie wskazuje na istotność zmian zarówno w ekstrudacie kukurydzanym, jak i gryczym.

Wyniki badań wpływului ultradźwiękowej na parametry jakościowe ekstrudatu kukurydzianego i gryczanego przedstawiono na rysunkach (1-6). Analizując wykres (rys. 1) można zaobserwować, że wodochłonność surowca (WAI) zarówno dla kukurydzy, jak i gryki jest największa (5,60 – kukurydza i 5,23 – gryka) dla ekstrudatów uzyskanych z całych ziaren oraz poddanych działaniu ultradźwięków. W przypadku ziaren poddanych obróbce ultradźwiękowej oraz rozdrobnionych wartości WAI były mniejsze w stosunku do ekstrudatów uzyskanych z całych ziaren. Ziarna niepodlane ekstrudatu ultradźwiękowej odznaczały się natomiast najmniejszą wodochłonnością pomiędzy 5,04 to 4,66 dla gryki i kukurydzy.

Table 2

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<th>Maize</th>
<th>Volume expansion indices (VEI) [-]</th>
<th>Buckwheat</th>
<th>Volume expansion indices (VEI) [-]</th>
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<td>df</td>
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<td>The sectional expansion indices (SEI) [-]</td>
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<tr>
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<tr>
<td>Ultrasound treated (2)</td>
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<td>1</td>
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<tr>
<td>1 vs. 2</td>
<td>0.3624</td>
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<tr>
<td>Error</td>
<td>0.1477</td>
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<td>0.0185</td>
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<tr>
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<td>0.5931</td>
<td>1</td>
<td>0.5931</td>
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<tr>
<td>1 vs. 2</td>
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Notes: * p < 0.05; ** p < 0.01; *** p < 0.001.
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<tr>
<td></td>
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<tr>
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<td>310.083 1</td>
<td>444.083 1</td>
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<tr>
<td></td>
<td>9.81794*</td>
<td>14.0607*</td>
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<td>0.0139</td>
<td>0.0056</td>
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<tr>
<td></td>
<td>20.0208 1</td>
<td>25.5208 1</td>
</tr>
<tr>
<td></td>
<td>4.9031</td>
<td>6.2500*</td>
</tr>
<tr>
<td></td>
<td>0.0577</td>
<td>0.0369</td>
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<td>1 vs. 2</td>
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<td>374.083 3</td>
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<tr>
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<tr>
<td>Overall SS</td>
<td>1380.32 11</td>
<td>11322.82 11</td>
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<th>Average of size pores [mm$^2$]</th>
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<td>0.0369</td>
</tr>
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* - significant at 5% (p ≤0.05)

Fig. 1 - The water absorption indices (WAI) changes for corn and buckwheat extrudates according to material pre-treatment

Analyzing figure 2 showing WSI parameter change, it can be observed that the course of the graph is reversed in relation to the WAI graph. The highest values for WSI amounting 22.63% were recorded for buckwheat extrudate obtained from raw material without ultrasonic pre-treatment. In the case of corn extrudate similar trend was also observed. This course of the graph can indicate that the degradation of the extrudate due to the conditions prevailing in the cylinder of the extruder was the highest. Increased degradation of starch, in turn, could be caused by an uncontrolled increase of shear and temperature of the extruder barrel as a result of the processing of grain with intact cell structure. According to Mason and Zhao (1994) and Kobus (2006) ultrasonic waves can disrupt plant cells. According to the authors, the cell content is released into the extraction solvent. Such a phenomenon occurs mainly in products with a high degree of hydration. Such a statement may be grounds to believe that the phenomenon took place in the case of raw materials subjected to sonication and led to a decrease in solubility.

Analizując wykres (rys. 2) przedstawiający zmiany wartości parametru WSI można zaobserwować, że przebieg wykresu jest odwrotny w stosunku do wykresu WAI. Największe wartości parametru WSI dla ekstrudatu (22,63%) uzyskanego z surowca niepoddanego działaniu ultradźwięków (gryka) mogą wskazywać, że degradacja ekstrudatu na skutek warunków panujących w cylindrze ekstrudera była największa. Mogło to być z kolei wynikiem niekontrolowanego zwiększenia sił ścinających i temperatury w cylindrze ekstrudera na skutek przetwarzania ziarna z nienaruszoną strukturą komórkową. Według Mason i Zhao (1994) i Kobus (2006) fale ultradźwiękowe mogą rozrywać komórki roślinne. Według autorów zawartość komórek uwalniana jest do rozpuszczalnika ekstrakcyjnego. Takie zjawisko zachodzi głównie w produktach o dużym stopniu uwodnienia. Stwierdzenie to może dać podstawy do podejrzezeń, że zjawisko takie miało miejsce w przypadku surowców, które poddano działaniu ultradźwięków i doprowadziło do spadku rozpuszczalności.
The qualitative parameter, which undergoes significant changes as a result of sonication was also extrudate porosity and average pore size measured on the surface of the extrudate cross-section. It was found that the porosity was the highest in the case of extrudates obtained from whole grains treated with ultrasound and time = 66.33 pores in cm$^2$ for corn and 42.33 pores in cm$^2$ for buckwheat. The lowest porosity characterized grounded while extrudates treated with ultrasound and extrudates obtained from whole grains and roasted effect of ultrasonic waves, reaches values are: 40.66 - 42.33 pores in cm$^2$ for both extrudated researched (Figure 3). According to Lanuay et al. (1983), Ekielski and Żelaziński (2012), the high porosity is usually a positive attribute of extruded materials and can provide a high homogeneity of the sample. Low porosity can be translated on the formation of large pores of irregular shape. The Figure 4 shows the variation in average pore size in the examined extrudates. The diagram of buckwheat treated with ultrasound can point to such a relationship.

![Fig. 2 - The water solubility indices (WSI) changes for corn and buckwheat extrudates according to material pretreatment](image2)

![Fig. 3 - The porosity indices changes for corn and buckwheat extrudates according to material pre-treatment](image3)
The volume expansion index (VEI) and sectional expansion index (SEI) shown only a slight change in the values of these indicators (Fig. 5 and 6). It should be noted, however, that the tendency of the changes, as in the case of a WAI or porosity decrease also. The smallest values volumetric expansion indices of the samples obtained were characterized with whole grains treated with ultrasonic waves. In the case of a sectional expansion ratio small differences also appear, however, the trend shown on the chart in comparison to the volume expansion ratio is reversed.

Fig. 4 - The porosity indices changes for corn and buckwheat extrudates according to material pre-treatment

![Graph showing porosity changes](image)

Badania stopnia ekspandowania objętościowego i radialnego (SEI) wskazują tylko na niewielkie zmiany wartości tych wskaźników (rys. 5 i 6). Należy jednak zaznaczyć, że najmniejszymi wartościami EO tego parametru zarówno dla gryki i kukurydzy (całe ziarna poddane falom ultradźwiękowym) natomiast największymi głównie kukurydza niepodana działaniu ultradźwięków. W przypadku Ekspansji radialnej różnice również wydają się niewielkie jednakże tendencja przebiegu wykresu w porównaniu do ekspansji objętościowej jest odwrotna.

Fig. 5 - The volume expansion indices (VEI) changes for corn and buckwheat extrudates according to material pre-treatment

![Graph showing volume expansion](image)

Fig. 6 - The sectional expansion indices (SEI) changes for corn and buckwheat extrudates according to material pre-treatment
CONCLUSIONS

In conclusion, it should be noted that the effect of 40kHz ultrasonic waves can contribute to improving the quality of extrudates, both corn and buckwheat. It is called for high values of the WAI and WSI also low, indicating a high degree of gelation of starch and, at the same time, low degree in comparison to other materials used in the study of WSI, the high porosity of the extrudates which can continue to provide a high sensory qualities of such materials (Lui and Peng (2005) and Desrumaux et al., (1998) Lanuay et al., (1983). Żelaziński and Ekielski, 2011) and slightly progressive changes in the indices of volume and sectional expansion. This may be a possible feature of such behavior of these indicators because the indicators value often depends on eg. the shape of the products themselves.

When using a raw material treated with ultrasound may not be necessary to reprogram extruder’s control systems to produce the same product as the native material. This may, however, require a number of additional tests using other types of extruders.

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WNIOSKI


Przy zastosowaniu surowców poddanych działaniu ultradźwięków być może nie będzie potrzebne przeprogramowanie ekstruderów w celu uzyskania takiego samego produktu, jak z surowca natynkowego. Wymagać to może jednak wielu dodatkowych prób z wykorzystaniem innych typów ekstruderów.

LITERATURA

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[28]. Vinatoru M., Toma M., Mason T.J., (1999) - Ultrasonically assisted extraction of bioactive principles from plants and the constituents. Advances in Sonochemistry, 5, 216;
Abstract: The aim of this study was to investigate the influence of the grounded extrudate fraction on the obtained particles' shape and attempt to link these characteristics with the quality of the extrudate from which they were originated. The material used in the study was the wheat-corn extrudate produced in the twin-screw extruder at 130, 140 and 150°C. The extrudates were grounded in the hammer shredder and then particles were separated on a laboratory sieve sifter. It was extrudate porosity and ground particle shape investigated. It was found that the products obtained in the twin-screw extruder at different temperatures of the process are distinguished by the variable internal structure which can affect obtaining extrudate fractions with varying percentage of particles and the shape of the extrudate after grinding. It was observed that the smallest and largest extrudate fractions were ground the most. Elongation factor showed an increase in the length of the fraction obtained with the reduction of extrudate particles size. Differentiation of the shape could be important because of the sensory evaluation of the products carried by consumers, and consequently it could be a very valuable insight for future producers of such products.

Keywords: food extrusion, grinding, breadcrumbs, shape

INTRODUCTION

A characteristic feature of extruded products is mostly the porous, expanded and highly differentiated internal structure. The pores in these products may have a different size, shape, occurring in varying numbers in a defined area, or differing with wall thickness. Their quality depends on many factors, which is the subject of many research works (Hayter et al., 1986; Mezreb et al., 2003; Włodarczyk-Stasiak, Jamroz, 2009; Crowley et al., 2010; Źelaziński, 2011; Stasiak, Jamroz, 2009; Crowley et al., 2010; Wojtowicz et al., 2010; Żelazinski, 2011; Bisharat et al., 2013).

It has been proven that the pores surrounding the outside of the extrudate are flattened, which may be due to the influence of the walls of the matrix outlet channel and the high speed of heat and mass transfer occurring in the surface layer. As approaching the center, the internal pore structure of the extrudate is usually symmetrical, but their size and shape can vary (Desrumaux et al., 1998, Ekielski, Żelasiński 2012). According to Lui and Peng (2005) and Desrumaux et al. (1998), changes in porosity affect the textural characteristics of extruded products. Lanuay et al. (1983) noted that the porosity has also a significant impact on the sensory evaluation - with increase of the pore size product crispness increases. This process is not entirely understood and still raises the interest of many authors (Desrumaux et al. 1998; Ays, e., et al., 2004; Lui and Peng, 2005; Biller et al., 2005; Biller, 2006; Agbisi et al., 2007; Wojtowicz et al., 2010; Żelasiński, 2011).

Therefore, the distinctive structure of the products obtained by extrusion can have a significant effect on further processing, e.g. by grinding for breadcrumbs. Currently, these products pose a number of requirements
including both appropriately selected composition and sensory characteristics. The same shape of such products particles can be also essential. Ultimately, it may be relevant for the breadcrumbs classification for a particular product type. In the literature, there are no tests found on breadcrumbs obtained from the extrudate as yet. In the context of the extrusion process it has been considered the particle size of the material to be extruded with its effects on the physicochemical properties and digestibility of the product (Al-Rabadi et al., 2011; Al-Rabadi et al., 2012).

Therefore, the objective of this study was to investigate the influence of the extrudate fineness degree on the obtained particles’ shape and an attempt to link these characteristics with the quality of the extrudate from which they were originated.

MATERIALS AND METHODS

The material used in the study was the wheat-corn extrudate (20% wheat, 80% maize), produced in the twin-screw co-extruder with a length to screw diameter L/d=27. At the head of the extruder die was used with a multiple outlet nozzles of 3 mm. Screw rotation speed of 300 rpm, and temperature profiles viewed from the extruder’s die, were: (130/130/100°C), (140/140/100°C) and (150/150/100°C) Celsius degrees. The temperature was controlled in the first and second section of the extruder using the PID controller.

Porosity was determined by the method of Gosselin and Rodrigue (2005), using an irregular boundary of the analyzed group of air pores in the analyzed images. The porosity analysis was lead with the use of LabView 7.1 package with visionary libraries and Vision Assistant 7.1.1 program, where the images were transposed to the monochrome area and were treated with specialized photo retouch. Then, the obtained images of byte grayscale (256 levels) were converted to divalent bitmaps and appropriate shades of gray thresholds were chosen in the range of 1-255 (treshold).

The resulting extrudates were ground in a hammer grinder with a sieve on the output of 3 mm. This was followed by separation of the particles on the laboratory sieve analyzer: Laboratory siever type LP2E-2e (MULTISERV) according to DIN ISO 3310-1, amplitude of 60, frequency of 2.00 Hz, duration of 10 minutes, sieve sizes: 2.0, 1.6, 1.0, 0.8, 0.5, 0.25, 0.1, <0.05 mm.

Individual breadcrumbs fractions were spread out on black paper, then photographed using a CCD camera KP-FD30 HITACHI in the light chamber, illuminated with fluorescent light TL-D De Luxe Pro 18W/965, with a color temperature of 6500K (Philips) and visual analysis was given using the Visio Assistant 7.1 program. This program allowed for the calculation of coefficients which characterize the particles shape according to the following formulas (1), (2), (3), (4), (5):

\[ F = \frac{\text{Elongation Factor}}{RF_b} \]  \hfill (1)

\[ P = \frac{\text{Heywood Circularity Factor}}{2\sqrt{\pi}A} \]  \hfill (2)


Celem pracy było zatem zbadanie wpływu stopnia rozdrobnienia ekstrudatu na kształt uzyskanych cząstek i próba powiązania tych cech z jakością ekstrudatu z którego powstały.

MATERIAŁ I METODYKA

Materiałem wykorzystywanym w badaniach był ekstrudat pszenno-kukurydziany (20% pszenica, 80% kukurydza), wyprodukowany na współbieżnym ekstruderze dwuślimakowym o stosunku długości do średnicy ślimaków L/d=27. Na głowicy ekstrudera zastosowano wieloowalową matrycę z dyszami wylotowymi 3 mm. Prędkość obrotowa ślimaków wynosiła 300 obr•min\(^{-1}\), a profil temperaturowy procesu w cylindrze ekstrudera, patrząc od ekstrudera do matrycy wynosił (130/130/100°C), (140/140/100°C), (150/150/100°C) stopni Celcjusza. Temperaturę utrzymywano w dwóch pierwszych sekcjach ekstrudera utrzymywano za pomocą sterownika PID.

Porowatość określano według metody Gosselin i Rodrigue (2005), stosując nieregularną obwiednię analizowaną grupę porów powierzchniowych na analizowanych zdjęciach. Do analizy porowatości wykorzystano pakiet LabView 7.1 z bibliotekami wizyjnymi oraz programem Vision Assistant 7.1, gdzie zdjęcia transponowano do przestrzeni monochromatycznej i poddawano specjalistycznej obróbce graficznej. Następnie otrzymane obrazy o bajowej skali szarości (256 odcieni) przekształciano w dwuwartościowe mapy bitowe i dobierano odpowiednie wartości progowe odcieni szarości z zakresu od 1–255 (treshold).

Wytworzone ekstrudaty rozdrobniono na rozdabniaczu bijakowym z sitem na wyjściu 3 mm. Następnie przeprowadzono separację cząstek na analizatorze laboratoriowym: przesiewacz laboratoryjny typ LP2E-2e (Multiserv) wg normy DIN ISO 3310-1, amplitude 60, częstotliwość 2.00 Hz, czas 10 minut, wielkości sit: 2.0; 1.6; 1.0; 0.8; 0.5; 0.25; 0.1; <0.05 mm.

Compactness Factor

\[ \frac{A}{W \cdot H} \]  

where:

\( F \) – Max Feret; \( RF_b \) – Feret (Rect Short Side); \( P \) – Perimeter; \( A \) – Area of the particle; \( W \) – Bounding Rect Width; \( H \) – Bounding Rect Height;

\( I_{xx} \) – Moment of Inertia \( XX \sum_x \sum_x \frac{x^2}{A} \)

\( I_{yy} \) – Moment of Inertia \( YY \sum_y \sum_y \frac{y^2}{A} \)

The experiment was planned by the Central Compositional Plan / Design of Experiments (DOE) - the number of input values: 2, number of blocks: 1, number of circuits: 24 with repetition. Different variables were coded as numeric values: -1, 0, 1. Furthermore, the additional repeat was applied at a central point. The plan was created using the Statistica 10, which was then used to obtain a response surface. Variable analysis of significance was performed using analysis of variance ANOVA, and statistical evaluation of the fit quality of surface response equations - a coefficient of determination \( R^2 \) and mean square error MSE (Mean Square Error).

RESULTS

Samples from twin-screw extruder had a uniform structure and visually, despite the use of three extrusion temperature \( t = \{130, 140, 150\}^\circ C \), did not differ significantly from each other. Mounted multi-hole die with a holes diameter of 3mm and a knife cutting device made it possible to produce extrudates in the shape of a cylinder with a diameter of about 4mm and a length of about 6 mm (Fig.1).

\[ A^2 \frac{4 \pi}{\sqrt{I_{xx} - I_{yy}}} \]  

gdzie: \( F \) – maksymalny rozmiar Fereta; \( RF_b \) – krótszy wymiar prostokątny Fereta; \( P \) – Obwód cząsteczki \( A \) – Pole rzutu cząstki; \( W \) – szerokość cząstki; \( H \) – długość cząstki;

\( I_{xx} \) – Moment bezzwładności osi \( xx \sum_x \sum_x \frac{x^2}{A} \)

\( I_{yy} \) – Moment bezzwładności osi \( yy \sum_y \sum_y \frac{y^2}{A} \)

The experiment was planned by the Central Compositional Plan / Design of Experiments (DOE) - the number of input values: 2, number of blocks: 1, number of circuits: 24 with repetition. Different variables were coded as numeric values: -1, 0, 1. Furthermore, the additional repeat was applied at a central point. The plan was created using the Statistica 10, which was then used to obtain a response surface. Variable analysis of significance was performed using analysis of variance ANOVA, and statistical evaluation of the fit quality of surface response equations - a coefficient of determination \( R^2 \) and mean square error MSE (Mean Square Error).

WYNIKI BADAŃ

Próbki uzyskane na dwuślimakowym ekstruderze charakteryzowały się jednorodną budową i wizualnie, pomimo zastosowania trzech temperatur procesu ekstruzji \( t = \{130, 140, 150\}^\circ C \), nie różniły się znacznie od siebie. Zamontowana wielo otworowa matryca o średnicy otworów 3mm z nożem obcinającym pozwoliła na wytworzenie ekstrudatów w kształcie walca o średnicy około 4mm i długości około 6mm (rys.1).

Fig.1 - View of whole-samples and cross-section of the samples obtained under different temperature conditions
Fig. 2 - Effect of extrusion temperature on the average of size of pores designated in cross-section of extrudate

Samples produced under these conditions differed significantly by the construction of the internal structure, which confirmed the results of empirical research. It was found that the samples obtained at the highest temperature (150°C) had the greatest pores, with the average size of about 0.07 mm². The average pore size obtained at 130 and 140°C ranged from 0.042 to 0.051 mm² (Fig. 2).

The graph (Fig. 3) shows the additional parameters determining the porosity of the resulting products, i.e. the number of pores in mm² in the extrudate cross-sectional area and the total surface pores, expressed as a percentage of pore surface in relation to the analyzed surface of the extrudate. It was found that the fewest number of pores (2 pores•mm⁻²) was in the extrudate made in a temperature of 150°C, while other samples prepared at lower temperatures contain as low as 4.5 to 5.5 pores in mm². The total area of pores in the analyzed extrudate samples is in the range from about 16% to 24%, as shown in Figure 3.

Fig. 3 - Effect of extrusion temperature on the overall pores area and the number of pores in the extrudate cross-section

As porosity of the obtained results showed that the individual extrudate samples obtained at different temperatures differed distinctly, one could assume that they behave in different ways when subjected to the action of hammer mill. Therefore, below in Table 1 there are summarized the results of the percentage distribution of the fractions obtained. Based on preliminary
examination it can be concluded that the percentage fraction of the extrudate varies depending on the sieve used, as well as the extrusion temperature employed. Additionally, it can be observed that the individual fractions of particulate ground extrudate distinguished not only by fragmentation but also by the shape of the resulting particles. Carry out a preliminary analysis of the image allowed for the characterization of particles shape with the four coefficients of the shape described in the methods. Below, there are some sample images of particulate extrudate samples fraction analyzed (Fig. 4).

On the basis of the statistical analysis it was found that the only important parameter influencing on the particle shape obtained during experiment is the degree of the extrudate fragmentation, obtained after separation of the ground extrudate to the appropriate fractions. The analysis of variance ANOVA indicated the importance of first and second order factor in analyzing elongation, roundness and compactness factor. In the case of the surface development factor (Type Factor) there were both temperature and fragmentation of the second row significant.

Table 1

<table>
<thead>
<tr>
<th>Sieve mesh size # DIN ISO 3310-1 [mm]</th>
<th>130 °C</th>
<th>140 °C</th>
<th>150 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05 &lt;</td>
<td>2.33</td>
<td>2.79</td>
<td>0.86</td>
</tr>
<tr>
<td>0.1</td>
<td>10.52</td>
<td>17.02</td>
<td>2.32</td>
</tr>
<tr>
<td>0.25</td>
<td>15.75</td>
<td>24.34</td>
<td>4.32</td>
</tr>
<tr>
<td>0.5</td>
<td>13.05</td>
<td>16.96</td>
<td>8.52</td>
</tr>
<tr>
<td>0.8</td>
<td>4.10</td>
<td>5.26</td>
<td>4.88</td>
</tr>
<tr>
<td>1.0</td>
<td>23.19</td>
<td>20.53</td>
<td>33.02</td>
</tr>
<tr>
<td>1.6</td>
<td>22.54</td>
<td>9.77</td>
<td>36.73</td>
</tr>
<tr>
<td>2.0</td>
<td>8.53</td>
<td>3.34</td>
<td>9.36</td>
</tr>
</tbody>
</table>

Fig. 4 - Example analysis of the ground fraction of the extrudate. a) the fraction of 0.1, b) the fraction of 0.25, c) the fraction of 0.8.
Table 2

Anova table with important factors for p<0.05

<table>
<thead>
<tr>
<th></th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Elongation factor, R² = 0.258, MS = 0.008, R² = 0.558, MS = 0.008</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature (L)</td>
<td>0.0131</td>
<td>1</td>
<td>0.0131</td>
<td>0.1712</td>
<td>0.6837</td>
</tr>
<tr>
<td>Temperature (Q)</td>
<td>0.0531</td>
<td>1</td>
<td>0.0531</td>
<td>0.6963</td>
<td>0.4144</td>
</tr>
<tr>
<td>Grinding (L)</td>
<td>0.3854</td>
<td>1</td>
<td>0.3854</td>
<td>4.7881</td>
<td>0.0414</td>
</tr>
<tr>
<td>Grinding (Q)</td>
<td>0.0287</td>
<td>1</td>
<td>0.0287</td>
<td>0.3759</td>
<td>0.5471</td>
</tr>
<tr>
<td>Error</td>
<td>1.4500</td>
<td>19</td>
<td>0.0763</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall SS</td>
<td>1.9542</td>
<td>23</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Roundness factor, R² = 0.687, MS = 0.008</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature (L)</td>
<td>0.0348</td>
<td>1</td>
<td>0.0348</td>
<td>4.3298</td>
<td>0.0512</td>
</tr>
<tr>
<td>Temperature (Q)</td>
<td>0.0008</td>
<td>1</td>
<td>0.0008</td>
<td>0.1052</td>
<td>0.7493</td>
</tr>
<tr>
<td>Grinding (L)</td>
<td>0.0008</td>
<td>1</td>
<td>0.0008</td>
<td>0.0992</td>
<td>0.7562</td>
</tr>
<tr>
<td>Grinding (Q)</td>
<td>0.2943</td>
<td>1</td>
<td>0.2943</td>
<td>36.6754</td>
<td>0.0000</td>
</tr>
<tr>
<td>Error</td>
<td>0.1525</td>
<td>19</td>
<td>0.0080</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall SS</td>
<td>0.4874</td>
<td>23</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Compactness factor, R² = 0.584, MS = 0.003</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature (L)</td>
<td>0.0102</td>
<td>1</td>
<td>0.0102</td>
<td>2.9790</td>
<td>0.1006</td>
</tr>
<tr>
<td>Temperature (Q)</td>
<td>0.0110</td>
<td>1</td>
<td>0.0110</td>
<td>3.1980</td>
<td>0.0897</td>
</tr>
<tr>
<td>Grinding (L)</td>
<td>0.0103</td>
<td>1</td>
<td>0.0103</td>
<td>2.9990</td>
<td>0.0995</td>
</tr>
<tr>
<td>Grinding (Q)</td>
<td>0.0523</td>
<td>1</td>
<td>0.0523</td>
<td>15.2418</td>
<td>0.0010</td>
</tr>
<tr>
<td>Error</td>
<td>0.0652</td>
<td>19</td>
<td>0.0034</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall SS</td>
<td>0.1568</td>
<td>23</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Type factor, R² = 0.463, MS = 0.001 / Współczynnik rozwiniecia, R² = 0.563, MS = 0.001</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature (L)</td>
<td>0.0051</td>
<td>1</td>
<td>0.0051</td>
<td>3.6954</td>
<td>0.0697</td>
</tr>
<tr>
<td>Temperature (Q)</td>
<td>0.0164</td>
<td>1</td>
<td>0.0164</td>
<td>11.8644</td>
<td>0.0027</td>
</tr>
<tr>
<td>Grinding (L)</td>
<td>0.0021</td>
<td>1</td>
<td>0.0021</td>
<td>1.5249</td>
<td>0.2319</td>
</tr>
<tr>
<td>Grinding (Q)</td>
<td>0.0063</td>
<td>1</td>
<td>0.0063</td>
<td>4.5219</td>
<td>0.0468</td>
</tr>
<tr>
<td>Error</td>
<td>0.0263</td>
<td>19</td>
<td>0.0014</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall SS</td>
<td>0.0592</td>
<td>23</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The values of the factors as a function of the analyzed fineness (obtained fraction) and the temperature of the extrusion process are shown in the form of three-dimensional response surface plots generated in Statistica 10. It was found that the smallest and largest extrudate fractions were close to unity, so were the most round. In the case of the middle fraction roundness values significantly increased, suggesting that the obtained fractions were less round and may have an irregular or elongated shape (Fig. 5).
Elongation factor (Fig. 6) showed an increase in the length of the fraction obtained with the reduction of extrudate particle size. Therefore, the greatest length had the particles retained on a sieve of 0.25, 0.1 and less than 0.05 mm. Extension of the fine particles is due to the fact that their main ingredients are shredded pieces of the pore walls structure. While, in the case of larger particles, the main component are whole extrudate’s pore fragments, creating a more rounded structure. This phenomenon can be explained physically - by the presence of pore wall fragments, and chemically - different chemical composition of extrudate fractions - bonds between the plant fibers and grain protein in given particles. The diversity of shape is important because of the sensory evaluation of the products obtained from the consumers. This can be extremely valuable insight for future producers of such products.

Współczynnik wydłużenia (rys.6) wskazywał natomiast na wzrost długości uzyskanych frakcji wraz z zmniejszeniem cząstek ekstrudatu. Największą długość posiadały zatem cząstki zatrzymane na sitach 0,25; 0,1 oraz poniżej 0,05 mm. Wydłużenie drobnych cząstek jest spowodowane tym, że głównym ich składnikiem są rozdrobnione fragmenty struktury ścianek porów. Podczas gdy, w przypadku większych cząstek, głównym ich składnikiem są całe fragmenty porów ekstrudatu, tworząc bardziej obłe struktury. Takie zjawisko można uzasadnić zarówno fizycznie - obecnością fragmentów ścianek por, jak i zróżnicowanym składem chemicznym frakcji ekstrudatu - wiązaniami między włóknami roślinnymi a białkiem zbożowym w danych cząstkach. Zróżnicowanie kształtu jest istotne ze względu na ocenę sensoryczną uzyskiwanych produktów przez odbiorców. Może być to niezwykle cenne spostrzeżenie dla przyszłych producentów tego typu produktów.

Analysis of compatibility factor showed that this parameter varies inversely than a roundness factor (Fig. 7). It was found that the lowest value of this ratio ranged from 0.5 to 0.6, indicating that the particles of such form in the slightest degree fill a rectangular boundary included in the calculated dependence (formula 3).

Współczynnik upakowania (compatness factor) wykazał, że parametr ten zmienia się odwrotnie niż współczynnik okrągłości (rys. 7). Stwierdzono, że najmniejsze wartości tego współczynnika zawierały się w przedziale 0,5-0,6, co świadczy, że cząstki o takim kształcie w najmniejszym stopniu wypełniają obwiednię prostokątną uwzględnioną w obliczanej zależności (wzór 3).
Graph showing the type factor (Fig. 8) as a function of temperature and fineness have a course close to the compactness factor.

Wykres przedstawiający współczynnik rozwinięcia powierzchni Type Factor (rys. 8) w funkcji rozdrobnienia i temperatury posiadał przebieg zbliżony do współczynnika upakowania (Compactness Factor).

Fig. 7 - Effect of extrusion temperature and the degree of extrudate fineness into compactness factor of breadcrumbs particles obtained

\[ z = 9.697 + 0.0126 \cdot x + 0.0004 \cdot x^2 - 0.287 \cdot y + 0.129 \cdot y^2 \]

Fig. 8 - Effect of extrusion temperature and the degree of extrudate fineness into type factor of breadcrumbs particles obtained

\[ z = 9.789 - 0.126 \cdot x + 0.0004 \cdot x^2 - 0.0812 \cdot y + 0.05 \cdot y^2 \]
CONCLUSIONS

Extrudates obtained in the twin-screw extruder at different temperatures of the process have distinguished by a variable internal structure, which may have an impact on obtaining extrudate fraction with different percentage of the particles and the shape of the extrudate particles after their fragmentation.

Analysed shape ratios are clearly different depending on the obtained sieved extrudate fractions. This may have a technological importance in the case of each fraction destination for selected food products. Such a relationship can be very useful in, for example, the design of breadcrumbs extrudates production lines intended for different products.

Further research requires the link between the chemical composition, sensory analysis with the shape and size of the particles of obtained breadcrumbs.

REFERENCES


WINOSKI

Ekstrudaty uzyskane na ekstruderze dwusślimakowym w różnych temperaturach procesu wyróżniała zmieniona struktura wewnętrzna co mogło mieć wpływ na uzyskanie frakcji ekstrudatu o różnym procentowym udziale oraz kształcie cząstek ekstrudatu po ich rozdrobnieniu.

Analizowane współczynniki kształtu wyraźnie różnią się w zależności od uzyskanej przesiewanej frakcji ekstrudatu. Może mieć to znaczenie technologiczne w przypadku przeznaczenia poszczególnych frakcji dla wybranych produktów żywnościowych. Taka zależność może być bardzo przydatna w przypadku np. projektowania linii technologicznych produkcji panieru ekstrudowanego z przeznaczeniem dla różnych produktów.

Dalszych badań wymaga również powiązanie składu chemicznego, analizy sensorycznej z kształtem i wielkością cząstek otrzymanego panieru.

LITERATURA

ALGORITHM FOR DETERMINATION OF CHARACTERISTIC PARAMETERS OF FILTERING PROCESS IN GRANULAR MATERIAL INCOMPRESSIBLE LAYER

INTRODUCTION

Filtration is the separation process of a heterogeneous liquid-solid system in constituent phases with the aid of a porous filter medium [1, 2].

The driving force which imposes the filtering process is usually the difference between the pressures on free surfaces of heterogeneous systems and filter medium.

Under the action of driving force the fluid from heterogeneous systems passes through the filter medium pores separating as filtered product while the solid particles in suspension in heterogeneous environment are retained by the filter medium especially on its surface, but also in its pores.

Thus, as the filtering process takes place, on the filter medium surface forms a wet solid particles cake which will act as an additional filter medium, its percentage in the filtering process being greater as the thickness increases.

Because of the large number of factors that interfere with filtration process, it is very difficult to develop a mathematical model to simulate the process framework. Therefore, models of filtering process for specific cases were developed.

For analysis of more complex cases we started from the basic models which have been developed and completed by results of experimental determinations [2].

MATERIALS AND METHODS

For filtering process, a base case from which it usually starts is filtering through incompressible porous media with incompressible solid particles cake formation, media that exhibit a constant resistance to filtrate passing through them.

In almost all cases the filtrate flow through this media is laminar. Thus, was obtained an equation (Darcy’s filter equation) experimentally confirmed, where filtration rate, \( w \), is directly proportional to the pressure difference acting as a driving force and inversely proportional to fluid viscosity and the resistances which oppose the filter medium and the solid particles cake at flow of filtrate [2],[4]:

\[
w = \frac{V}{A} = \frac{\Delta p}{\left(R_m + R_m^0\right) \eta}
\]

where: \( V = \frac{dV}{dt} \) [m³/s] – derived of filtrate volume separated in relation with time, namely the filtrate flow rate separated;

\( A \) [m²] – filter area;

\( \Delta p \) – difference of pressures on filter medium;

\( \eta \) – fluid viscosity;

\( R_m \) – resistance of filter medium;

\( R_m^0 \) – resistance of filter medium at static state.

\( P \) – pressure difference acting as a driving force.

Thus, as the filtering process takes place, on the filter medium surface forms a wet solid particles cake which at rândul său va acţiona ca un mediu de filtrare suplimentar, ponderea sa în procesul de filtrare fiind din ce în ce mai mare, pe măsură ce grosimea sa creşte.

Datorită numărului foartelor de factori ce intervin în procesul de filtrare este foarte greu de elaborat un model matematic care să simuleze procesul în cadru general. De aceea, s-au elaborat modele ale procesului de filtrare pentru cazuri particulare elementare. Pentru analiza cazurilor mai complexe s-a plecat de la modelele elementare care au fost dezvoltate și completeate cu rezultatele unor determinări experimentale [2].

MATELIALE ŞI METODE

Pentru procesul de filtrare, un caz de bază de la care se pleacă de regulă îl constituie filtrarea prin medi poroase incompressibile cu formare de precipitat de asemenea incompressibil, medi care opun o rezistență constantă la trecerea filtratului prin ele. Aproape în toate cazurile curgerea filtratului prin aceste medi este laminară. Pe baza acestui fapt s-a ajuns la o relație (relația lui Darcy) confirmată și experimental, potrivit căreia viteză \( w \) de filtrare este direct proporcională cu diferența de presiune care acționează ca forță motrice și invers proporțională cu vâscozitatea lichidului și rezistențele pe care le opun mediul de filtrare, \( \Delta p \), și stratul de filtrat separat in funcție de timp, adică debitul volumic de filtrat separat:

\[
\frac{\Delta p}{\left(R_m + R_m^0\right) \eta} = \frac{V}{A}
\]

în care: \( V = \frac{dV}{dt} \) [m³/s] – derivata volumului de filtrat separat în funcție de timp, adică debitul volumic de filtrat separat;

\( A \) [m²] – suprafața mediului de filtrare;

\( \eta \) – vâscozitatea lichidului.
**Δp** [Pa] – differential pressure across the free surfaces of heterogeneous system and the filter medium; 
**R** <sub>p</sub> [m<sup>−1</sup>] – the resistance of solid particles cake deposited on the filter surface to the passing filtrate; 
**R** <sub>m</sub> [m<sup>−1</sup>] – the filter medium resistance opposed to filtrate passing; 

Taking into account the resistance of the solid particles cake deposited on the filter surface, the filtrate passing can be expressed by the following expressions:

\[
R_p = \alpha \cdot h = \alpha \cdot \frac{c_p}{\rho_p} \cdot \frac{V}{A} = \alpha \cdot y \cdot \frac{V}{A} \quad (2)
\]

where: **α** [m<sup>−1</sup>] – specific solid particles cake resistance deposited on the filter surface; 
**h** [m] – filter cake thickness deposited on the filter surface; 
**c<sub>p</sub>** [kg/m<sup>3</sup>] – mass concentration of suspension from heterogeneous system; 
**ρ<sub>p</sub>** [kg/m<sup>3</sup>] – solid particles cake density deposited on the filter surface; 
**V** [m<sup>3</sup>] – filtrate volume; 
**A** [m<sup>2</sup>] – filter area; 
**y** – solid content of the suspension.

and that the resistance **R** <sub>m</sub>, opposed by the filter medium is usually noted with **β** [m<sup>−1</sup>], resulting the following expression known as the fundamental differential equation of filtration through incompressible filter medium, with solid particles cake incompressible formation:

\[
\frac{dV}{A \cdot dt} = \frac{\Delta p}{\alpha \cdot y \cdot \frac{V}{A} + \beta} \cdot \eta \quad (3)
\]

Analysis of the filtration process through incompressible filter media with incompressible solid particles cake formation is done for two particular cases commonly found in liquid suspension filtration practice, namely: if the filtering process takes place under a constant pressure difference (Δp = ct) and if the filtering process takes place with constant filtration rate (w = ct), namely, the flow rate separation of the filtrate is constant (V = ct).

If the filtering process takes place with constant filtration rate, respectively constant filtered flow (w = ct, respectively V = ct) the pressure difference under which the process takes place should increase throughout its duration. In this case the relation 3 can be linearized as:

\[
\Delta p = \eta \cdot y \cdot \frac{V}{A} \cdot \alpha + \eta \cdot \frac{V}{\beta} \cdot \beta \quad (4)
\]

If the function **Δp** = f(V) is plotted, it will result a straight line (Figure 1) characterized by the slope and ordinate interval at the origin. Determining the values of the slope and ordinate interval of the line drawn on **Δp** [Pa] - presiunea diferențială care se exercită pe suprafețele libere ale sistemului eterogen și mediului de filtrare; 
**R** <sub>p</sub> [m<sup>−1</sup>] – rezistența stratului de precipitat depus pe suprafața de filtrare; 
**R** <sub>m</sub> [m<sup>−1</sup>] – rezistența mediului de filtrare opusă la trecerea filtratului; 

Ținând seama că rezistența opusă de stratul de precipitat depus pe suprafața de filtrare la trecerea filtratului mai poate fi exprimată cu următoarele expresii [3]:

\[
\Delta p = \frac{\eta \cdot y \cdot V}{A} \cdot \alpha + \frac{\eta \cdot V}{\beta} \cdot \beta \quad (4)
\]

**Fig. 1 – Filtration at constant filtrate flow rate**

Dacă se reprezintă grafic funcția **Δp** = f(V) rezultă o dreaptă (Figura 1) [5] caracterizată de panta sa și de ordonata la origine. Determinându-se valorile pantei și ordonatei la origine ale dreptei construite pe baze experimentale, se pot determina valorile rezistențelor α și
experimental basis, we can determine $\alpha$ and $\beta$ resistance values opposed by precipitate layer formed on the surface during filtration process, respectively filtrate medium, which are constant values and are the main indices of the filtration process under constant filtration rate, respectively constant filtered flow to a certain suspension and a filter medium. If the filtering process takes place under a constant pressure difference ($\Delta p = ct$), filtration rate $w_f$ (filtrate volume) decreases as the process takes place. In this case the relation 3 can be linearized as:

$$\frac{1}{V} = \frac{\eta \cdot \alpha}{2 \cdot A^2 \cdot \Delta p} + \frac{\eta \cdot \beta}{A \cdot \Delta p}$$

(5)

Algorithm and calculation program

For processing the experimental data obtained in laboratory experiments, we used an algorithm whose structural scheme is shown in Figure 2.

---

**DATA SPECIFIC TO THE EXPERIMENT**
- density of particle, filtrate, and solid particles from the suspension subjected to filtration;
- dynamic viscosity of filtrate [Pas] of the filtrate;
- concentration $C_0$ [g/l] of solid particles from the suspension subjected to filtration;
- the debit filtrate [m3/s] of filtered out resulted from filtration, whose value is kept constant throughout the period of filtration;
- transversal surface area $A_{mf}$ [m2] of filter medium;
- gravitational acceleration $g$ [m/s2];

**ENTRY DATA OF RESULTS OF MEASUREMENTS:**
- time moments $t_j$ [s] undergoing measurements and record results;
- mass of filtrate $m_i$ [g] separated in the moments of measurements;
- differential pressure $p_i$ [mm col. api] between inputs and outputs of filter medium in the moments of measurements.

**Limiting ranges of values of $\eta$, $m_i$, $p_i$, $p_{a}$ to areas with significant, pertinent values.**

**Selection of significant and pertinent values of $\eta$, $m_i$, $p_i$, $p_{a}$.**

**Development of chart that contains the variation curve of the pertinent values $p_{a}$ based on pertinent values $m_i$.**

**Performing a linear regression to the variation curve of the pertinent values $p_{a}$ based on pertinent values $m_i$.**

**Determining the slope of the line from linear regression.**

**Determining the ordinate to origin of the line resulting from the linear regression.**

**Determining the value $\eta$ linear correct [Pa·s] through a correction of homogenization in dimensional terms to the slope value obtained from the chart.**

**Determining the value $\eta$ linear correct [Pa] through a correction of homogenization in dimensional terms to the origin ordinate value.**

**Determination of volumetric fraction $\gamma$ of the solid phase from the suspension subjected to filtration process.**

**Determination of specific resistance $\alpha$ [m-1] which opposes precipitated layer deposited on the surface of filtration medium, at filtrate passing.**

**Determination of specific resistances $\beta$ [m-1] which opposes the filtration medium at the passing of filtrate.**

**STOP**
RESULTATE

Pe baza algoritmului prezentat anterior a fost conceput un program de calcul în mediul de programare MathCad care este prezentat în figura 3.

CALCULUS PROGRAM OF THE FILTRATION PROCESS PARAMETERS OF A AQUEOUS SUSPENSION THROUGH AN INCOMPRESSIBLE MEDIUM WITHINCOMPRESSIBLE SOLID PARTICLES CAKE FORMATION

PROGRAM DE CALCUL AL PARAMETRILOR PROCESULUI DE FILTRARE A UNEI SUSPENSIII APOASE PRIN MEDIU INCOMPRESIBIL CU FORMARE DE STRAT DE PRECIPITAT INCOMPRESIBIL

The density \( \rho_{\text{apa}} \) [kg/m³] of the water at the environmental temperature during the experiment.

Densitatea \( \rho_{\text{apa}} \) [kg/m³] apei la temperatura mediului ambient din timpul experimentului.

The density \( \rho_{\text{filtrat}} \) [kg/m³] of the filtrate resulted from the aqueous suspension filtration at the environmental temperature.

Densitatea \( \rho_{\text{filtrat}} \) [kg/m³] filtratului rezultat din filtrarea emulsiei aposii la temperatura mediului ambient.

The density \( \rho_{\text{particule}} \) [kg/m³] of the aqueous suspension solid particles (calcium acid carbonate).

Densitatea \( \rho_{\text{particule}} \) [kg/m³] particulelor solide din suspensia aposii (carbonat de calciu).

The dynamic viscosity \( \eta_{\text{filtrat}} \) [Pa·s] of the filtrate at the environmental temperature during the experiment.

\[ \eta_{\text{filtrat}} = 1.002 \times 10^{-3} \]

The concentration \( C_{s} \) [g/l] of solid particles from the aqueous suspension subjected to the filtration process. Concentratia \( C_{s} \) [g/l] a particulelor solide din suspensia supusă filtratului.

The volumetric flow \( Q_{\text{filtrat}} \) [m³/s] of filtrate, kept constant during the experiment. Debitul volumic \( Q_{\text{filtrat}} \) [m³/s] de filtrat, păstrat constant în timpul experimentului.

The area \( A_{\text{tmf}} \) [m²] of the transversal surface of the filtration medium. Aria \( A_{\text{tmf}} \) [m²] supărată transversală a mediului de filtrare.

The velocity \( g \) [m/s²] gravitational.

The elaboration of the input data matrix DI concerning the measurements, with 3 rows and 25 columns, wherein:

- on the row 0, there are written the moments \( \text{DI} \) 0,j of time \( [\text{h}] \) when the measurements are effectuated and registered their results, noted as: DI 0,j;
- on the row 1, there are written the filtrate mass \( mf \) [g] separated in the measurement moments, noted as DI 1,j;
- on the row 2, there are written the differential pressures \( pd \) [mm water col.] between the entrance and the exit of the filtration medium, in the measurement moments noted as DI 2,j;

\[ \text{DI} = \begin{pmatrix}
\end{pmatrix} \]

wherein, with \( j \) is noted the number of measurements effectuated during the experiment, which corresponds to the number of columns of the matrix DI, in care cu \( j \) se notează numărul de măsurări care se efectuează în timpul experimentului, care corespunde numărului de coloane ale matricei DI.

The limitation of the range of the moments of time \( t \) to the zone with significant values (when can be measured relevant values of the filtrate mass \( mf \) and differential pressure \( pd \)).

Se limitară intervalul de momente de timp \( t \) zona de măsurări semnificative (când se pot măsura și înregistra valori pertinente ale măsoi de filtrat \( mf \) și presiunii diferentiale \( pd \)).
The application of a linear regression to the variation curve pdj values depending on the correspondant mfj values, in order to determine the slope Panta [mm col.apâ/g] (noted as m in the explicative graph) and the ordinate interval Ordonata involuntary [mm col.apâ/g] (noted as o in the explicative graph) of the regression line.

Se efectuează o regresie liniară a curbei de variație a valorilor pdj în funcție de mfj, în scopul determinării pantei Panta [mm col.apâ/g] (notată cu m în graficul explicativ) și ordinatei la origine Ordonatala involuntary [mm col.apâ/g] (notată cu o în graficul explicativ) ale dreptei de regresie.

Panta := slope (mf, pd)
Ordonatala involuntary := intercept (mf, pd)

The correlation index square R of the linear regression has the following value:

\[ \text{R}^2 = 0.944 \]

The graphical representation of the variation curve of pdj values depending on the correspondant mfj values.

Se reprezintă grafic curba de variatie a valorilor pdj în funcție de mfj, în scopul determinării pantei Panta [mm col.apâ/g] (notată cu m în graficul explicativ) ale dreptei de regresie.

Se efectuează o regresie liniară a curbei de variație a valorilor pdj în funcție de mfj, în scopul determinării pantei Panta [mm col.apâ/g] (notată cu m în graficul explicativ) ale dreptei de regresie.

\[ \text{R}^2 = 0.944 \]

\[ \text{Panta} = 0.135 \]

\[ \text{Ordonatala involuntary} = 142.948 \]

The effectuation of a dimensional homogenizing correction of the regression line slope, noted as Pantacorrectata \[ \text{Pa/imp} \].

Se efectuează o corectie de omogenizare din punct de vedere dimensiunilor a dreptei de regresie, notată cu Pantacorrectata \[ \text{Pa/imp} \].

\[ \text{Pantacorrectata} := \text{Panta} \cdot \text{g} \cdot \text{apa} \cdot \text{ filtrat} \]

\[ \text{Pantacorrectata} = 1.316 \times 10^8 \]

The determination of the volumic fraction \( y \) of the solid phase of the aqueous suspension submitted to the filtration process, in order to calculate the specific resistance \( \alpha \).

Se determină fraxția volumică \( y \) a fazei solide din suspensia aposă supusă procesului de filtrare, în scopul calculării rezistenței specifice \( \alpha \).

\[ y = \frac{\text{Cs}}{\text{pparticule}} \]

\[ y = 0.022 \]

The determination of the specific resistance \( \alpha [\text{1/imp}] \) opposed by the cake formed on the surface of the filtration medium at the filtrate passage.

Se determină rezistența specifică \( \alpha [\text{1/imp}] \) pe care o opune stratul de precipitat depus pe suprafața mediului de filtrare la trecerea filtratului

\[ \alpha := \frac{\text{Pantacorrectata} \cdot \text{Atmf}^2}{\text{sfiltrat} \cdot y \cdot Qfiltrat} = 4.45 \times 10^3 \]

The determination of the specific resistance \( \beta [\text{1/imp}] \) opposed by the cake formed on the surface of the filtration medium at the filtrate passage.

Se determină rezistența specifică \( \beta [\text{1/imp}] \) pe care o opune stratul de filtrat la trecerea filtratului

\[ \beta := \frac{\text{Ordonatala involuntarycorrectata} \cdot \text{Atmf}^2}{\text{sfiltrat} \cdot Qfiltrat} = 9.284 \times 10^8 \]

Fig. 3 – Program for calculating characteristic indices of the filtration process

CONCLUSII

Algoritmul a fost realizat în scopul efectuării rapide și comode a calculor aferente rezultatelor obținute în urma experimentelor de laborator pentru determinarea indicilor caracteristici ai procesului de filtrare prin strat incompresibil de material granular.
The algorithm allows obtaining the values of characteristic parameters of filtering process, $\alpha$ (the specific resistivity of the layer deposited on the filter surface opposite to the passage of filtrate), respectively $\beta$ (the resistivity of filter media opposite the filtrate passing) in a very short time. This wouldn't have been possible if the calculations required were carried out graphically – analytically with hand tools (calculator, graph paper).

It is to be noted that this algorithm is original, designed by the authors in the Department of Biotechnical Systems, in order to improve educational technology used in the laboratory sessions.

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Algoritmul permite obţinerea indicilor caracteristici ai procesului de filtrare, $\alpha$ (rezistenţa specifică a stratului de precipitat depus pe suprafaţa de filtrare opusă la trecerea filtratului), respectiv $\beta$ (rezistenţa mediului de filtrare opusă la trecerea filtratului) într-un interval de timp foarte scurt, ceea ce nu ar fi fost posibil dacă calculele necesare ar fi fost efectuate grafolic – analitic cu mijloace manuale (calculator, hârtie milimetrică).

De menţionat faptul că acest algoritm de calcul este original, conceput de către autori în cadrul Departamentului Sisteme Biotehnice, în scopul perfeclonării tehnologiei didactice utilizate în orele de laborator.

Menţiune


**BIBLIOGRAFIE**

TESTING IN SIMULATED AND ACCELERATED REGIME OF RESISTANCE STRUCTURES

/ TESTAREA IN REGIM SIMULAT SI ACCELERAT A STRUCTURILOR DE REZISTENTA


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Abstract: In the paper there are presented experimental researches regarding testing in simulated and accelerated regime of bogie frame type resistance structures. Starting from the loads at which the structure is exposed in daily exploitation, there was developed a testing programme in simulated and accelerated regime in order to verify its structural integrity and estimate its span of.

Keywords: testing, simulated and accelerated regime, resistance structure.

INTRODUCTION

Testing in accelerated regime is the testing process of a product by subjecting it to working conditions (stress, specific strain, temperatures etc.) exceeding the normal operating parameters for discovering the failures and ways of failure in a short period of time. The purpose of the accelerated testing is to provide information on the reliability of the equipment over an as short as possible period of time [1]. By analyzing the product response to such tests, the engineers can predict the active span of life and its maintenance intervals.

Testing in simulated and accelerated regime of the resistance structure of bogie frame type equipping the passenger wagons is imposed mainly by the product final destination. The bogie frame is a critical resistance structure of the component of passenger wagons that support the wagon bodywork and taking over the most of the stresses that occur in operation. Thus, this structure must be subjected to a validation program, consisting of the following stages:
- designing;
- structural analysis with finite element;
- simulated and accelerated regime testing in the laboratory;
- testing on the railway.

As shown, the testing stage follows after the stage of structural analysis. Within the stage of structural analysis it simulates on the computer the stresses that may arise in operation and which will generate some internal stress states within the structure of the bogie. Thus, it identifies the simulated loading configurations of the bogie frame and the points likely to be subjected to maximum stresses during service duration. Within the testing phase is verified the structural integrity of the bogie frame and its resistance to fatigue. Thus the testing stage is composed of two types of tests: tests carried out in static regime and test carried out in dynamic regime that follows on the first ones.

The tests carried out in static regime simulate the stress that occurs in service. The static tests are divided into tests in which the loadings are made with exceptional strains, loads that rarely occur during exploitation of the bogie frame and testings in which the loadings are done with service chargings, strains that occur routinely during its exploitation. The tests with exceptional loads have the role to check the condition in which the structure is exposed in daily exploitation.

Rezumat: In lucrare sunt prezentate cercetările experimentale privind testarea in regim simulat si accelerat a structurilor de rezistenta din tip rama de boghiu. Plecând de la sarcinile la care este supus structura in exploatare zilnică, s-a dezvoltat un program de testare in regim simulat si accelerat cu scopul de a verifica integritatea structurala a acesteia si de a-l estima durata activa de viata.

Cuvinte cheie: testeare, regim simulat si accelerat, structura de rezistenta.

INTRODUCERE

Testarea in regim accelerat reprezinta procesul de testare a unui produs prin supunerea la conditii de lucru (tensiune, deformatie specifica, temperaturi etc) care depasesc parametrii normali de exploatare in scopul descoperirii defectelor si a modalitatilor de esuare intr-o perioada scurta de timp. Scopul incercarilor accelerate este acela de a furniza informatii privind fiabilitatea echipamentelor intr-o perioada cat mai scurta de timp [1]. Prin analizarea rapsusului produsului la asemenea teste, inginerii pot previziona durata activa de viata si intervalele de mentenanta ale acestuia.

Testarea in regim simulat si accelerat a structurii de rezistenta din tip rama de boghiu care echipeaza vagoanele de calatori este impusa in principal de destinatia finala a produsului, acesta intrand in compunenta unui tren de calatori. Rama de boghiu este o structura de rezistenta critica din componenta vagoanelor de calatori pe care se sprijina caroseria wagonului si care preia majoritatea sarcinilor care apar in exploatare. Astfel aceasta structura trebuie supusa unui program de validare, compus din urmatoarele etape:
- proiectare;
- analiza structurala cu element finit;
- testare in regim simulat si accelerat in laborator;
- testare pe cale ferata.

Dupa cum se observa, etapa de testare urmeaza etapei de analiza structurala. In cadrul etapei de analiza structurala se simuleaza pe calculator sarcinile care pot apare in exploatare si care vor genera anumite stari de tensiuni interne in cadrul structurii de boghiu. Astfel se identifica configuratiile de incarcare simulata ale ramei de boghiu si punctele susceptibile a fi supuse unor tensiuni maxime in timpul duratei de exploatare. In cadrul etapei de testare se verifica integritatea structurala a ramei de boghiu si rezistenta acesteia la oboseala. Astfel etapa de testare este compusa din doua tipuri de teste: teste efectuate in regim static si teste efectuate in regim dinamic care le succeda pe primele.

Testele efectuate in regim static simuleaza sarcinile care apar in exploatare. Testele statice sunt impartite in teste in care incarcarile se fac cu sarcini exceptionale, sarcini care apar foarte rar in timpul exploatarii ramei de boghiu si teste in care incarcarile se fac cu sarcini de serviciu, sarcini care apar in mod curent in timpul exploatarii. Testele cu sarcini exceptionale au rolul de a verifica conditii ca in lucru sa nu se depaseasa limita de
that during work the yield strength of the material in which the bogie frame it is built, should not be surpassed, namely not to enter the field of plastic deformations. The tests with exploitation loadings represent tests that are performed in static regime, using for loading the extreme values that occur in the testing phase in dynamical regime. Using the results of these tests it checks the framing within the Goodmann-Smith diagram of the recorded stresses, thus estimating an “infinite” lifetime.

The tests carried out in dynamic regime actually verify the active length of life of the resistance structure of bogie frame type, this being subjected to a combination of loadings that simulate the state of stresses at which it is subjected in real working regime. The testing is accelerated because the loads are applied with a higher frequency than the actual working frequency, ratio between the two frequencies being the acceleration factor.

The test program presented is based on the European norm EN 13749:2011 which stipulates the methods for specifying the requirements regarding the resistance of the bogie frame structures.

MATERIALS AND METHODS

Researches regarding testing in simulated and accelerated regime of resistance structures of bogie frame type were carried out on a Hidropuls type testing installation, following a fatigue testing accelerated program for one bogie frame. This paper presents the program of accelerated fatigue testing regime of a prototype bogie frame.

In operation, the bogie frame is subjected to the following load cases:
- vehicle weight including the payload,
- variations in the payload,
- irregularities of the rolling track,
- travel in curves,
- accelerations and brakings,
- minor derailments,
- impact (collision).

In reality, the loads are combining in a complex manner difficult to achieve in laboratory testing conditions. Therefore, in the current practice, are normalized load cases that are considered to be coverings for the real situations encountered on the duration of exploitation.

Fatigue tests are intended to confirm that the bogie frame is able to withstand the stresses caused by operating loads on its whole lifetime. The main acting loads are those responsible for inducing mechanical stresses in the whole structure of the bogie frame, namely: vertical forces, transversal forces and the forces due to twisting strains.

Fatigue testing program consists of repeating of cycles based on vertical and transversal forces combined with the shear demands (twisting).

The vertical forces applied on both longerons comprise:
- one statical part (1)
- one quasi-statical part: (2)
- one dynamical part: (3) (defined in Annex G2 of SR EN 13749:2011).

\[ F_z1 = F_z2 = \frac{F_z}{2} = \frac{(Mv + 1.2P2 - 2m^2)g}{4} \] (1)

curring a materialului din care este construita rama de boghiu, adica de a nu intra in domeniul deformatiilor plastice. Testele cu sarcini de exploatare reprezinta teste care se fac in regim static, folosind pentru incarcare valorile extreme care apar in cadrul etapei de testare in regim dinamic. Folosind rezultatele acestor teste se verifica incadarea in interiorul diagramei Goodmann-Smith a tensiunilor inregistrate, estimandu-se astfel o durata de viata “infitnita”.

Testele efectuate in regim dinamic verifica efectiv durata activa de viata a structurii de rezistenta de tip rama de boghiu, aceasta fiind supusa la o combinatie de sarcini care simuleaza starea de tensiuni la care aceasta este supusa in regim real de lucru. Testarea este accelerata deoarece sarcinile sunt aplicate cu o frecventa superioara frecventei reale de lucru, raportul dintre cele doua frecvente fiind factorul de accelerare.

Programul de testare prezentat are la baza norma europeana EN 13749:2011 care stipuleaza metodele pentru specificarea corintelor referitoare la rezistenta structurilor cadrelor de boghiuri.

MATERIALE ŞI METODE

Cercetările privind testarea în regim simulat și accelerat a structurilor de rezistenta de tip rama de boghiu s-au realizat pe o instalatie de incercari de tip Hidropuls, urmarind un program de testare in regim accelerat la oboseala pentru un prototip de rama de boghiu.

In exploatare, rama de boghiu este supusa la urmatoarele cazuri de incarcare:
- greutatea vehiculului, incluzand sarcina utila,
- varati in sarcina utila,
- neregularitati ale caii de rulare,
- mers in curbe,
- acceleratii și franari,
- deraieri minore
- impact (tamponare).

In realitate sarcinile se combina intr-o maniera complexa, greu de realizat in conditiile incercarilor de laborator. In consecinta, in practica curenta, sunt normate cazuri de incarcare, care se considera a fi acoperitoare pentru situatiile reale intalnite pe durata de exploatare.

Incercarile la obosela sunt destinate sa confirm pe rama boghiului este capacabil sa reziste solicitarii datorate sarcinilor de exploatare pe toata durata de vitan a acestui. Sarcinile principale care actioneaza sunt cele responsabile de inducerea solicitarii mecanice in intreaga structura a ramei de boghiu, anume: fortele verticale, fortele transversale si fortele datorate solicitarii de rasucire.

Programul incercarilor la obosela consta in repetarea ciclurilor bazate pe fortele verticale si transversale combinat cu solicitarii de forfcarare (rasucire).

Fortele verticale, aplicate pe ambele lonjeroane cuprind:
- o parte statica (1)
- o parte cvasi-statica: (2)
- o parte dinamica: (3) (defineşte conform anexei G2 din SR EN 13749:2011).
The transversal forces applied on each axis, comprise:
- the quasi-static component (4);
- the dynamical component (5).

\[
F_{zqs1} = F_{zqs2} = \pm \frac{0.1F_z}{2} \\
F_{zd1} = F_{zd2} = \pm \frac{0.2F_z}{2}
\]  

where \( g \) has the approximate value of 9.81 m/s\(^2\) and represents the gravitational acceleration and \( m + \) represents the mass of the wagon loaded.

The variations of these forces in relation to the time are indicated in Figure 1.

\[
F_{yqs1} = F_{yqs2} = \pm 0.063(F_z + m^+g) \\
F_{yd1} = F_{yd2} = \pm 0.063(F_z + m^+g)
\]

where \( g \) are valoarea aproximativa 9.81 m/s\(^2\) și reprezinta accelerația gravitațională și \( m^+ \) reprezinta masa vagonului incarcat.

The quasi-static stress cycles are normally reversed every 10 ... 20 dynamic cycles and the number of these cycles will be proportionally lower comparing to the number of dynamic cycles.

Ciclurile de solicitare cvasi-statica sunt inversate in mod normal la fiecare 10 ... 20 cicluri dinamice, iar numarul acestor cicluri va fi proporțional mai mic comparativ cu numarul ciclurilor dinamice.

The torsional stress cycles (of twisting) consist of loads (or equivalent displacements) applied to primary suspension to generate a torsion in vertical plane of angle \( +\theta_y \) followed by a torsion of angle \(-\theta_y\) of the bogie frame longerons, which are synchronous with the torsional stress cycles (of twisting) (defined in Annex G2 of SR EN 13749:2011).

Ciclurile de solicitare cvasi-statica sunt inversate in mod normal la fiecare 10 ... 20 cicluri dinamice, iar numarul acestor cicluri va fi proporțional mai mic comparativ cu numarul ciclurilor dinamice.

Fig.1 – The form of strains at the dynamic test to fatigue of bogies [5]
sequence of quasi-static loads. The twisting force applied to the bogie frame corresponds to an angular misalignment of the longerons in vertical plane of 0.5%.

The dynamic components of vertical and transversal forces are applied in phase, at the same frequency, so that to allow a simulation of loadings acting on the bogie frame. The same thing applies to the quasi-static components at an appropriate frequency of changing the curves direction. The sense of curves is alternately changed at every 10 dynamic cycles.

Dynamic stress fatigue loads are applied to a total of \(10 \times 10^6\) cycles as follows:

- \(6 \times 10^6\) cycles with the loads calculated according to 5.2.2 and Annexes C, F and G of SR EN 13749:2011;
- \(2 \times 10^6\) cycles with the loads calculated above, increased by 20%;
- \(2 \times 10^6\) cycles with the loads calculated at the first point, increased by 40%.

The assessment method of resistance to fatigue chosen was the method of fatigue limit achieving, which according to [2] is the most commonly used method. For this purpose, during the application of loads are recorded the mechanical stresses and the forces applied to the bogie frame. It analyzes mechanical stresses and it is evaluated the return to “zero” after removal of loadings. For each measurement point is determined the maximum values, \(\sigma_{\max}\), and minimum values, \(\sigma_{\min}\), from which are calculated the mean values and the mechanical stress amplitudes \((\sigma_m = \text{the abscissa and } \sigma_a = \text{the ordinate in the Goodman-Smith diagram})\) using the relations (6):

\[
\sigma_m = \frac{\sigma_{\max} + \sigma_{\min}}{2}
\]

\[
\sigma_a = \frac{\sigma_{\max} - \sigma_{\min}}{2}
\]

Table 1 shows the calculated values of the loadings that have been applied within the bogie frame fatigue testings performed in simulated and accelerated regime for the first \(6 \times 10^6\) dynamic stress cycles to fatigue.

Figure 2 shows a schematic diagram of loadings used for the application of loadings at static and fatigue tests of the trailer bogie frame.

<table>
<thead>
<tr>
<th>Type of strain</th>
<th>Component type</th>
<th>Strain value [kN]</th>
<th>Strain value [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>(F_v) (Transversal)</td>
<td>quasi-static</td>
<td>19.85</td>
<td>-</td>
</tr>
<tr>
<td>dynamic</td>
<td>19.85</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>(F_z) (Vertical)</td>
<td>static</td>
<td>128</td>
<td>-</td>
</tr>
<tr>
<td>quasi-static</td>
<td>12.8</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>dynamic</td>
<td>25.6</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Twisting (Torsion)</td>
<td>quasi-static</td>
<td>-</td>
<td>1.6</td>
</tr>
</tbody>
</table>

In tabelul 1 se prezinta valorile calculate ale sarcinilor care au fost aplicate ramei de boghiu purtator in cadrul testarilor de oboseala efectuate in regim simulat si accelerat, pentru primele \(6 \times 10^6\) cicluri de solicitare dinamica la oboseala.

In figura 2 este prezentata schema de principiu folosita pentru aplicarea sarcinilor la incercarile statice si oboseala ale ramei de boghiu purtator.
The frequency for the dynamic application of loadings was chosen at 3.5 Hz, after modal identification tests previously undertaken [3]. Thus it has complied to a good practice rule, the test frequency not exceeding the value of 1/3 of the first fundamental frequency of the bogie frame, which has been identified around the value of 18 Hz.

For monitoring the evolution of fatigue tests, were performed stresses measurements recorded in the critical points of the bogie frame, previously identified through finite element analysis.

Were applied a total of 44 strain gauges LY11-6/350 manufactured by Hottinger having the base of 6mm and the electrical resistance of 350 Ohm, the factor $k=2.09 \pm 0.7\%$, transversal sensitivity -0.9%.

Also were acquired and the data relating at the amplitude and frequency of the applied loads to the bogie frame.

**RESULTS**

Product for which the dynamic test was performed was the trailer bogie frame for electrical frames which is shown in Figure 4.

The trailer bogie frame is made of welded steel type S355J2G3-STD01W03 (ERRI B12/RP60) of varying thicknesses (8,10,12mm), with the mechanical breaking effort of 510 MPa and the proportionality elastic limit of 350 MPa for unwelded material, respectively 325 MPa, for welded material.

Fig. 2 – Application scheme of static and fatigue loads for the bogie frame

Frecventa de aplicare dinamica a sarcinilor a fost alesa la 3.5 Hz, in urma testelor de identificare modala intreprente anterior [3]. Astfel s-a respectat o regula de buna practica, frecventa de incercare nedepasind valoarea de 1/3 din prima frecventa fundamentala a ramei de boghiu, care a fost identificata in jurul valorii de 18 Hz.

In scopul urmaririi evolutiei testelor de oboseala, s-au efectuat masuratori ale tensiunilor inregistrate in punctele critice ale ramei de boghiu, identificate anterior prin analiza cu element finit.

Au fost aplicate un numar de 44 de marci tensometrice LY11-6/350, produse de firma Hottinger avand baza de 6mm si rezistenta de 350Ohm, factorul $k=2.09 \pm 0.7\%$, sensibilitate transversala -0.9%.

De asemenea au fost achizitionate si datele referitoare la amplitudinea si frecventa sarcinilor aplicate ramei de boghiu.

Fig.3 – Detail of strain gauge application

**REZULTATE**

Produsul pentru care s-au efectuat incercarile dinamice a fost rama de boghiu purtator pentru rame electrice prezentata in figura 4.

Rama de boghiu purtator este o constructie sudata sudata confectionata din otel tip S355J2G3-STD01W03 (ERRI B12/RP60) de diferite grosimi (8,10,12mm), cu efortul mecanic la rupere de 510 MPa si limita de proportionalitate elastică de 350 MPa pentru material nesudat, respectiv 325 MPa, pentru material sudat.
Accelerated fatigue tests were performed on a specialized stand (fig.5) that simulates the real operating conditions. Installation used for the application of loadings in dynamic regime was the installation of Hydropulse type from the endowment of Testing Department within INMA Bucharest. For the application of vertical loads were used two hydraulic cylinders of 250 kN, one for each longeron. The application of transversal loads was made through two 100 kN hydraulic cylinders, one for each axle. The twisting strains were applied through two hydraulic cylinders of 250 kN.

To succeed in the application of a test frequency of 3.5 Hz, the primary suspension of the bogie frame was artificially stiffened by pre-stressing with a force of 90 kN, the twisting strain being recalculated for this reason.

In figura 6 se prezinta diagrama fortelor aplicate ramei de boghiu in regim dinamic, pentru primele 6 milioane cicluri de incarcare dinamica. Analizand diagrama se pot identifica componentele statica, cvasi-statica si dinamica caracteristice fiecarei forte sau deplasari aplicate. De asemenea se observa corelarea intre semnalul de referinta (fig.2) si semnalul real achizitionat (fig.6).

Diagramele sunt asociate prin culoare cu display-uri plasate in partea inferioara a fiecarii reprezentari grafice. In display-uri sunt transmise valorile parametrilor reprezentati, la momente de timp selectate prin cele doua cursore de culoare rosu si albastru. Valorile corespunzatoare primului cursor, rosu, sunt transmise in randul superior de display-uri, iar in randul inferior sunt transmise valorile corespunzatoare celui de al doilea cursor, cel albastru.

Pentru toate tipurile de solicitari sunt valabile urmatoarele reguli de citire si de interpretare:
Forces applied vertically FZ1 and FZ2 are reported in right ordinate. Forces applied horizontally FY1 and FY2 are ordered relative to the left. Twisting sites S1 (DTw1) and S2 (DTw2) are relative to the middle ordinate.

In the diagram in Figure 7 is observed a part of the strains measured in the critical points of the bogie frame during the 10 million cycles of dynamic load. Mechanical stresses were obtained by multiplying the measured specific deformation modulus $E = 206000$ MPa which is specific for the steel from which the bogie frame is built. It can be seen that the shape of the mechanical stresses complies with the profile of the strains applied to bogie frame.

---

**Fig. 6** – Applied forces diagram / Diagrama forte aplicate

**Fig. 7** – Mechanical tensions diagram

Figure 8 shows the framing into the Goodman-Smith stress diagram $\sigma_m$ and $\sigma_a$ calculated for each specific deformation measured in the critical points of the bogie frame. It can be seen that all the points of coordinates $(\sigma_m, \sigma_a)$ are within the chart except one, which is on the border. Framing points within the chart predicts a value of strains below the limit of fatigue. The point from the boundary suggests possible fatigue limit reaching in the critical area which it represents. This area was observed until the end of tests, and have not presented the appearance of cracks or fractures caused by fatigue.

---

In figura 8 se prezinta incadrarea in diagrama Goodman-Smith a tensiunilor $\sigma_m$ si $\sigma_a$ calculate pentru fiecare deformatie specifica masurata in puntele critice ale ramei de boghiu. Se poate observa ca toate punctele de coordonate $(\sigma_m, \sigma_a)$ se afla in interiorul diagramei cu exceptia unui singur, care se afla pe frontiera. Incadrarea punctelor in interiorul diagramei previzeaza o valoare a tensiunilor sub limita de oboseala. Punctul de pe frontiera sugera o eventuala atingere a limitei de oboseala in zona critica pe care o reprezinta. Aceasta zona a fost tinuta sub observatie pana la finalul testelor si nu a prezentat aparitia unor fisuri sau rupturi datorate oboselei.
CONCLUSIONS

Testing in simulated and accelerated regime of the bogie frames is done in order to verify the structure from the perspective of the resistance to fatigue.

Within the dynamic tests to fatigue the assessment of fatigue strength using the fatigue diagrams GOODMAN - SMITH only allows assessing of a compliance with the limits imposed by diagrams [4]. It can assess the fatigue resistance using the approach of accumulation of flaws, based on summation of effects of stresses due to all load cases and including them into the Wohler curve for the material in which is constructed the structure. Then, using a hypothesis for damages accumulation due to the fatigue (Palmer-Miner for example) can be estimated the total degree of fatigue that will be accumulated during the active period of life of the structure [2]. However, this method requires complex calculations and definition of the complete spectrum of stresses to which may be subjected the structure.

The groups of stresses to which was subjected the structure are based on waveforms experimentally established on the railways and accelerated from the perspective of increasing the testing frequency and the amplitudes of the strains in order to obtain results as correlated with reality in good time.

Acknowledgement

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CONCLUZII

Testarea în regim simulat și accelerat a ramelor de boghiu se face în scopul verificării structurii din punctul de vedere al rezistenței la oboseală. În cadrul încercărilor dinamice la oboseala aprecierea rezistenței la oboseală folosind diagramele de oboseală GOODMAN – SMITH permite doar evaluarea unei încadrări în limitele impuse de diagrame [4]. Se poate evalua rezistenta la oboseala folosind abordarea cumulului de defekte, prin insumarea efectelor tensiunilor datorate tuturor cazurilor de incarcare și încadrarea acestora în curba lui Wohler pentru materialul din care este construita structura. Apoi folosind ipoteza pentru acumularea stricăturilor datorita oboesii (Palmer-Miner de exemplu) se poate estima gradul total de oboseală care va fi acumulat pe parcursul duratei active de viața a structurii [2]. Totusi aceasta metoda presupune calcule complexe si definirea spectrului complet de sarcini la care poate fi supusa structura. Colectivele de solicitare la care a fost supusa structura au la baza forme de unda stabilite experimental pe calea ferata si accelerate din punctul de vedere al cresterii frecventei de testare si a amplitudinilor solicitarilor in scopul obtinerii unor rezultate cat mai corelate cu realitatea in timp util.

Recunoaştere

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INTRODUCTION

In references [2] and [3] a calculation method is presented for the inertial characteristics of simple bodies, based on their assimilation with finite systems of material points. It is shown that, in the case of a homogeneous triangular plate of mass \( m \), the equivalent system is composed of three points of mass \( \frac{m}{12} \) applied in the corners and one of mass \( \frac{3m}{4} \) applied in the mass center. Let \( OA_1A_2 \ldots A_{n-1}A_n \) be a plate of mass \( m \), with bending edges concurrent in point \( O \) (Fig. 1a).

Abstract: The paper presents a method to determine the inertial characteristics (coordinates of the mass center, moments and products of inertia) of a plate with concurrent bending edges, each face representing a homogeneous triangle. By generalising a method previously published by the first author, the plate is assimilated, from the inertial point of view, with a discrete system of material points, applied in the corners and in the mass centres of the faces. The results are particularised for several cases frequently found in practice: homogeneous bent plate, plane plate with the shape of an arbitrary polygon, of a quadrilateral and of a right-angled trapezoid, respectively. Two applications are also presented.

Keywords: bent plate, mass center, moment of inertia, product of inertia.

MATERIALS AND METHODS

The orthogonal reference system \( Oxyz \) is considered, with the origin in point \( O \). External edges \( OA_1 \) and \( OA_n \) are supposed to pass also through the corner \( O \), which is the concurrence point of all visible edges of the plate. On the figure, the bending edges are drawn with solid line: \( OA_2, OA_3, \ldots, OA_{n-1} \).

Rezumat: Lucrarea prezintă o metodă de calcul al caracteristicilor inerțiale (coordonatele centrului de masă și momente de inerție mecanice) ale unei plăci cu muchii de îndoire concurrente, fiecare dintre fețele acesteia reprezentând un triunghi omogen. Generalizând o metodă publicată anterior de către primul autor, placa este echivalată, din punct de vedere inerțial, cu un sistem discret de puncte materiale, aplicate în colțuri și în centrele de masă ale fețelor. Rezultatele sunt particularizate pentru mai multe cazuri frecvent întâlnite în practică: placă îndoită, placă plană iar placa dreptunghiului. Sunt prezentate, de asemenea, două aplicații.

Cuvinte cheie: centru de masă, momente de inerție, placă îndoită.

MATERIALEȘI METODE
Se consideră sistemul de referință ortogonal \( Oxyz \), cu originea în punctul \( O \). Se presupune că muchiile de tăiere exterioare, \( OA_1 \) și \( OA_n \), trec, de asemenea, prin vârful \( O \), care este punctul de concurență al tuturor muchiilor vizibile ale plăcii. Pe figură, muchiile de îndoire sunt
The coordinates of all corners are also considered known: \(O(0, 0, 0), A_1(x_1, y_1, z_1), A_2(x_2, y_2, z_2), ..., A_n(x_n, y_n, z_n)\).

It is also supposed that all triangles \(O A_1 A_2, O A_2 A_3, ..., O A_{n-1} A_n\), which define the faces of the body, are homogeneous plates. The coordinates of the mass center of an arbitrary triangle, \(O A A_i\), can be easily calculated:

\[
C_i \left( \frac{x_i + x_{i+1}}{3}, \frac{y_i + y_{i+1}}{3}, \frac{z_i + z_{i+1}}{3} \right) \quad (i = 1, 2, ..., n - 1)
\]

Taking into account the above mentioned equivalence theorem, it results that the plate can be reduced to a system of material points with the following masses (fig. 1b):

\[
A_i \left( \frac{m_i}{12}, \frac{m_i}{12}, \frac{m_i + m_{i+1}}{12} \right), \quad A_i \left( \frac{m_i + m_{i+1}}{12}, \frac{m_i}{12}, \frac{m_i + m_{i+1}}{12} \right), \quad C_i \left( \frac{3m_i}{4} \right), \quad C_i \left( \frac{3m_i}{4} \right)
\]

RESULTATE
Calculation of the inertial characteristics of an arbitrary bent plate

The abscissa of the mass center is:

\[
x_c = \frac{\sum_{i=1}^{n} \frac{m_i}{12} (x_i + x_{i+1}) + \sum_{i=1}^{n-1} \frac{3m_i}{4} x_{i+1}}{12m}
\]

By arranging this expression and proceeding in the same manner for the other coordinates, it follows:

\[
x_c = \frac{1}{3m} \sum_{i=1}^{n} m_i (x_i + x_{i+1}) \quad y_c = \frac{1}{3m} \sum_{i=1}^{n} m_i (y_i + y_{i+1}) \quad z_c = \frac{1}{3m} \sum_{i=1}^{n} m_i (z_i + z_{i+1})
\]

The calculation relations of the moments and products of inertia are based on the definition formulae of these quantities, for discrete systems of material points [1].

Thus,

\[
J_{xx} = \sum_{i=1}^{n} \frac{m_i}{12} \left( y_i^2 + z_i^2 \right) + \sum_{i=1}^{n} \frac{3m_i}{4} \left[ \left( \frac{y_i + y_{i+1}}{3} \right)^2 + \left( \frac{z_i + z_{i+1}}{3} \right)^2 \right]
\]

\[
J_{yy} = \sum_{i=1}^{n} \frac{m_i}{12} \left( x_i^2 + z_i^2 \right) + \sum_{i=1}^{n} \frac{3m_i}{4} \left[ \left( \frac{x_i + x_{i+1}}{3} \right)^2 + \left( \frac{y_i + y_{i+1}}{3} \right)^2 \right]
\]

By arranging these expressions and by proceeding in the same manner for the other moments and products of inertia, it follows:

\[
J_{xx} = \frac{1}{6} \sum_{i=1}^{n} m_i \left( x_i^2 + x_{i+1}y_i + y_i^2 + y_{i+1}z_i + z_i^2 + z_{i+1}x_i \right)
\]

\[
J_{yy} = \frac{1}{6} \sum_{i=1}^{n} m_i \left( y_i^2 + y_{i+1}z_i + z_i^2 + z_{i+1}x_i + x_i^2 + x_{i+1}y_i \right)
\]

\[
J_{zz} = \frac{1}{6} \sum_{i=1}^{n} m_i \left( z_i^2 + z_{i+1}x_i + x_i^2 + x_{i+1}y_i + y_i^2 + y_{i+1}z_i \right)
\]
Calculation of the inertial characteristics of a homogeneous plate

If the bent plate is homogeneous, its superficial density, \( \rho_s \), is constant and has the expression:

\[
\rho_s = \frac{m}{S}
\]

(8)

The total area, \( S \), can be obtained by adding the areas of the composing triangles:

\[
S = S_1 + S_2 + \ldots S_i + \ldots S_{n+1} = \sum_{i=1}^{n+1} S_i
\]

(9)

As it is known, the modulus of the vector product of two position vectors equals twice the area of the triangle determined by the vectors:

\[
S_i = \frac{1}{2} \left| \overrightarrow{OA} \times \overrightarrow{OW} \right| = \frac{1}{2} \sqrt{(y_1 z_{i+1} - y_{i+1} z_i)^2 + (z_1 x_{i+1} - z_{i+1} x_i)^2 + (x_1 y_{i+1} - x_{i+1} y_i)^2}
\]

(10)

where:

\[
\overrightarrow{OA} \times \overrightarrow{OW} = \begin{vmatrix}
\hat{i} & \hat{j} & \hat{k} \\
x_i & y_i & z_i \\
x_{i+1} & y_{i+1} & z_{i+1}
\end{vmatrix}
\]

(11)

The masses of the triangular plates have the expressions:

\[
m_i = \rho_s \cdot S_i = m \cdot \frac{S_i}{S} \quad m_2 = \rho_s \cdot S_2 = m \cdot \frac{S_2}{S} \quad \ldots \quad m_i = \rho_s \cdot S_i = m \cdot \frac{S_i}{S} \quad \ldots \quad m_{n+1} = \rho_s \cdot S_{n+1} = m \cdot \frac{S_{n+1}}{S}
\]

(12)

It follows that, in the case of a homogeneous plate, formulae (4)- (7) can be brought to simpler forms:

\[
x_c = \frac{1}{3S} \sum_{i=1}^{n+1} S_i (x_i + x_{i+1}) \quad y_c = \frac{1}{3S} \sum_{i=1}^{n+1} S_i (y_i + y_{i+1}) \quad z_c = \frac{1}{3S} \sum_{i=1}^{n+1} S_i (z_i + z_{i+1})
\]

(13)

\[
J_x = \frac{m}{6S} \sum_{i=1}^{n+1} S_i (y_i + y_{i+1})^2 + z_i^2 + z_{i+1}^2 + y_{i+1}^2 + x_i^2 + x_{i+1}^2
\]

\[
J_y = \frac{m}{6S} \sum_{i=1}^{n+1} S_i (z_i + z_{i+1})^2 + x_i^2 + x_{i+1}^2 + z_i^2 + z_{i+1}^2 + x_{i+1}^2
\]

\[
J_z = \frac{m}{6S} \sum_{i=1}^{n+1} S_i (x_i + x_{i+1})^2 + y_i^2 + y_{i+1}^2 + x_i^2 + x_{i+1}^2 + y_{i+1}^2
\]

(14)

\[
J_{xy} = \frac{m}{12S} \sum_{i=1}^{n+1} S_i (2x_i y_i + 2x_{i+1} y_{i+1} + x_i y_{i+1} + x_{i+1} y_i)
\]

\[
J_{xz} = \frac{m}{12S} \sum_{i=1}^{n+1} S_i (2y_i z_i + 2y_{i+1} z_{i+1} + y_i z_{i+1} + y_{i+1} z_i)
\]

\[
J_{yz} = \frac{m}{12S} \sum_{i=1}^{n+1} S_i (2z_i x_i + 2z_{i+1} x_{i+1} + z_i x_{i+1} + z_{i+1} x_i)
\]

(15)
Case of a homogeneous plane polygon

The general relations determined above can be used for any homogeneous plane polygon, if the following geometrical condition is fulfilled: point $O$ can be chosen in any corner or in any point placed inside the polygon, so that no segment $OA_i$ ($i=1,2,...,n$) intersects any edge of the polygon:

$$OA_i \cap A_jA_{j+1} = \emptyset \quad (i=1,2,...,n, j=1,2,...,n-1)$$  \hspace{1cm} (16)

where the corners are consecutively counted.

In the case of plane polygons, all $z$-coordinates are null: $z=0$ ($i=1,2,...,n$). If such bodies present symmetries, calculations are simplified by choosing point $O$ on the symmetry element (point, axis or plane). The same reasoning is valid for the choice of axis $Ox$.

The triangle areas are:

$$S_i = \frac{1}{2} \left( y_{i+1} - y_i \right) \left( x_i - x_{i+1} \right)$$

The coordinates of the mass center have the following general expressions:

$$x_c = \frac{1}{3S} \sum_{i=1}^{n} S(x_i + x_{i+1}), \quad y_c = \frac{1}{3S} \sum_{i=1}^{n} S(y_i + y_{i+1}), \quad z_c = 0$$  \hspace{1cm} (18)

The moments and products of de inertia become:

$$J_x = \frac{m}{6S} \sum_{i=1}^{n} S \left( y_i^2 + y_iy_{i+1} + y_{i+1}^2 \right)$$

$$J_y = \frac{m}{6S} \sum_{i=1}^{n} S \left( x_i^2 + x_ix_{i+1} + x_{i+1}^2 \right)$$

$$J_z = \frac{m}{6S} \sum_{i=1}^{n} S \left( y_i^2 + y_iy_{i+1} + y_{i+1}^2 \right)$$

$$J_{xz} = \frac{m}{12S} \sum_{i=1}^{n} S \left( 2x_iy_i + 2x_iy_{i+1} + x_iy_{i+1}y_{i+1} + x_{i+1}y_i \right)$$

$$J_{yz} = 0$$

$$J_{zx} = 0$$

Application 1

Half of the cross-section of a symmetrical part of a mechanical device has the polygonal shape in Figure 2.

Cazul poligonului plan omogen

Relațiile generale determinate mai sus își găsesc o utilizare imediată pentru orice poligon plan omogen, dacă se respectă următoarea condiție geometrică: punctul $O$ poate fi ales în orice vârf sau în orice punct situat în interiorul unui poligonul, astfel încât nici un segment $OA_i$ ($i=1,2,...,n$) să nu intersecteze vreo muchie a poligonului:

unde vârfurile sunt numerotate consecutiv;

în cazul corpurilor plane, toate cotele sunt nule: $z=0$ ($i=1,2,...,n$). Dacă aceste corpuri prezintă simetrie, calculele se simplifică alegând punctul $O$ pe elementul de simetrie (punct, axă sau plan). Același raționament este valabil și pentru alegerea axei $Ox$.

Arile triunghiurilor sunt:

$$S_i = \frac{1}{2} \left( y_{i+1} - y_i \right) \left( x_i - x_{i+1} \right)$$

Coordonatele centrului de masă au următoarele expresii generale:

$$x_c = \frac{1}{3S} \sum_{i=1}^{n} S(x_i + x_{i+1}), \quad y_c = \frac{1}{3S} \sum_{i=1}^{n} S(y_i + y_{i+1}), \quad z_c = 0$$  \hspace{1cm} (18)

Momentele de inerție devin:

$$J_x = \frac{m}{6S} \sum_{i=1}^{n} S \left( y_i^2 + y_iy_{i+1} + y_{i+1}^2 \right)$$

$$J_y = \frac{m}{6S} \sum_{i=1}^{n} S \left( x_i^2 + x_ix_{i+1} + x_{i+1}^2 \right)$$

$$J_z = \frac{m}{6S} \sum_{i=1}^{n} S \left( y_i^2 + y_iy_{i+1} + y_{i+1}^2 \right)$$

$$J_{xz} = \frac{m}{12S} \sum_{i=1}^{n} S \left( 2x_iy_i + 2x_iy_{i+1} + x_iy_{i+1}y_{i+1} + x_{i+1}y_i \right)$$

$$J_{yz} = 0$$

$$J_{zx} = 0$$

Aplicația 1

Jumătate din secțiunea transversală a unei piese simetrice din componența unui dispozitiv mecanic are forma poligonală din figura 2.
The coordinates of corners $A_i$ are defined in Table 1.

<table>
<thead>
<tr>
<th>Punct</th>
<th>$A_1$</th>
<th>$A_2$</th>
<th>$A_3$</th>
<th>$A_4$</th>
<th>$A_5$</th>
<th>$A_6$</th>
<th>$A_7$</th>
<th>$A_8$</th>
<th>$A_9$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x_i$</td>
<td>4a</td>
<td>4a</td>
<td>3a</td>
<td>3a</td>
<td>2a</td>
<td>2a</td>
<td>a</td>
<td>a</td>
<td>0</td>
</tr>
<tr>
<td>$y_i$</td>
<td>0</td>
<td>2a</td>
<td>4a</td>
<td>6a</td>
<td>8a</td>
<td>10a</td>
<td>12a</td>
<td>14a</td>
<td>16a</td>
</tr>
</tbody>
</table>

Assuming that the plate is homogeneous, its inertia properties can be determined.

By applying relation (17), the areas result of the eight triangles composing the polygon:

$$S_1 = 4a^2, \quad S_2 = 5a^2, \quad S_3 = 3a^2, \quad S_4 = 6a^2, \quad S_5 = 2a^2, \quad S_6 = 7a^2, \quad S_7 = a^2, \quad S_8 = 8a^2$$

The area of the whole polygonal section is:

$$S = \sum S_i = 36a^2$$

After some elementary operations, the coordinates of the center of mass are obtained:

$$C(x_c = 1.426a, y_c = 6.556a)$$

The elements of the matrix of inertia can be also easily calculated:

$$J_x = 44.39ma^4, \quad J_y = 3.037ma^4, \quad J_z = 47.333ma^4$$

$$J_{x y} = 6.093ma^4, \quad J_{x z} = J_{y z} = 0$$

**Application 2**

Let $OA_1A_2A_3A_4A_5A_6$ be a homogeneous plate of mass $m$, part of the header of a corn-picker-husker, with the shape of a pyramid surface (fig. 3).

**Aplicația 2**

Fie placa omogenă de masă $m$, din componența unui heder al unei combine de recoltat porumb, care are forma unei suprafețe piramidale $OA_1A_2A_3A_4A_5A_6$ (fig. 3).

The orthogonal reference system with plane $Oxy$ situated in the plane of the plate $OA_1A_2$ is used, with axis $Ox$ in the symmetry plane of the body, perpendicular on the side $A_3A_6$.

The plate is divided into six triangles: $OA_1A_2, OA_2A_3, ..., OA_6A_7$.

The coordinates of the corners of the surface are: $(0, 0, 0), A_1(l, 0, 0), A_2(l, a, 0), A_3(l, a-b, c), A_4(l, 0, d), A_5(l, b-a, c), A_6(l, -a, 0)$ and $A_7=A_1(l, 0, 0)$.

Se utilizează sistemul de referință ortogonal, cu planul $Oxy$ situat în planul plăcii $OA_1A_2$, alegându-se axa $Ox$ în planul de simetrie al corpului, perpendiculară pe latura $A_3A_6$.

Placa se împarte în şase triunghiuri: $OA_1A_2, OA_2A_3, ..., OA_6A_7$.

Coordonatele vârfurilor suprafeței sunt: $(0, 0, 0), A_1(l, 0, 0), A_2(l, a, 0), A_3(l, a-b, c), A_4(l, 0, d), A_5(l, b-a, c), A_6(l, -a, 0)$ și $A_7=A_1(l, 0, 0)$. 
According to formula (10), the areas of the triangles composing the body are

\[ S_1 = S_2 = \frac{la}{2} \quad \text{and} \quad S_3 = \frac{\sqrt{2}a^2 + 2b^2c^2}{2} \]

By replacing the particular values of the studied body into relation (13), the following coordinates of the mass center are obtained:

\[ x_c = \frac{2f}{3}, \quad y_c = 0, \quad z_c = \frac{2}{3} \frac{cS_2 + (c + d)S_3}{\sum S_i} \]

Case of an arbitrary homogeneous quadrilateral

The homogeneous plate described by quadrilateral \( OA_1A_2A_3 \), situated in plane \( Oxy \), is considered (Fig. 4a). The plate is divided into triangles \( OA_1A_2 \) and \( OA_2A_3 \). The coordinates of the corners are known: \( O(0, 0, 0) \), \( A_1(x_1, y_1, 0) \), \( A_2(x_2, y_2, 0) \), \( A_3(x_3, y_3, 0) \).

The areas have the expressions

\[ S_1 = x_1y_2, \quad S_2 = x_2y_1 - x_1y_1, \quad S_3 = x_3y_2 - x_2y_2 \]

The superficial density is

\[ \rho_s = \frac{m}{S} \]

The masses of the two triangular plates are:

\[ m_1 = \rho_s S_1 = \frac{mx_1y_2}{x_1y_2 - x_1y_1}, \quad m_2 = \rho_s S_2 = \frac{mx_2y_1 - x_1y_2}{x_1y_2 - x_1y_1} \]

The coordinates of the mass centers of the two triangles can be easily calculated:

\[ C_1 \left( \frac{x_1 + x_1}{3}, \frac{y_2}{3} \right), \quad C_2 \left( \frac{x_2 + x_2}{3}, \frac{y_1 + y_1}{3} \right) \]

By taking into account the presented results, it can be concluded that an arbitrary quadrilateral may be reduced to a system of six material points, with the following masses (Fig. 4b):

\[ O \left( \frac{m}{12} \right), A_1 \left( \frac{m}{12} \right), A_2 \left( \frac{m}{12} \right), A_3 \left( \frac{m}{12} \right), A_1 \left( \frac{m}{12} \right), C_1 \left( \frac{3m}{4} \right), C_2 \left( \frac{3m}{4} \right) \]

Conform formulei (10), ariile triunghiurilor care compun corpul sunt:

\[ S_1 = S_2 = \frac{la}{2} \quad \text{și} \quad S_3 = \frac{\sqrt{2}a^2 + 2b^2c^2}{2} \]

Înlocuind valorile particulare ale corpului studiat în relațiile (13), se obțin următoarele coordonate ale centrului de masă:

\[ x_c = \frac{2f}{3}, \quad y_c = 0, \quad z_c = \frac{2}{3} \frac{cS_2 + (c + d)S_3}{\sum S_i} \]

Cazul patrulaterului omogen oarecare

Se consideră placa omogenă plană descrisă de patrulaterul \( OA_1A_2A_3 \), situată în planul \( Oxy \) (fig. 4a). Placa se împărte în triunghiurile \( OA_1A_2 \) și \( OA_2A_3 \). Sunt cunoscute coordonatele punctelor plăci: \( O(0, 0, 0) \), \( A_1(x_1, 0, 0) \), \( A_2(x_2, y_2, 0) \), \( A_3(x_3, y_3, 0) \).

The areas have the expressions

\[ S_1 = x_1y_2, \quad S_2 = x_2y_1 - x_1y_1, \quad S_3 = x_3y_2 - x_2y_2 \]

The superficial density is

\[ \rho_s = \frac{m}{S} \]

The masses of the two triangular plates are:

\[ m_1 = \rho_s S_1 = \frac{mx_1y_2}{x_1y_2 - x_1y_1}, \quad m_2 = \rho_s S_2 = \frac{mx_2y_1 - x_1y_2}{x_1y_2 - x_1y_1} \]

The coordinates of the mass centers of the two triangles can be easily calculated:

\[ C_1 \left( \frac{x_1 + x_2}{3}, \frac{y_2}{3} \right), \quad C_2 \left( \frac{x_2 + x_2}{3}, \frac{y_1 + y_1}{3} \right) \]

By taking into account the presented results, it can be concluded that an arbitrary quadrilateral may be reduced to a system of six material points, with the following masses (fig. 4b):

\[ O \left( \frac{m}{12} \right), A_1 \left( \frac{m}{12} \right), A_2 \left( \frac{m}{12} \right), A_3 \left( \frac{m}{12} \right), A_1 \left( \frac{m}{12} \right), C_1 \left( \frac{3m}{4} \right), C_2 \left( \frac{3m}{4} \right) \]
The coordinates of the mass center of the quadrilateral are:

\[
x_c = \frac{\sum x_i}{m}, \quad y_c = \frac{\sum y_i}{m},
\]

where \(m\) is the total mass of the quadrilateral, and \(x_i, y_i\) are the coordinates of the mass points.

The moments and products of inertia with respect to the chosen reference system take, respectively, the forms:

\[
J_x = \sum m_i y_i^2, \quad J_y = \sum m_i x_i^2, \quad J_{xy} = \sum m_i x_i y_i
\]

Moments of inertia in report with system of reference chosen, respectively, the forms:

\[
J_x = \sum m_i y_i^2 + m_2(y_2 + y_1), \quad J_y = \sum m_i x_i^2 + m_2(x_1 + x_2), \quad J_{xy} = \sum m_i x_i y_i
\]

Case of a right-angled trapezoid

A right-angled trapezoid is represented in Figure 5, corresponding to a homogeneous plate of mass \(m\), with the following geometrical characteristics: the large base \(B\), the small base \(b\) and the height \(h\).

The moments and products of inertia, determined by relations (6)- (7), have the following expressions:

\[
J_x = \frac{mh^3(B + 3b)}{6(B + b)}, \quad J_y = \frac{m(B^2 + b^2)}{6}, \quad J_{xy} = \frac{h^2(B + 3b) + B^2 + b^2}{6}
\]

moments of inertia in report with system of references chosen, respectively, the forms:

\[
J_x = \frac{h(B + 2b)}{3}, \quad J_{xy} = 0, \quad J_{xy} = 0
\]

According to relations (10) and (12), the masses of the two composing triangles are:

\[
m_1 = \frac{mB}{B + b}, \quad m_2 = \frac{mb}{B + b}
\]

By applying relations (3), the coordinates of the mass center can be calculated:

\[
x_c = \frac{B^2 + Bb + b^2}{3(B + b)}, \quad y_c = \frac{h(B + 2b)}{3(B + b)}
\]

Moments de inerție în raport cu sistemul de referință ales iau, respectiv, formele:

\[
J_x = \sum m_i y_i^2, \quad J_y = \sum m_i x_i^2, \quad J_{xy} = \sum m_i x_i y_i
\]

In conformitate cu relațiile (10) și (12), masele celor două triunghiuri componente sunt:

\[
m_1 = \frac{mB}{B + b}, \quad m_2 = \frac{mb}{B + b}
\]

Aplicând relațiile (3), se calculează coordonatele centrii de masă:

\[
x_c = \frac{B^2 + Bb + b^2}{3(B + b)}, \quad y_c = \frac{h(B + 2b)}{3(B + b)}
\]

În figura 5 este reprezentat trapezul dreptunghic corespunzător unei plăci omogene de masă \(m\), cu următoarele caracteristici geometrice: baza mare \(B\), baza mică \(b\) și înălțimea \(h\).
CONCLUSIONS
The presented method allows a fast calculation of the inertia characteristics of a plate with concurrent bending edges, as well as of a plane plate with polygonal shape and, in particular, of a quadrilateral one.
The method, which can be easily implemented in a computer code, represents a useful tool in machine and mechanical device design activity.
The two chosen applications certify for its benefits.

REFERENCES

CONCLUZII
Metoda prezentată permite calculul rapid al caracteristicilor inerţiale ale unei plăci cu muchii de îndoire concurrente, precum și al unor plăci plane de forme poligonale și, în particular, de formă patrulateră.
Metoda, care poate fi uşor implementată în programe de calcul automat, reprezintă un instrument valoros în activitatea de proiectare a maşinilor şi utilajelor mecanice. Cele două aplicaţii alese atestă avantajele sale.

BIBLIOGRAFIE
STUDY ON THE DEVELOPMENTAL EFFICIENCY EVALUATION OF RURAL INFORMATIZATION IN CHINA AND ITS INFLUENCE FACTOR ANALYSIS

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Abstract: Rural informatization is an inevitable requirement of agricultural development. In the paper a two-phase model with DEA-Tobit was adopted to analyze the developmental efficiency and the influencing factors of rural informatization in China during 2007-2010. The results showed that, on the whole, the overall developmental efficiency of rural informatization in the Middle and Northwest China was lower than that in other regions of China. In addition, the decisive influencing factors on developmental efficiency of rural informatization were resulted from the nation’s macro policy and the global construction of rural informatization projects. The level difference in regional economic development was the main reason for the variation in developmental efficiency. Moreover, the structure and level of consumption by rural residents was an important source that had affected the developmental efficiency. Furthermore, the age of rural population and the education level had a significant influence on the developmental efficiency of rural informatization.

Keywords: Rural Informatization; Developmental Efficiency; DEA; Tobit Model

INTRODUCTION

With the development of information technology and the advance of agricultural globalization, governments all over the world have attached great importance to the development of rural informatization. Since the 21st century, rural informatization has been a continual concern by Chinese central government in its No. 1 Document. Rural informatization has been comprehensively organized, promoted and implemented by the central government and institutional sectors at all levels, therefore great progress has been made in rural informatization. However, constrained by various factors such as lack of technical equipment, funding and human resources, the rural informatization in China is still less developed compared with other countries in the world (see Table 1). What is the status quo of rural informatization? What factors influence the development of rural informatization? Study and answer of these two questions will contribute to a reasonable resource allocation, the structural optimization of construction and improvements to management strategy when further studying the development of rural informatization.

<table>
<thead>
<tr>
<th>Characteristic and current status of rural informatization in 5 countries all over the world (2013)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Country</strong></td>
</tr>
<tr>
<td>United States</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>France</td>
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</tr>
</tbody>
</table>

Table 1
To date, studies on rural informatization of China can be grouped into the following aspects: 1) theoretical studies of strategies and suggestions for rural informatization development, which includes the improvement of the policy system for rural informatization development (Yang Cheng, 2009)[13] and the market development strategies for rural informatization products (Ma Mingyuan et al., 2009)[9]; 2) comparative studies of rural informatization in China and abroad about domestic and overseas experiences and lessons in rural informatization development, and the advantages in Chinese rural informatization process (He Hongming et al., 2011)[2]; 3) detailed technical frameworks and schemes, in which the platform construction of rural informatization is discussed (Zhou Wei, 2011)[14]. This part emphasizes on technology although literature for reference is lacking; and 4) evaluative studies on rural informatization construction. As rural informatization construction has further deepened, literature in this area has also increased; however, most studies are restricted to the evaluation index system of rural informatization and comparison among different levels of informatization in different regions on the basis of the evaluation index system(Zhou yuefeng, et al., 2011)[15]. It is noteworthy that only a small number of studies analyzed influencing factors in rural informatization. The specific methods employed in these studies include regression analysis (Liu Chunhuan et al., 2006)[6], grey relational analysis (Wang Shuangying, 2008)[12], and factor analysis (Zhao Hui et al., 2010)[16]. Other studies in this area have characterized rural informatization as a social economic phenomenon and discussed the relationship between rural informatization and other social phenomena, e.g., the relationship between rural informatization and rural income (Zeng Shuxun et al., 2010)[17], the relationship between rural informatization and economic development (Huang Zhiven)[5], and the effects of rural informatization on improving farmers livelihoods(Zhang Li et al., 2011)[18].

The paper belongs to the fourth aspect above. Through analysis of the existing literature, it can be found that the method of subjective model analysis is applied to most current studies and the selection of model indexes and the determination of index weights differ largely from each other. Therefore the result of previous studies lacks reliability and is less convincing. In this study, the widely used two-phase analysis method is adopted in related studies. In Phase I, the output-oriented CCR Model from DEA (Data Envelopment Analysis) method is used in order to measure the overall efficiency of rural informatization; in Phase II, Tobit regression model is used in order to empirically test the influencing factors of developmental efficiency of rural informatization and to carry out a systematic analysis.

<table>
<thead>
<tr>
<th>Country</th>
<th>Infrastructure of informatization</th>
<th>Environment of informatization</th>
<th>Stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>India</td>
<td>Imperfect infrastructure Low popularizing rate of telephone and computer Telephones per 100 farmers:39.29 Wireless users: 345.85 million farmers Inadequate infrastructure</td>
<td>Developing the application of agricultural information service Public-private partnerships Priority to the development strategy of Rural informatization Extra subsidy</td>
<td>Developing</td>
</tr>
<tr>
<td>China</td>
<td>Fixed telephones per 100 farmers:42.2 Computers per 100 farmers: 21.4</td>
<td>Government-led investment Rural informatization and to carry out a systematic analysis</td>
<td>Developing</td>
</tr>
</tbody>
</table>


Note: According to present research achievements [4-6], the indexes system for the measurement of rural informatization level consists of six categories of the resources, infrastructure, technology application, industry, human resource and external environment of rural informatization. In Table 1, this paper chooses three indicators of infrastructure, technology application and external environment to analyze and compare characteristic and current status of rural informatization in 5 countries all over the world.

China and abroad about domestic and overseas experiences and lessons in rural informatization development, and the advantages in Chinese rural informatization process (He Hongming et al., 2011)[2]; 3) detailed technical frameworks and schemes, in which the platform construction of rural informatization is discussed (Zhou Wei, 2011)[14]. This part emphasizes on technology although literature for reference is lacking; and 4) evaluative studies on rural informatization construction. As rural informatization construction has further deepened, literature in this area has also increased; however, most studies are restricted to the evaluation index system of rural informatization and comparison among different levels of informatization in different regions on the basis of the evaluation index system(Zhou yuefeng, et al., 2011)[15]. It is noteworthy that only a small number of studies analyzed influencing factors in rural informatization. The specific methods employed in these studies include regression analysis (Liu Chunhuan et al., 2006)[6], grey relational analysis (Wang Shuangying, 2008)[12], and factor analysis (Zhao Hui et al., 2010)[16]. Other studies in this area have characterized rural informatization as a social economic phenomenon and discussed the relationship between rural informatization and other social phenomena, e.g., the relationship between rural informatization and rural income (Zeng Shuxun et al., 2010)[17], the relationship between rural informatization and economic development (Huang Zhiven)[5], and the effects of rural informatization on improving farmers livelihoods(Zhang Li et al., 2011)[18].

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Currently, there are two major perspectives on the relationship between rural informatization and economic development: one is that rural informatization can improve farmers’ income (Zeng Shuoxun et al., 2010), and the other is that rural informatization has an impact on economic development (Zhang Li et al., 2011). This paper belongs to the fourth aspect above. Through analysis of the existing literature, it can be found that the method of subjective model analysis is applied to most current studies and the selection of model indexes and the determination of index weights differ largely from each other. Therefore the result of previous studies lacks reliability and is less convincing. In this study, the widely used two-phase analysis method is adopted in related studies. In Phase I, the output-oriented CCR Model from DEA (Data Envelopment Analysis) method is used in order to measure the overall efficiency of rural informatization; in Phase II, Tobit regression model is used in order to empirically test the influencing factors of developmental efficiency of rural informatization and to carry out a systematic analysis.
METHODS AND MATERIALS

Research methods and index data

The DEA method is a nonparametric evaluating method that uses a mathematical programming model to measure the relative efficiency of DMUs (Decision Making Units) in multi-input and multi-output situations. By observing numerous and practical production data, we construct a relatively effective frontier efficiency surface, and then calculate efficiency level of the preset DMU relative to the efficiency level on the efficiency surface, i.e., the preset DMU's relative efficiency value. As a nonparametric method, the DEA method neither needs specific production function specifying its input and output, nor considering the efficiency of parameter estimation and reasonable inspection. This method has an advantage when evaluating the efficiency of DEA in complicated productive relations. Moreover, in the DEA model, the input and output variables' weights are produced by mathematical programming precisely according to practical data, the result of which cannot be affected by human factors. Therefore, the DEA method is often applied to studies of developmental efficiency of rural informatization, and furthermore it has advantages over most current methods.

By analyzing slack variables of input and output, the DEA method could determine the degree of the effect of the input and output factors on its efficiency and improvement approaches. However, with regard to factors that are not appropriate as input and output indexes, but that have objectively affected DMU efficiency, the DEA method could not directly analyze the effects of these factors on efficiency. Therefore, on the basis of the DEA method, a two-phase method is developed. In Phase I, the relative efficiency value of DMU is calculated by the DEA model. In Phase II a regression model is constructed to analyze data with the efficiency value obtained in Phase I as an explained variable. Due to the fact that the efficiency value calculated by the usual DEA method is between 0 and 1 (maximum 1), the explained variable of the regression equation in Phase II is restricted to this interval. Since it has a censored feature, Tobit regression model is usually selected.

The DEA-Tobit two-phase method is a mature approach when analyzing efficiency and influencing factors. But it is not applied in studies of Chinese rural informatization. So in this paper, the method is employed to study Chinese rural informatization development so as to improve current methods and compensate for present deficiencies. According to the DEA-Tobit two-phase requirement, corresponding indexes are selected for different phases. Rural informatization could be regarded as a productive system, in which the investment in certain production resources should lead to corresponding economic and social output. Therefore, in the analysis phase of DEA, output and input indexes are usually selected. With present research achievements and informatization development index of the International Telecommunication Union as references, DEA indexes for this study are selected. See Table 2.

Table 2

<table>
<thead>
<tr>
<th>Index Category</th>
<th>Index Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Index</td>
<td>Consumption levels of rural residents in different regions</td>
</tr>
<tr>
<td></td>
<td>Average living consumption of a rural family (transportation, communication, cultural and educational entertainment products and services) in different regions</td>
</tr>
<tr>
<td></td>
<td>Employment numbers in telecommunication industry and other service industries of information transmission</td>
</tr>
<tr>
<td></td>
<td>Expenditure on education, culture, media and finance in different regions</td>
</tr>
</tbody>
</table>
In Tobit analysis, economic and social factors that affect developmental efficiency of rural informatization are of great concern. The World Bank has reported that the development of Chinese rural informatization mainly depends on the construction of informatization projects conducted and participated in by government and telecommunication enterprises. Thus, the paper put forward the following assumptions. The first is the assumption that various overall construction projects are important influencing factors in determining developmental efficiency of rural informatization. As there are no fundamental differences between these construction projects in different regions, they can be grouped as a comprehensive influencing factor, which is represented by a constant term in Tobit Model. The second is the assumption that the difference in developmental efficiency in different regions is mainly affected by rural informatization consumption and regional levels in economic development.

Specific indexes and descriptions of corresponding theoretical assumption are shown in Table 3.

Table 3

<table>
<thead>
<tr>
<th>Index Category</th>
<th>Index Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output Index</td>
<td>Total investment in fixed assets of information transmission, computer services and software industry in different regions</td>
</tr>
<tr>
<td>Output Index</td>
<td>Average number of televisions by every 100 rural households in different regions</td>
</tr>
<tr>
<td>Output Index</td>
<td>Average number of home computers by every 100 rural households in different regions</td>
</tr>
<tr>
<td>Output Index</td>
<td>Average number of telephones by every 100 rural households in different regions</td>
</tr>
</tbody>
</table>

According to the assumptions above, an empirical Tobit regression model is established as follows:

$$ Y_{it} = \beta_0 + \beta_1 DR_{it} + \beta_2 EDU_{it} + \beta_3 \ln(CE_{it}) + \beta_4 EP_{it} + \beta_5 VA_{it} + \varepsilon_{it} $$

(1)

In this model, $t$ represents Year; $i$ represents DMU; $Y_{it}$, the overall relative efficiency value of different regions and years in Phase I; $DR_{it}$, the total dependency proportion of rural population; $EDU_{it}$, the Proportion of education level; $CE_{it}$, final consumption expenditure; $EP_{it}$, proportion of primary industry employment in all employment; $VA_{it}$, proportion of primary industry’s employment in all employments; $\beta_1$ to $\beta_5$ are regression coefficients of corresponding explanatory variables; $\beta_0$, a constant term; $\varepsilon_{it}$, a residual term. A logarithmic transformation of rural residents’ final consumption expenditure index data is conducted to facilitate the explanation of model measurement results and to ensure a good fit.

In the Tobit analysis stage, research focuses on which economic and social factors influence the developmental efficiency of rural informatization. According to the World Bank’s research reports, the development of Chinese rural informatization mainly depends on the construction and participation of informatization projects by government and telecommunication enterprises. Therefore, the paper proposed the following assumptions. The first is the assumption that various overall construction projects are important influencing factors in determining developmental efficiency of rural informatization. Since these construction projects do not fundamentally differ between regions, they can be grouped as a comprehensive influencing factor, represented by a constant term in the Tobit Model. The second is the assumption that the difference in developmental efficiency between regions is primarily affected by rural informatization consumption and regional levels in economic development. Specific indexes and corresponding theoretical assumptions are shown in Table 3.
The study is based on public data, all of which have been collected from China Statistical Yearbook, China Rural Statistical Yearbook, China City Statistical Yearbook, China Population and Employment Statistical Yearbook and China Information Yearbook. Part of the data is from province and city statistical yearbooks and the survey report of rural internet development from China Internet Network Information Center.

RESULTS, ANALYSIS AND DISCUSSIONS

Empirical analysis

1) DEA analysis: study of the overall efficiency of rural informatization development

In this paper, the provincial administrative region is taken as the DMU of DEA analysis. Due to the restriction of data availability and integrity, Tibet, Taiwan, Hong Kong and Macao are not included.

Different DEA models can measure and decompose different relative efficiencies. However, this paper only involves the overall relative efficiency of rural informatization development, which can be obtained by CCR model. For now, the development strategy of urban-rural integration has been determined, but there are still big differences between rural and urban informatization both now and in the future. So the key to studies of rural informatization development is to improve output ability as much as possible under the constraints of fixed resources or in the situation of maintaining the present input level and environment; thus an output-oriented model is adopted.

Table 4

The overall developmental efficiencies of China rural informatization in different regions during 2007-2010

<table>
<thead>
<tr>
<th>DMU</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beijing</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Tianjin</td>
<td>1</td>
<td>1</td>
<td>0.9610</td>
<td>0.9676</td>
</tr>
<tr>
<td>Hebei</td>
<td>0.8270</td>
<td>0.8852</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Shanghai</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Jiangsu</td>
<td>0.9436</td>
<td>0.6522</td>
<td>0.6062</td>
<td>0.5976</td>
</tr>
<tr>
<td>Zhejiang</td>
<td>0.8850</td>
<td>0.9631</td>
<td>1</td>
<td>0.9752</td>
</tr>
<tr>
<td>Fujian</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Shandong</td>
<td>0.7364</td>
<td>0.7435</td>
<td>0.7905</td>
<td>0.9198</td>
</tr>
<tr>
<td>Guangdong</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Hainan</td>
<td>1</td>
<td>0.9375</td>
<td>0.9272</td>
<td>0.9502</td>
</tr>
<tr>
<td>Average value</td>
<td>0.9392</td>
<td>0.9181</td>
<td>0.9285</td>
<td>0.9410</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>0.0396</td>
<td>0.1239</td>
<td>0.1311</td>
<td>0.1237</td>
</tr>
</tbody>
</table>

East

<table>
<thead>
<tr>
<th>DMU</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inner Mongolia</td>
<td>0.6541</td>
<td>0.6515</td>
<td>0.6290</td>
<td>0.6344</td>
</tr>
<tr>
<td>Guangxi</td>
<td>1</td>
<td>0.9805</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Chongqing</td>
<td>1</td>
<td>0.9128</td>
<td>0.8835</td>
<td>0.9482</td>
</tr>
<tr>
<td>Sichuan</td>
<td>1</td>
<td>1</td>
<td>0.9133</td>
<td>0.8689</td>
</tr>
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<td>Guizhou</td>
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<td>1</td>
<td>1</td>
<td>0.9875</td>
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<tr>
<td>Yunnan</td>
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<tr>
<td>Shaanxi</td>
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<td>Xinjiang</td>
<td>0.8835</td>
<td>0.8614</td>
<td>0.8641</td>
<td>0.8301</td>
</tr>
<tr>
<td>Average value</td>
<td>0.9402</td>
<td>0.9349</td>
<td>0.9187</td>
<td>0.9155</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>0.1149</td>
<td>0.1082</td>
<td>0.1176</td>
<td>0.1168</td>
</tr>
</tbody>
</table>

West

<table>
<thead>
<tr>
<th>DMU</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liaoning</td>
<td>0.7823</td>
<td>0.7427</td>
<td>0.6883</td>
<td>0.7131</td>
</tr>
<tr>
<td>Jilin</td>
<td>0.8895</td>
<td>0.8453</td>
<td>0.7861</td>
<td>0.7835</td>
</tr>
<tr>
<td>Heilongjiang</td>
<td>0.9040</td>
<td>0.8409</td>
<td>0.8520</td>
<td>0.9169</td>
</tr>
<tr>
<td>Average value</td>
<td>0.8586</td>
<td>0.8096</td>
<td>0.7755</td>
<td>0.8045</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>0.0665</td>
<td>0.0580</td>
<td>0.0824</td>
<td>0.1035</td>
</tr>
</tbody>
</table>

Middle

<table>
<thead>
<tr>
<th>DMU</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shanxi</td>
<td>0.8888</td>
<td>0.8797</td>
<td>0.8943</td>
<td>0.8424</td>
</tr>
<tr>
<td>Anhui</td>
<td>0.9373</td>
<td>0.9235</td>
<td>0.8396</td>
<td>0.8818</td>
</tr>
<tr>
<td>Jiangxi</td>
<td>0.9089</td>
<td>0.8321</td>
<td>0.9136</td>
<td>0.8934</td>
</tr>
<tr>
<td>Henan</td>
<td>0.9205</td>
<td>0.8938</td>
<td>0.8903</td>
<td>0.8905</td>
</tr>
<tr>
<td>Hubei</td>
<td>0.8692</td>
<td>0.8569</td>
<td>0.9142</td>
<td>0.9544</td>
</tr>
<tr>
<td>Hunan</td>
<td>0.7051</td>
<td>0.7062</td>
<td>0.7221</td>
<td>0.7363</td>
</tr>
<tr>
<td>Average value</td>
<td>0.8716</td>
<td>0.8487</td>
<td>0.8624</td>
<td>0.8665</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>0.0850</td>
<td>0.0765</td>
<td>0.0739</td>
<td>0.0732</td>
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</table>

It can be seen in DEA analysis that developmental efficiencies of rural informatization in the middle and northeast regions are lower than that of the east and west regions. Observation of standard deviations of the developmental efficiency in different provinces and cities also finds that rural informatization of provinces and cities.

DEA分析发现，中部和东北地区的农村信息化发展效率低于东部和西部地区。观察各区域内不同省区市之间的发有效率的标准差，又可以发现中部和东北地区各省区市农村
in the middle regions is close to that of the northeast regions, and its difference is lower than that of provinces and cities in the east and west regions.

The Kruskal-Wallis Regional Difference Test is conducted to learn China’s developmental efficiency of rural informatization in different regions. However, the data need to be regrouped to avoid a distortion of results due to insufficient sample sizes of a group. China has successively developed and strengthened its macro development strategies in different regions, e.g., East Open, West Development, Northeast Promote and Rising of Central China. The strategies and corresponding preferential policies, project construction as well as domestic and foreign investment promotion are the main reasons for social and economic development in different regions. Since 2005, divisions of Chinese economic regions in national statistics have been consistent with the divisions determined by the above strategies. In view of the actual influence of regional development strategies and the economic development levels in other provinces and cities, this paper incorporates the northeast region into the middle; and then conducts a difference test according to trichotomy of dividing the country to the east, the middle and the west.

An investigation of regional differences in Chinese developmental efficiency of rural informatization

<table>
<thead>
<tr>
<th>Regional comparison</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>East-Middle</td>
<td>3.962(0.0465)**</td>
<td>4.947(0.0261)**</td>
<td>6.190(0.0128)**</td>
<td>7.844(0.0051)***</td>
</tr>
<tr>
<td>East-West</td>
<td>0.113(0.7372)</td>
<td>0.023(0.8791)</td>
<td>0.097(0.7549)</td>
<td>0.436(0.5093)</td>
</tr>
<tr>
<td>Middle-West</td>
<td>4.659(0.0309)**</td>
<td>6.653(0.0099)***</td>
<td>3.558(0.0592)*</td>
<td>2.944(0.0862)*</td>
</tr>
<tr>
<td>East-Middle-West</td>
<td>6.100(0.0474)**</td>
<td>7.920(0.0191)**</td>
<td>6.667(0.0357)**</td>
<td>7.373(0.0251)**</td>
</tr>
</tbody>
</table>

Notes: *, ** and *** represent 10%, 5%, and 1% significance levels of statistics respectively; the number in brackets is the p value.

At the national level, the investigation shows that differences are significant at the 5% level regarding the three regions’ developmental efficiency of rural informatization. Further studies of differences show that there are significant differences between the west and the middle, the east and the middle regarding their developmental efficiencies. It can’t be denied that there is no significant difference between the developmental efficiency of the east and west regions. In light of the relative average efficiency value of different regional development (Table 5), it is clear that the phenomenon of “central China subsidence” still exists in rural informatization development in 2007-2010.

在全国意义上，检验证明三个区域农村信息化发展效率的差异性在5%水平上是显著的。继续进行两两差异性检验，结果发现，西部和中部，东部和中部发展效率都存在显著差异，东部和西部之间的发展效率，都不能拒绝二者无显著差异的假设。联系表 5 中不同区域发展相对效率均值的大小，可以发现，2007-2010 年期间，“中部塌陷”现象在农村信息化发展中也同样有所表现。
2) Tobit regression analysis: The influencing factor analysis of developmental efficiency of rural informatization

This paper uses stata12.0 to carry out regression analysis and estimation.

Figure 1 depicts the distribution and discrete option of developmental efficiency of rural informatization. We can see the censoring in the data, because the efficiency values are bounded to the interval \([0, 1]\). In the right of discrete option, the spike is the frequencies for cases where efficiency=1. The relationship between developmental efficiency with explanatory variables is shown in Figure 2. The total dependency proportion of rural population seems to present a positive correlation with efficiency and other variables present a negative correlation.

Two indexes, i.e., the proportion of primary industry’s employment in all employments and proportion of primary industry’s total output value in regional total output value are similar indexes that reflect development level of economy. Although they can be used as explanatory variables for now, these two indexes cannot pass a multi-co-linearity examination. Therefore a different model is used for analysis. Regression results are shown in Models 1 and 2. Table 6. Model 3 is the regression results of the effects of rural informatization consumption factors on its developmental efficiency.

<table>
<thead>
<tr>
<th>Explaining variable</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total dependency proportion of rural population</td>
<td>1.358***</td>
<td>1.252***</td>
<td>1.002***</td>
</tr>
<tr>
<td></td>
<td>(0.263)</td>
<td>(0.243)</td>
<td>(0.235)</td>
</tr>
<tr>
<td>Proportion of education level (Junior high school and below)</td>
<td>-0.950***</td>
<td>-0.638**</td>
<td>-1.152***</td>
</tr>
<tr>
<td></td>
<td>(0.281)</td>
<td>(0.313)</td>
<td>(0.278)</td>
</tr>
<tr>
<td>Final consumption expenditure of the rural residents</td>
<td>-0.0873***</td>
<td>-0.0860***</td>
<td>-0.0840***</td>
</tr>
<tr>
<td></td>
<td>(0.0170)</td>
<td>(0.0166)</td>
<td>(0.0168)</td>
</tr>
<tr>
<td>Proportion of the employed in primary industry</td>
<td>-0.432***</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.145)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total output value of the primary industry</td>
<td>-0.884***</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.296)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant term</td>
<td>1.927***</td>
<td>1.759***</td>
<td>2.095***</td>
</tr>
<tr>
<td></td>
<td>(0.261)</td>
<td>(0.270)</td>
<td>(0.257)</td>
</tr>
<tr>
<td>Sigma</td>
<td>0.129***</td>
<td>0.127***</td>
<td>0.133***</td>
</tr>
</tbody>
</table>

Fig. 2 - The relationship between pairs of the six variables
In this paper, the proposed theoretical assumptions that the rural population age structure, education level of rural households, consumption ability and development level of economy are related to developmental efficiency of rural informatization are strongly supported by regression results and mainly stay at the 1% level which is statistically significant. The total dependency proportion of rural population and constant term present a positive correlation with developmental efficiency of rural informatization, whereas proportion of education level (Junior high school and below), final consumption expenditure of rural residents and proportion of the employed in the primary industry present a negative correlation with the total output value of the primary industry.

When comparing Models 1 and 2, it is found that as two indexes to measure regional economic development level, the proportion of the employed in the primary industry leads to less loss that affects developmental efficiency of rural informatization than that of the total output value of the primary industry. Moreover, the overall variation degree is much smaller whilst its reliability as an explanatory factor is bigger.

### Table 1

<table>
<thead>
<tr>
<th>Explaining variable</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>VIF average value</td>
<td>(0.0113)</td>
<td>(0.0112)</td>
<td>(0.0117)</td>
</tr>
<tr>
<td>Log likelihood</td>
<td>1.68</td>
<td>1.96</td>
<td>1.46</td>
</tr>
<tr>
<td>LR chi2</td>
<td>18.63</td>
<td>18.47</td>
<td>14.14</td>
</tr>
<tr>
<td>Prob &gt; chi2</td>
<td>52.52</td>
<td>52.19</td>
<td>43.53</td>
</tr>
<tr>
<td>Pseudo R-squared</td>
<td>1.08e-10</td>
<td>1.26e-10</td>
<td>1.90e-09</td>
</tr>
</tbody>
</table>

**Notes:** *, ** and *** represent 10%, 5% and 1% significance levels of statistics respectively; the number in brackets is the standard deviation.

![Figure 3](image1.png)  
**Fig.3** - The relationship between pairs of the efficiency and the structure of population age

![Figure 4](image2.png)  
**Fig.4** - The relationship between pairs of the efficiency and the structure of education level
From Figure 3 and 4, we can see the different structure of population age seems to have influence on developmental efficiency, the same as the structure of education level. Thus, based on the regression analysis in Table 6, and in order to further study the effects of consumption on developmental efficiency of rural informatization, a further regression analysis is carried out which decomposes the total dependency proportion of rural population and education level indexes. The results are shown in Tables 7 and 8 respectively.

<table>
<thead>
<tr>
<th>Explaining variable</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
<th>Model 5</th>
<th>Model 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion of the employed in primary industry</td>
<td>-1.67*** (0.028)</td>
<td>-1.67*** (0.028)</td>
<td>-1.67*** (0.028)</td>
<td>-1.67*** (0.028)</td>
<td>-1.67*** (0.028)</td>
<td>-1.67*** (0.028)</td>
</tr>
<tr>
<td>Population proportion from 0-14 years old</td>
<td>1.77*** (0.367)</td>
<td>1.77*** (0.367)</td>
<td>1.77*** (0.367)</td>
<td>1.77*** (0.367)</td>
<td>1.77*** (0.367)</td>
<td>1.77*** (0.367)</td>
</tr>
<tr>
<td>Population proportion of 15-64 years old</td>
<td>-0.57** (0.045)</td>
<td>-0.57** (0.045)</td>
<td>-0.57** (0.045)</td>
<td>-0.57** (0.045)</td>
<td>-0.57** (0.045)</td>
<td>-0.57** (0.045)</td>
</tr>
<tr>
<td>Population proportion of 65 years old and above</td>
<td>-0.015 (0.038)</td>
<td>-0.015 (0.038)</td>
<td>-0.015 (0.038)</td>
<td>-0.015 (0.038)</td>
<td>-0.015 (0.038)</td>
<td>-0.015 (0.038)</td>
</tr>
<tr>
<td>Constant term</td>
<td>1.34*** (0.016)</td>
<td>1.34*** (0.016)</td>
<td>1.34*** (0.016)</td>
<td>1.34*** (0.016)</td>
<td>1.34*** (0.016)</td>
<td>1.34*** (0.016)</td>
</tr>
<tr>
<td>Sigma</td>
<td>0.13*** (0.0114)</td>
<td>0.13*** (0.0114)</td>
<td>0.13*** (0.0114)</td>
<td>0.13*** (0.0114)</td>
<td>0.13*** (0.0114)</td>
<td>0.13*** (0.0114)</td>
</tr>
<tr>
<td>Prob &gt; chi2</td>
<td>1.73e-10</td>
<td>1.73e-10</td>
<td>1.73e-10</td>
<td>1.73e-10</td>
<td>1.73e-10</td>
<td>1.73e-10</td>
</tr>
<tr>
<td>Pseudo R-squared</td>
<td>3.175</td>
<td>3.175</td>
<td>3.175</td>
<td>3.175</td>
<td>3.175</td>
<td>3.175</td>
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</tbody>
</table>

Notes: *, ** and *** represent 10%, 5% and 1% significance levels of statistics respectively; the number in brackets is the standard deviation.
Table 8

<table>
<thead>
<tr>
<th>Explaining variable</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
<th>Model 5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proportion of population independency</td>
<td>0.267 (0.268)</td>
<td>0.826*** (0.247)</td>
<td>0.285 (0.243)</td>
<td>0.891*** (0.230)</td>
<td>1.036*** (0.248)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final consumption expenditure of rural residents</td>
<td>-0.0705*** (0.0188)</td>
<td>-0.0855*** (0.0175)</td>
<td>-0.0684*** (0.0186)</td>
<td>-0.0858*** (0.0169)</td>
<td>-0.0759*** (0.0172)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proportion of education level</td>
<td>0.621 (0.439)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Illiterate or semi-literate)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Proportion of education level</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Primary school)</td>
<td>-0.562* (0.215)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proportion of education level</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Junior high school)</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proportion of education level</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Senior high school and vocational school)</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Proportion of education level</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Junior college and above)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant term</td>
<td>1.277*** (0.137)</td>
<td>1.349*** (0.136)</td>
<td>1.522*** (0.191)</td>
<td>0.992*** (0.143)</td>
<td>0.993*** (0.142)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>sigma</td>
<td>0.144*** (0.0128)</td>
<td>0.139*** (0.0123)</td>
<td>0.144*** (0.0128)</td>
<td>0.135*** (0.0119)</td>
<td>0.136*** (0.0119)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VIF average value</td>
<td>1.49</td>
<td>1.43</td>
<td>1.32</td>
<td>1.41</td>
<td>1.42</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Log likelihood</td>
<td>5.307</td>
<td>7.626</td>
<td>6.099</td>
<td>12.09</td>
<td>13.37</td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LR chi2</td>
<td>25.86</td>
<td>30.50</td>
<td>27.45</td>
<td>39.43</td>
<td>41.98</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prob &gt; chi2</td>
<td>1.02e-05</td>
<td>1.08e-06</td>
<td>4.75e-06</td>
<td>1.41e-08</td>
<td>4.05e-09</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pseudo R-squared</td>
<td>1.696</td>
<td>2.000</td>
<td>1.800</td>
<td>2.586</td>
<td>2.753</td>
</tr>
</tbody>
</table>

Notes: * *, ** and *** represent 10%, 5% and 1% significance levels of statistics respectively; the number in brackets is the standard deviation.

Likewise, the regression results in Table 8 and those in Table 6 and 7 can verify each other. The results of the final consumption expenditure of rural residents and the constant term are highly consistent with each other. The regression results of different education levels show that, apart from the statistic non-significance at the illiterate and semi-literate education levels, education levels at 5% and 10% significance levels in primary schools and junior high schools retain a negative correlation with developmental efficiency of rural informatization. Senior high school, vocational school, junior college and above at the 1% significance level retains a positive correlation.

In the analysis of Tobit regression results, it can be seen that in all models the constant term passed the statistically significant verification at the 1% significance level. Further comparison of regression coefficients in various models shows that the constant term has the greatest influence on developmental efficiency of rural informatization. According to the theoretical assumptions above, the regression results show that with the macro policies aimed at strengthening agriculture and benefiting farmers during 2007-2010, various overall rural informatization development projects focused in infrastructure construction have been the main influencing factors in improving the overall developmental efficiency of rural informatization. About the development modes of China's rural informatization, the World Bank research report (2009) holds that the mode dominated by the Chinese central government has obvious and...
Urbanization and industrialization would lead to inevitable loss of social and economic resources in rural areas. Although the present policies and measures set by non-market systems compensate for resource loss, the overall efficiency loss of resource allocation is inevitable. Research shows that the level of regional economic development presents a significantly negative correlation with the overall developmental efficiency of rural informatization. Since Chinese urbanization is generally lagging behind industrialization, the extent of influence that regional urbanization and industrialization have on the overall developmental efficiency of rural informatization also differs. The regression results show that relatively hysteretic urbanization avoids the rapid decline in rural population, thus stabilizing the number of consumption population of rural informatization. Under the condition of a vigorous national construction of infrastructure projects related to rural informatization, a quantitative balance between consumption and production could alleviate to a certain extent the negative effects by rural social and economic resource loss.

The rural residents’ final consumption expenditure has a significantly negative correlation with developmental efficiency of rural informatization. During 2007-2010, the rural per capita net income and per capita annual living expenditure have increased by 12.69% and 10.79% respectively. About the expenditure constitution, consumption is inclined to be more material-oriented than spirit-oriented. Material consumption, represented by housing and household facilities, keeps increasing in absolute amount and in the proportion of all consumption. However, spiritual consumption, represented by cultural, educational and entertainment products and services, accounts for a smaller proportion of expenditure, and this trend continues to decrease. This indicates that the consumption structure of a Chinese rural resident is still at a low stage and is characterized by meeting basic needs, with food and shelter accounting for the most shares. In addition the infrastructure construction for rural informatization is still weak with insufficient basic services. Rural residents lack knowledge and skills of how to apply informatization. Inappropriate ideas and understanding, the unchanged traditional consumption structure, consumption custom and consumption mode all lead to insufficient informatization consumption.

The rural population structure correlates with the overall efficiency of informatization development. From the perspective of the population age structure, a large rural population outflow for work in urban areas aggravates the issues of the left-behind children and population aging. However, the demand of migrant workers contacting their hometown increases the demand of rural informatization consumption, which is a reasonable explanation for the regression results. From the perspective of the education level, the higher the education level is, the more it contributes to the developmental efficiency of rural informatization. The proportions of education levels at senior high school, vocational school and above are important factors of improving efficiency. Based on the common understanding that education level not only affects income but also influences consumption expenditure and structure, this paper assumes that a higher education level contributes to improving informatization consumption level and optimizing consumption structure appropriately, thus can improve the overall developmental efficiency of rural informatization.
CONCLUSIONS

Evaluation on the developmental efficiency of rural informatization is of great importance for improving the overall informatization level and optimizing the informatization input structure. In this paper, a CCR model of DEA is used to measure the developmental efficiency of Chinese rural informatization during 2007-2010. The results show that the developmental efficiencies in the middle and northeast regions are lower than those in the east and west regions. The Kruskal-Wallis difference investigation also indicates that there are significant differences of developmental efficiency between the east and west regions, and between the east and middle regions. The phenomenon of “central China subsidence” is clearly manifested in rural informatization. A Tobit analysis shows that the construction projects of rural informatization are the main influencing factor improving the overall developmental efficiency. Both the developmental level of regional economy and the final expenditure output of rural residents have negative correlation with the developmental efficiency of rural informatization. The structure of population age, the structure of education level and the overall developmental efficiency of informatization are all correlated with one another.

With regard to the strategies that could improve the developmental efficiency of rural informatization, one is to increase the overall construction of rural informatization infrastructure; the other is to supplement local projects according to different development levels in various regions. The construction of rural informatization conducted by the central government is the main reason for the great achievements in a short period. However, rural informatization is a complicated and comprehensive social project, and construction of infrastructure like information facilities and information services, is just one part of it. Therefore, a long-term development should be based on a sound market for rural informatization. Thus, to guarantee a healthy development of rural informatization, we should encourage a shift away from policy support to development of market consumption, enhance the level of rural informatization consumption and optimize the structure of consumption.

The methods used in this paper have great significance and implications for future studies of developmental efficiency of rural informatization in similar areas; however there is still room for further improvements and discussion on the study. For example, there are certain controversies over the selection of model variable indexes in the DEA analysis phases, and controversies over whether the index of education level and the variable index of information industry macro contribution should be included in evaluating informatization levels. Moreover, in the Tobit analysis phase, in light of the consumption environment and external macro development environment, certain representative influencing factors are selected in this paper, and the effects of the overall and regional factors on rural informatization are decomposed in the Tobit analysis. However, comprehensive external influencing factors can also be further divided in other manners, e.g., division of system factors and non-system factors, division of market factors and non-market factors. Other external influencing factors like differences in regional development strategy are also noteworthy. All of these factors are not considered in this paper, so they can be used for future in-depth researches.

Conclusion

农村信息化发展效率评价对于提高农村信息化整体水平、优化农村信息化投入结构具有重要作用。本文运用DEA的CCR模型对2007-2010年间中国农村信息化发展效率进行了测度，研究发现，中部和东北地区的农村信息化发展效率低于东部和西部地区，Kruskal-Wallis差异性检验显示，西部和中部，东部和中部发展效率都存在显著差异，“中部塌陷”现象在农村信息化发展表现明显：Tobit分析表明，农村信息化建设项目是推动农村信息化整体发展效率提升的主要影响因素，区域经济发展水平、农村居民最终消费支出与农村信息化整体发展效率之间均呈现显著负相关性，人口年龄结构、文化程度结构与信息化整体发展效率之间存在相关性。

改善提高农村信息化发展效率的对策措施，首先仍然是继续加大全局性农村信息化基础设施建设，不同地区根据经济发展水平不同应实施地方性项目加以补充；中央政府主导的政策性农村信息化建设是在短期内取得巨大成就的主要原因，但农村信息化是一个复杂的社会化综合性工程，信息设施、信息服务等基础建设只是其中的一部分内容，长期发展应建立在健全的农村信息化市场的基础上，因此要保证未来农村信息化的健康发展，应逐步从强调政策性供给转向同时重视发展市场消费需求、扩大农村信息化消费水平，优化消费结构。

本文的研究思路和方法对于深入进行农村信息化发展效率的相关研究具有一定的启示和借鉴意义。当然，本研究仍存在需要改进和讨论之处：DEA分析阶段主要涉及模型变量指标的选取，在评价信息化水平中是否应该包括教育变量指标，信息产业宏观贡献变量指标等，有一定的争论；Tobit分析阶段本文从消费环境和外部宏观发展环境角度选择了具代表性的影响因素指标，在模型分析中初步分辨出全局性和地区性因素对农村信息化发展效率的影响，可以进一步考虑以其他方式细分外部综合性影响因素，如分为制度和非制度、市场和非市场因素，还可以考虑其他一些外部影响因素，如区域发展战略差异等，这些在本文中没有涉及，有继续深入研究的价值。
ACKNOWLEDGEMENT

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WRITING NORMS / NORME DE REDACTARE

**Article Types**

Three types of manuscripts may be submitted:

1. **Regular articles**: These should describe new and carefully confirmed findings, and experimental procedures should be given in sufficient detail for others to verify the work. The length of a full paper should be the minimum required to describe and interpret the work clearly (max. 8 pages);

2. **Short Communications**: A Short Communication is suitable for recording the results of complete small investigations or giving details of new models or hypotheses, innovative methods, techniques or apparatus. The style of main sections has not necessarily to be in accordance with that of full-length papers (max. 6 pages);

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All manuscripts are reviewed by the 2 members of the Scientifically Review. Decisions will be made as rapidly as possible, and the journal strives to return reviews’ comments to authors in approx. 3 weeks. The editorial board will re-review manuscripts that are accepted pending revision.

**NOTE**: Submission of a manuscript implies that the work described has not been published before (excepting as an abstract or as part of a published lecture, or thesis) that it is not under consideration for publication elsewhere.

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   - All portions of the manuscript must be typed single-spaced, 4 cm, top and bottom; 2 cm; left: 2 cm; right: 2 cm, font: Arial, size 9 pt, except the title which will be 11 pt. and explicit figures, which will be 8 pt.
   - Text paper will be written in two equal columns of 8.3 cm, 0.4 cm space between them, except the title, authors and their affiliations, tables, figures, graphs and equations to be entered once.
   - Text will be written in English in the left column, respectively in native language in the right column.
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The **Title** should be a brief phrase describing the contents of the paper. PAPER’S **TITLE** will be uppercase, Bold (the title in English language) and **Bold italic** (the title in native language), center, 11 pt. Under the paper’s title, after an space (enter) 9 pt., write authors’ names (eg: Vasiliscu G.), (font: 9 pt., bold) and affiliations, the name of the corresponding author (next row), (9 pt., regular). Also be passed: the phone, fax and E-mail information, for the first author of paper’s (font: 8 pt., italic). Title should be short, specific and informative. Avoid long titles; a running title of no more than 100 characters is encouraged (without spaces).

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Trei tipuri de manuscris pot fi trimise:

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Toate manuscrisele sunt evaluat de către 2 membri ai Comitetului Științific. Deciziile vor fi luate cât mai rapid posibil și revista va returna comentariile evaluărilor înapoi la autorii în aproximativ 3 săptămâni. Conducerea editorială va reevalua manuscrisele care sunt acceptate în vederea publicării în revistă.

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**1. ARTICOLE OBIȘNUITE**

   - Toate capitolele manuscrisului trebuie să fie scrise single-spaced, 4 cm, sus și jos: 2 cm; stânga: 2 cm; dreapta: 2 cm, font: Arial, mărime 9 pt, cu excepția titlului care se scriu cu 11 pt. și figurele explicite, care se scriu cu 8 pt.
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**Rezumatul** trebuie să fie informativ și ușor de înțeles; prezentată pe scurt topica, stadiul experimentelor, date semnificative, și evidență descoperirile majore și concluziile. Rezumatul trebuie să cuprindă între 100 și 300 cuvinte. Propozițiile complete, verbele active, și persoana
verbs, and the third person should be used, and the abstract should be written in the past tense. Standard nomenclature should be used and abbreviations should be avoided. No literature should be cited (font: 9 pt.; the title - bold italic; the text of abstract: italic).

Following the abstract, about 3 to 10 Keywords that will provide indexing references should be listed (font: 9, bold italic - the title and 9 pt., italic - the text).

A list of non-standard Abbreviations should be added. In general, non-standard abbreviations should be used only when the full term is very long and used often. Each abbreviation should be spelled out and introduced in parentheses the first time it is used in the text. Only recommended SI units should be used. Authors should use the Solidus presentation (mg/ml). Standard abbreviations (such as ATP and DNA) need not be defined.

INTRODUCTION should provide a clear statement of the problem, the relevant literature on the subject, and the proposed approach or solution. It should be understandable to colleagues from a broad range of scientific subjects.

MATERIALS AND METHODS should be complete enough to allow experiments to be reproduced. However, only truly new procedures should be described in detail; previously published procedures should be cited, and important modifications of published procedures should be mentioned briefly. Capitalize trade names and include the manufacturer's name and address. Subheadings should be used. Methods in general use need not be described in detail.

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The CONCLUSIONS should interpret the findings in terms of the results obtained in this and in past studies on this topic. State the conclusions in a few sentences at the end of the paper. The Results and Discussion sections can include subheadings, and when appropriate, both sections can be combined.

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Tables should be kept to a minimum and be designed to be as simple as possible. Tables are to be typed single-spaced throughout, including headings and footnotes. Each table must be written on the entire width of the page, into the text where reference is made, the columns are broken - one column (see attached sample). Tables should be self-explanatory without reference to the text. The details of the methods used in the experiments should preferably be described in the legend instead of in the text. The same data should not be presented in both table and graph form or repeated in the text. Table's title will be centered bold (in English) and bold italic native language then separated by a slash. In the table, each row will be written in English (Arial, regular, size: 9 pt.) / native language (Arial, italic, 9 pt.). The table and its number is written right justified, bold - in English and bold italic - native language, separated by a slash (/).

RESULTS

introduces the methodology and materials. The methodology should be complete enough to allow experiments to be reproduced. However, only truly new procedures should be described in detail; previously published procedures should be cited, and important modifications of published procedures should be mentioned briefly. Capitalize trade names and include the manufacturer's name and address. Subheadings should be used. Methods in general use need not be described in detail.

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Figure legends should be typed in numerical order. Graphics should be prepared using applications capable of generating high resolution JPEG before to introducing in the Microsoft Word manuscript file (Insert - From File - ...[jpeg]). Use Arabic numerals to designate figures and upper case letters for their parts (Figure 1). Begin each legend with a title and include sufficient description so that the figure is understandable without reading the text of the manuscript. Information given in legends should not be repeated in the text. Each figure must be inserted on the entire width of the page, into the text where reference is made, single columns (see attached sample). Leave a space between the figure and the text of figure, size: 3 pt., figure number is written in Arial bold, size: 8 pt., followed by what represent the figure or graph, written with Arial, regular, 8 pt. Left to write in English (regular), followed by a separating slash (/) and text in native language (Arial italic). Eg:

Fig 1 - Test stand / Stand de testare (size: 8 pt.)
The figures should be "In line with text" - Center, not "Square"; "Tight"; "Behind text" or "In front of text" (from "Format picture" - right mouse button on picture and then "Layout".

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Authors must provide instructions on how symbols and equations should be set. Equations should be numbered sequentially in the right-hand side and in parenthesis. They should be referred to in the text as Equation (4) or Eq. (4). Each equation must be written on the entire width of the page, into the text where reference is made, the columns are broken (see attached sample).

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References should be listed at the end of the paper in alphabetical order. Articles in preparation or articles submitted for publication, unpublished observations, personal communications, etc. should not be included in the reference list but should only be mentioned in the article-text (e.g., A. Danciu, University of Bucharest, Romania, personal communication). Authors are fully responsible for the accuracy of the references.

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- Units should be metric, generally SI, and expressed in standard abbreviated form.
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2. SHORT COMMUNICATIONS
Short Communications are limited to a maximum of two figures and one table. They should present a complete study that is more limited in scope than is found in full-length papers. The items of manuscript preparation listed above apply to Short Communications with the following differences: (1) Abstracts are limited to 100 words; (2) instead of a separate Materials and Methods section, experimental procedures may be incorporated into Figure Legends and Table footnotes; (3) Results and Conclusions should be combined into a single section.

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Summaries, reviews and perspectives covering topics of current interest in the field, are encouraged and accepted for publication. Reviews should be concise (max. 8 pages). All the other conditions are similar with regular articles.

Capitol din carte

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- unităţile metrice trebuie să fie, în general, SI, şi exprimate în formă prescurtată standard;
- acronimele pot fi acceptate, dar trebuie să fie definite la prima utilizare.

2. COMUNICĂRILE SCURTE
Comunicările scurte sunt limitate la maxim 2 figuri şi un tabel. Acestea trebuie să prezinte un studiu complet, care este mai limitat decât în cazul articolelor normale (de dimensiuni mai mari). Elementele de pregătire a articolelor normale (manuscriselor) enumerate mai sus se aplică şi la comunicările scurte, cu următoarele diferenţe: (1) Rezumatul este limitat la 100 cuvinte; (2) capitolele Materiale şi Metode, Procedurile experimentale pot fi scris fi scris împreună, încorporând figurile şi tabelele; (3) Rezultatele şi Concluziile pot fi combinate într-o singură secţiune.

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Sintezele, comentariile şi perspectivele acoperind subiecte de interes din domeniul sunt încurajate şi acceptate spre publicare. Sintezele trebuie să fie concise şi nu mai mari 8 pagini. Toate celelalte condiţii sunt similare cu cele de la articolele normale (obişnuite), enumerate mai sus.