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 ŞIŞESTI);
- In 1952, was established the Research Institute for Mechanization and Electrification of Agriculture - ICMA Bâneasa, 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 MAA with 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.1508/25.11.1996. by reorganizing ICSITMUA, G.D no. 1508/1996 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 2008 was founded the institute magazine, issued under the name of SCIENTIFIC PAPERS (INMATEH), ISSN 1583 – 1019.

Starting with volume 50, 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”.

We are thankful to all readers, publishers and assessors.

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S.C. AVI – GIIS S.R.L. Stuparei, Valcea County / Romania
A MECHANIZED TECHNIQUE OF ECOLOGICAL SOIL PLANTING FOR THE ANNUAL DOUBLE CROPPING OF WHEAT AND MAIZE WITH A FIVE-YEAR CYCLE

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School of Agricultural Engineering and Food Science, Shandong University of Technology, Zibo / China
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Abstract: An ecological soil planting method was proposed for the annual double cropping of wheat and maize with a five-year cycle. This method is suitable for Huang-Huai-Hai Region and aims to address the problems of reduced crop yield and soil crust as a result of soil and water loss, deteriorated land fertility, and protective tillage in intensive cultivation. Moreover, the planting specifications of the annual double-cropping rotation patterns of wheat and maize were unified, and the key agricultural equipment was designed for full mechanization. Research results on the test demonstration base showed that the return of straw to the field and scientific fertilization can limit the emissions of harmful gas and the use of fertilizer. Furthermore, these steps can enhance ecological agricultural production. The return of straw to the field and suitable cultivation can increase the content of organic matters in soil, improve the aggregate structure, and enhance soil fertility. Finally, the implementation of the ecological fertile soil planting technique can overcome the disadvantages of intensive cultivation and protective tillage, thereby facilitating stable and high crop yield.

Keywords: Intensive cultivation; protective tillage; planting specification; Agricultural mechanization

INTRODUCTION

The population of China comprises 18.84% of the world population. However, its arable land constitutes only 8.7% of that of the world. As a result, the development pattern of high agricultural yield involves a gradual increase in labor input-intensive cultivation. Intensive cultivation is essentially for a comprehensive technological system of traditional agriculture. In line with this knowledge, a series of studies has been conducted on intensive cultivation technology and its development. The results indicate that although intensive cultivation improves crop yield and solves the employment problem, it also induces soil erosion, environmental degradation, and other problems [1], [3], [5-7], [12], [20]. This process can also significantly reduce the earthworm population [6-7], as well as affect organic matter content, enzyme activities, microbial quantity, the abundance of fungal mycelium, the functional diversity of microbes, the abundance of bacterial species, and other soil properties [3, 7]. The increase in cropping intensity eliminated the self-protection function and activity of soil. In addition, straw burning enhanced atmospheric pollution.

Strong black storms hit the western US and the former Soviet Union in the 20th century. Many experiments have been conducted on sandstorm treatment, and they confirmed that protective tillage is the most successful suppression method [10]. Research on this method
mainly focused on its influence on soil properties\[2\], [11], [13-17], [21-24], the composition of soil species \[4\], and the microbial quantity and fungi abundance in soil \[19], [25]. Protective tillage can limit soil erosion and water loss \[8\], increase the contents of organic matters in soil, improve soil structure, control soil loss, reduce wind and water erosion, and shorten tillage times. In addition, straw residue cover can limit dust hazard. Thus, its implementation can prevent the loss of dust, water, and soil in farmlands. It can also store and preserve water, promote the productivity of fertilized land, save costs, increase efficiency, reduce emissions from straw burning and greenhouse gas, and enhance the sustainable development of agriculture. However, many researchers believe that simple protective tillage is not conducive to high yield given that the overuse of chemical fertilizers, pesticides, and other chemicals has generated ecological issues and problems with soil crust.

Based on a survey of the annual double-cropping patterns of wheat and maize in the Huang-Huai-Hai Region and on the advantages of intensive cultivation and protective tillage following years of field experiment research, a new method of ecological soil planting is proposed in the current study for these patterns. This mechanized ecological soil planting technique is investigated by determining the representative dry area, well irrigation area, and saline land. The results suggest that scientific and reasonable soil cultivation can enhance ecological agricultural production, soil structure, and the contents of organic matters in soil to ensure the stable and high yield of grain, as well as to realize the sustainable development of agriculture.

MATERIAL AND METHOD

Description of the Mechanized Ecological Soil Planting Technique

The so-called ecological soil planting technique guides scientific development. It focuses on the stable and sustainable development of agriculture in the long term, as well as on ecological agriculture construction and soil fertility cultivation. Crops are planted using ecological and mechanized techniques and methods. Furthermore, straw is treated scientifically to increase the contents of organic matters in soil, to improve soil structure, and to reduce the use of chemical fertilizers, pesticides, and other chemicals. Ultimately, it achieves the purpose of ecology, which is to facilitate high-quality, low-consumption, and high-efficiency agricultural production.

Key Techniques of Mechanized Ecological Soil Planting

Scientific Tillage Method

Tillage method is a general term for all techniques and measures that recirculate several crop systems in a region, including planting, soil tillage, fertilization, and weed control methods. The ecological soil planting technique is an establishment of the ecological soil tillage method, which combines tillage and protection with the ecological planting method. Agricultural machinery and agronomy are integrated as well.

Soil Tillage Method

The ecological soil tillage method with a five-year cycle (ploughing in the first year, digging the soil in the

...
third and fourth years, and no ploughing or digging in the second and fifth years) was developed to emphasize both soil tillage and protection equally. Thus, the tillage and protective measures complement each other.

Ploughing in the first year: Ploughing can improve soil structure, the capacity of water storage and preservation, and crop root growth and nutrient absorption. It can also adjust nutrient distribution, loosen the organic matters accumulated on the soil surface, continuously improve the fertility of the tilth layer of soil, enhance the soil ecosystem, and promote the balance of the biological population in soil. Finally, it buries weed seeds, pathogen spores, and pest eggs deep into the soil to inhibit diseases and pests.

Digging deeply into the soil in the third and fourth years: This process mainly protects the soil surface and its dynamic configuration. Its main role is to break the plough pan to help the roots of crops adhere to the soil, to improve water storage and preservation capabilities, to enhance soil porosity, to improve air and water operation in soil, to generate conditions for the decomposition of organic matters by soil microorganisms, and to promote soil fertility and nutrient absorption.

No ploughing or digging in the second and fifth years: Over-tillage has many disadvantages, and the most serious is water and soil loss. No ploughing after tillage and complete digging is conducive to shortening the times of mechanized farming and to protecting the soil surface.

**Planting Specification**

The unification of planting specifications is the premise of the scientific design of mechanized agronomy. Planting specification mainly includes row width, line quantity and spacing, as well as the strip width and line spacing of deep digging. The parameters are agricultural machinery, agronomy, and irrigation methods. For convenient machine configuration, planting specifications must be unified, such as line spacing and row width. To adapt to the annual double-cropping patterns of wheat and maize in the well irrigation area of the Huang-Huai-Hai Region, a planting specification is designed as shown in Fig.1.

**Fig. 1 - Planting Specification in the Well Irrigation Area (Unit: mm)**
Key Agricultural Equipment

The mechanized ecological soil planting technique emphasizes the heavy integration of agricultural machinery and agronomy, enhances standardized planting procedures, and regards high efficiency, low consumption, and low investment as the goals of the system configuration and of machine operation. The tillage and planting requirements of this technique are presented in Table 1.

### Table 1

<table>
<thead>
<tr>
<th>Item Name</th>
<th>Requirements of Agronomy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ploughing depth (mm)</td>
<td>200 – 250</td>
</tr>
<tr>
<td>Digging depth (mm)</td>
<td>230 – 300</td>
</tr>
<tr>
<td>Wheat planting depth (mm)</td>
<td>30 – 50</td>
</tr>
<tr>
<td>Fertilization depth for wheat planting (mm)</td>
<td>80 – 100</td>
</tr>
<tr>
<td>Interval width between wheat seeds and fertilizer (mm)</td>
<td>50 – 60</td>
</tr>
<tr>
<td>Suppression strength for wheat sowing (N/cm²)</td>
<td>20 – 30</td>
</tr>
<tr>
<td>Maize planting depth (mm)</td>
<td>30 – 40</td>
</tr>
<tr>
<td>Fertilization depth for maize sowing (mm)</td>
<td>100 – 120</td>
</tr>
<tr>
<td>Interval width between maize seeds and fertilizer (mm)</td>
<td>60 – 80</td>
</tr>
<tr>
<td>Suppression strength for maize sowing (N/cm²)</td>
<td>20 – 50</td>
</tr>
<tr>
<td>Cutting length of maize straw (mm)</td>
<td>&lt;100</td>
</tr>
</tbody>
</table>

Given the annual double-cropping patterns of wheat and maize, the key agricultural equipment and techniques include:

**Wheat Seeder**

The deep-digging wheat seeder performs six processes, namely, deep digging, rotary tilling, fertilizing, sowing, covering, and suppressing. Two rows of deep digging spades are staggered to prevent grass entangling and plugging effectively and to enhance the stability of deep digging [18]. On October 12, 2012, the Shandong Agricultural Machinery Test Evaluation Station assessed the performance of the deep-digging wheat seeder. The main parameters are displayed in Table 2.

**Maize Seeder**

The maize seeder sows maize on a narrow strip and is adaptable for sowing and transplanting. The seeder is a low-cost, universal, and easy-to-use agricultural machine. On October 12, 2012, the Shandong Agricultural Machinery Test Evaluation Station assessed the performance of the maize seeder. The main parameters are displayed in Table 2.

---

*Fig. 2 - Sowing by Wheat Deep Digging and Fertilization Seeder and Seedlings*
Performance Parameters of Wheat Deep Digging Fertilization Seeder

<table>
<thead>
<tr>
<th>Performance Index</th>
<th>Parameter</th>
<th>Performance Index</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supporting Dynamics (kW)</td>
<td>≥ 73.5</td>
<td>Fertilization spacing qualified rate (%)</td>
<td>≥ 98</td>
</tr>
<tr>
<td>Number of sowing Lines</td>
<td>8</td>
<td>Sowing rate error (%)</td>
<td>± 0.4</td>
</tr>
<tr>
<td>Productivity (hm²/h)</td>
<td>≥ 0.8</td>
<td>Linking spacing qualified rate (%)</td>
<td>≥ 90</td>
</tr>
<tr>
<td>Sowing depth qualified rate (%)</td>
<td>≥ 80</td>
<td>Digging depth (cm)</td>
<td>≥ 30</td>
</tr>
<tr>
<td>Sowing uniformity variation coefficient (%)</td>
<td>≤ 45</td>
<td>Digging depth stability (%)</td>
<td>≥ 85</td>
</tr>
</tbody>
</table>

The wide strip sowing technique can improve the effective tillage of seeds and assist in ventilation, lighting, and crop growth. Wheat seeds are distributed in the field uniformly, and yield increases by 6% to 8% in comparison with that obtained with conventional sowing.

Maize Seeder and Dynamic Anti-plugging Device

The strip grooming device depicted in Fig. 3(b) is adopted to solve the plugging problem of the furrow opener on the no-tillage maize seeder when straw coverage is large (more than 0.6 kg/m²) or when straws are long (more than 22 cm) and scattered unevenly. This device exhibits the functions of dynamic anti-plugging and stubble ploughing. The number of the rotating knives is similar to that of furrow openers. In this device, a group of rotating knives is placed in front of the pillar of each furrow opener. Each group of rotating knives contains two rotating knives that are installed symmetrically at 180°.

The strip grooming device not only clears straw residues but also breaks the dry and hard soil layer on the surface, thus generating a good seeding bed and increasing the seedling rate by 2.5%. The monomer copying technique reduces the leakage sowing rate caused by uneven ground and enhances the consistency of seedlings.

Maize Straw Returning Machine

Given that the spacing of maize does not match the wheel tread of the harvester, the maize straws may be crushed during harvest. This phenomenon strongly affects the returning quality. To solve this problem, the technique employed by the crushing machine is improved by installing a stubble digging device in front of the machine (as exhibited in Fig. 4). This device digs maize straws up from the surface of the ground slowly and returns them to the straw returning machine. The straw returning machine crushes the straws rapidly to prevent its blade from hitting the earth, to reduce dynamic consumption, and to slow the onset of blade wear. Thus, the problem wherein maize straws cannot be returned to the field as a result of wheel rolling is solved.
The comprehensive crushing and returning of maize straws and roots after harvest not only limits the dynamic harvest but also gathers the remaining ears in the harvesting process to reduce harvest loss and the cleaning of emerging wheat seedlings.

RESULT ANALYSIS

The representative dry area, well irrigation area, and saline land were selected as per the proposed mechanized ecological soil planting technique to determine the test demonstration bases (as indicated in Table 3).

In the case in which all straws were returned to the field, 11 t/hm2 to 15 t/hm2 of maize straws were recovered annually. The amount of wheat straws returned ranged from 7.5 t/hm2 to 9 t/hm2. The concentrations of gas emissions reduced directly by straw returning per hm2 are displayed in Table 4 based on the data reported in the literature [9].

Table 3

<table>
<thead>
<tr>
<th>Serial No.</th>
<th>Item Name</th>
<th>Cooperation Unit</th>
<th>Construction Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dry Area Test Demonstration Base</td>
<td>Longyi Village in Zichuan District, Zibo</td>
<td>2011</td>
</tr>
<tr>
<td>2</td>
<td>Well Irrigation Area Test Demonstration Base</td>
<td>Donglai Agricultural Machinery Cooperative in Changshan Town, Zhouping County, Bingzhou</td>
<td>2012</td>
</tr>
<tr>
<td>3</td>
<td>Saline Land Test Demonstration Park</td>
<td>Jin Fu Xiang Peasant Planting Cooperative in Mingji Village, Lijin County, Dongying</td>
<td>2012</td>
</tr>
<tr>
<td>4</td>
<td>Well Irrigation Area Test Demonstration Base</td>
<td>Fujia Village, Zhangdian, Zibo</td>
<td>2005</td>
</tr>
</tbody>
</table>

Table 4

<table>
<thead>
<tr>
<th>Directly Reduced Gas Emissions per hm² (unit:kg)</th>
<th>Chemical Name</th>
<th>Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>2413.45 ~ 3150.3</td>
<td></td>
</tr>
<tr>
<td>CO₂</td>
<td>26598.15 ~ 34722</td>
<td></td>
</tr>
<tr>
<td>NO</td>
<td>15.07 ~ 19.5</td>
<td></td>
</tr>
<tr>
<td>NO₂</td>
<td>6.75 ~ 8.67</td>
<td></td>
</tr>
<tr>
<td>NO₃</td>
<td>21.92 ~ 28.32</td>
<td></td>
</tr>
</tbody>
</table>
The return of straw to the field can reduce air pollution and prevent damage to the soil structure as a result of straw burning. It can also improve the efficiency of fertilizer use and reduce usage by 40%. Root stubble crushing loosens and stirs the topsoil, thereby changing the physical and chemical properties of the soil and destroying the parasitic environment of insects and other pests on the surface. This process inhibits the onset of plant diseases and pest invasion.

**Organic Soil Fertilization**

The scientific processing of crop straws increases the content of organic matters in soil consistently every year, improves the aggregate structure of soil, enhances soil permeability, balances soil microorganisms, and improves the microenvironment of the field, thus realizing stable and high yields. The changes in the contents of organic matters, the increment of water content, and the volume-to-weight ratio reduction in the soil of test demonstration base no. 4 are shown in Fig. 5.

Since 2011, soil tillage has strictly accorded with the requirements of the ecological soil planting project, thereby steadily increasing the yields of wheat and corn. Scientific fertilization limits the use of fertilizer and fundamentally weakens the adverse influence of fertilizer production and use on soil and ecology. The yields of wheat and corn, as well as the amount of fertilizer used in test demonstration base no. 4, are depicted in Fig. 6 (Note: The crops in Shandong were frozen because of the low temperature, snow, and rain in the spring of 2013). Late in May, rare rainstorms and strong winds resulted in a severe loss of wheat. Moreover, droughts in the late summer and early autumn affected sowing. In the middle of September, Luzhong experienced hail, which intensified the disaster and reduced yield.

**Fig. 5 - Influence of the return of straw to the field on soil**

从2011年以来，严格按照生态沃土种植工程要求，进行土壤的耕作，小麦玉米产量得到了稳步提高。通过科学施肥，减少了化肥的用量，从根本上减少化肥生产和使用对土壤和生态的不利影响。4号试验示范基地小麦玉米产量及化肥使用量如图6所示（说明：山东省2013年春季低温雨雪使农作物受冻，5月下旬罕见的大风暴雨气候导致小麦倒伏严重，夏末秋初少雨干旱影响秋播。9月中旬鲁中遭受风雹袭击令灾害严重，导致粮食减产）
CONCLUSIONS

Based on the analysis of the two typical planting patterns of intensive cultivation and protective tillage and according to several years of testing and research, a mechanized ecological soil planting technique was proposed for the annual double cropping of wheat and maize. This method is suitable for the Huang-Huai-Hai Region. The characteristics of the planting technique were explained, and the planting specification was designed. This specification was appropriate for the ecological soil tillage method employed in the mechanized ecological soil planting technique and for the combination of agricultural machinery and agronomy. The corresponding key agronomic equipment was designed to mechanize the operation of the annual double cropping of wheat and maize fully. The proposed technique was applied, and the results showed that it reduced the emissions of polluted gases and the amount of fertilizer used through scientific fertilization to establish the ecological production mode. In addition, it increased the contents of organic matters in soil, improved the microenvironment of farmland, and enhanced the organic fertilization through the return of straw to the field and through suitable soil tillage. Thus, the implementation of this tillage method ensured stable and high crop yields, as well as the sustainable development of agricultural production.

ACKNOWLEDGEMENT

This research was supported by the Young Teachers Program of Shandong University of Technology and the Maize Industry Innovation Team Program of Shandong Modern Agricultural Industrial Technique System (SDAIT-01-022-10).

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vol. 47, no.3, pp. 184–194;

INIMATEH - Agricultural Engineering

Vol.45, No.1 / 2015

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DESIGN OF AN INTELLIGENT MONITORING SYSTEM FOR A PESTICIDE SPRAYING MACHINE BASED ON ZIGBEE TECHNOLOGY

基于ZIGBEE技术的农药喷施机智能监控系统设计

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Abstract: Implementing intelligent control in pesticide spraying machines is a key technology in improving spray efficiency, decreasing pesticide pollution, and lowering production cost. This paper presents an intelligent monitoring system for pesticide spraying machines. This system focuses on the ZigBee technology and integrates sensors, motors, a Wi-Fi camera, and a 32-bit embedded controller. This intelligent monitoring system consists of a monitoring node of a rotary pesticide selection unit, monitoring node of a real-time preparation unit, monitoring node of a nozzle unit, monitoring node of an intelligent mobile platform, a Wi-Fi camera image collecting module, and a PDA remote controller. Test results show that the average packet drop ratio of the ZigBee network is 0.21%, and the success ratio of sending 10,000 commands through the responder communication strategy of the ZigBee network is 100%. This intelligent monitoring system can be remotely controlled from a distance of up to 110 m. The spraying efficiency is 2–3 times greater than that of manual spraying. The wireless remote operation is also convenient for pesticide preparation and operator safety.

Keywords: Pesticide Spraying Machine; ZigBee; PDA; Embedded Controller; Sensor

INTRODUCTION

Given the excessive use of pesticides, the additive effect of toxicity residues in the environment and food is an increasingly serious problem that has exceeded the natural degrading capacity of the environment. Thus, it has caused underground water and surface water pollution, as well as toxin accumulation in foods [11]. Therefore, intelligent pesticide application technology developed on the basis of agricultural mechanical equipment is an efficient way to promote the health and sustainable development of agriculture, as well as lower the harmful effects of pesticides on the environment and human body [8].

Researchers have proposed many methods in terms of pesticide spraying technologies in recent years [1], [2], [5]. Spraying technologies presented in literature [3], [6], [7], [9] mainly realize variable application control. Spraying machines are usually costly, whereas some application technologies are in high demand in the landform. This paper presents a pesticide application technology based on ZigBee technology to realize its operation in a diversified environment, decrease waste and excessive use of pesticides, prevent operators from directly contacting with pesticides, and improve the spraying efficiency of pesticides. ZigBee technology is a short-distance wireless network communication technology with low energy consumption, cost, and complexity [10]. It is applicable to multipoint control

摘要：对农药喷施机实施智能控制是提高喷施效率，减少农药污染，降低生产成本的关键技术。该文以ZigBee技术为核心，结合传感器、电机、Wi-Fi摄像头、32位嵌入式控制器等对农药喷施机设计了智能监控系统。该监控系统由旋转式选药装置监控节点、实时配药装置监控节点、喷头装置监控节点、智能移动平台监控节点、Wi-Fi摄像头图像采集模块和PDA遥控器组成。试验测试结果表明，ZigBee网络平均丢包率为0.21%，通过应答式通信策略ZigBee网络发送1万个指令的成功率达100%。该智能监控系统的遥控距离可达110m，喷施效率是人工的2~3倍，无线遥控操作保障了配药作业的便捷和作业人员的安全。

关键词：农药喷施机; ZigBee; PDA; 嵌入式控制器; 传感器

引言

农药的过量使用，在环境和食物中残留毒性的积累效应日益成为严重问题，超过了环境对农药的自然消解能力，造成了地下水以及地表水污染，形成了食物中有害毒素的积累[11]。因此，为促进农业的健康和可持续发展，减少农药对环境和人体的危害，发展基于农用机械装备的智能施药技术是一种有效途径[8]。

近年来，针对农药喷施技术研究人员提出了很多方法[1]，[2]，[5]。文献[3]，[6]，[7]，[9]提出的喷施技术主要实现变量施药控制，其中，有些喷施设备成本高，有些喷施技术对地形要求较高。为了实现多种环境作业，减少农药的浪费和过量使用，避免作业人员与农药直接接触，提高农药喷施效率本文提出一种以ZigBee技术为核心的施药技术。ZigBee技术是一种低能耗、低成本、低复杂度的短距离无线网络通信技术[10]，适合多点控制应用系统，农药喷施机通常是由多个装置组成，因此，采用ZigBee技术为核心结合PDA（Personal Digital Assistant）等技
application systems. A pesticide spraying machine consists of multiple units. Therefore, an intelligent monitoring system for such a machine is developed by employing ZigBee technology combined with a personal digital assistant (PDA) to realize intelligent control of pesticide selection, pesticide preparation, multi-mode spraying, and nozzle.

MATERIAL AND METHOD
The Structure and Principle of the Pesticide Spraying Machine

This pesticide spraying machine consists of a rotary pesticide selection unit, real-time preparation unit, nozzle unit, and intelligent mobile platform. Figure 1 shows pesticide spraying machine [4].

The rotary pesticide selection unit mainly consists of a solution tank, laser photoelectric sensor, solenoid valve, and stepper motor. The operator selects the exact type of pesticide according to the images sent to the PDA remote controller. It then controls the rotation of the solution tank and makes it rise to a corresponding height to draw the pesticide. The solution tank is divided into eight sections with the same volume for holding eight types of pesticides. The corresponding solenoid valve hole is mounted at the bottom of each section for the operator to select appropriate pesticides according to the state of crop disease.

The real-time preparation unit mainly consists of a solution preparation tank, solution temporary storage tank, water storage tank, and level switch. When the level switch in the solution temporary storage tank detects that the level of the solution is lower than the set value, it immediately starts to prepare the solution for the next round of spraying. The real-time preparation unit can realize real-time rapid preparation.

The nozzle unit mainly consists of a lifting rod, stepper motor, water pump, and nozzle, which adjust the nozzle height by driving the lifting rod with the stepper motor.

The intelligent mobile platform employs Beijing Borch Company’s Traveler No. 4 whole landform mobile platform, which is applicable for traveling on sand, soil, and grass. It can also run in diversified environments such as fruit gardens, vegetable bases, and greenhouses.

Fig. 1 - The pesticide spraying machine
智能监控系统设计

通过传感器、摄像头监测农药喷施机的工作状态，该智能监控系统控制旋转式选药装置、实时配药装置和喷头装置协调工作，使得农药喷施机可以实现三种喷施作业模式，即定点喷施自动模式、边走边喷自动模式和手动模式。智能监控系统设计方案如图2所示，此方案由农药喷施机监控器和PDA遥控器两大部分组成。农药喷施机监控器以ZigBee技术为核心进行设计，由选药装置监控节点、实时配药装置监控节点、喷头装置监控节点、移动平台监控节点和Wi-Fi摄像头图像采集模块共同构成。PDA遥控器与Wi-Fi摄像头图像采集模块通过Wi-Fi实现互联互通，与ZigBee监控节点通过ZigBee网络实现互联互通。Wi-Fi摄像头图像采集模块采用CS-R5110模块，其主要性能参数是，支持1280×760像素，自带8位DC/DC，支持水平335°，上下120°范围转动，内置Wi-Fi通信芯片且无线通信距离达120m，完全满足农药喷施机作业图像采集需求。4个监控节点和PAD遥控器都采用12V5AH蓄电池提供电能，经LM2596-5、LM1117-3.3调压芯片调整提供5V和3.3V直流供电电压。智能移动平台采用48V20AH蓄电池提供电能。

**Design of an Intelligent Monitoring System**

通过传感器、摄像头监测农药喷施机的工作状态，该智能监控系统控制旋转式选药装置、实时配药装置和喷头装置协调工作，使得农药喷施机可以实现三种喷施作业模式，即定点喷施自动模式、边走边喷自动模式和手动模式。智能监控系统设计方案如图2所示，此方案由农药喷施机监控器和PDA遥控器两大部分组成。农药喷施机监控器以ZigBee技术为核心进行设计，由选药装置监控节点、实时配药装置监控节点、喷头装置监控节点、移动平台监控节点和Wi-Fi摄像头图像采集模块共同构成。PDA遥控器与Wi-Fi摄像头图像采集模块通过Wi-Fi实现互联互通，与ZigBee监控节点通过ZigBee网络实现互联互通。Wi-Fi摄像头图像采集模块采用CS-R5110模块，其主要性能参数是，支持1280×760像素，自带8位DC/DC，支持水平335°，上下120°范围转动，内置Wi-Fi通信芯片且无线通信距离达120m，完全满足农药喷施机作业图像采集需求。4个监控节点和PAD遥控器都采用12V5AH蓄电池提供电能，经LM2596-5、LM1117-3.3调压芯片调整提供5V和3.3V直流供电电压。智能移动平台采用48V20AH蓄电池提供电能。

**Design of the pesticide spraying machine monitor**

所有监控节点的旋转植剂选择单元、实时配药单元、喷头单元和移动平台单元均与CC2530无线单片系统计算机（SCM）为内核的CC2530无线SCM系统对系统芯片，而CC2530无线SCM系统是TI公司开发单片系统，它结合了性能领先的RF收发器和业界标准的增强型8051CPU，具有出色的灵敏度和抗干扰能力，同时还具有强大的GPIO接口，遵循ZigBee协议。
个监控节点采用TI公司推荐的最小应用系统电路，并结合GPIO接口电路设计而成，监控节点程序在TI公司Z-Stack-CC2530协议栈的基础上进行二次应用开发。

旋转式选药装置监控节点

旋转式选药装置的溶液箱由步进电机驱动其旋转，用于选择待喷施的农药类型。其中，步进电机选用57BYGH模块。CC2530无线单片机的P1.0-P1.2端口分别接57BYGH模块的脉冲端口CLK、方向端口DIR和使能端口EN。

CC2530无线单片机根据PDA遥控器发送的指令，用于控制溶液箱的转动。8个激光光电传感器的发射头安装在溶液箱的底部，每个发射头对应溶液箱的一个分割区域。

CC2530无线单片机的P0.0-P0.7端口驱动8个继电器开关，8个继电器开关的输出端口控制相应发射头发出激光。激光光电传感器选用M12NPN对管，激光发射光束集中且能量强，可以极大地降低误报率。CC2530无线单片机的外部中断输入端口INT1连接激光光电传感器的接收头的输出端口NO。当接收头接收到激光信号时，NO端口输出的低电平触发CC2530无线单片机的外部中断，从而实现了选药控制。选药控制的步骤为：

（1）根据PDA遥控器的指令，CC2530无线单片机驱动相应的发射头发出激光，接收头接收到激光信号时，溶液箱停止转动，此时，安装在溶液箱对应区域底部的电磁阀对准了实时配药装置的取药管，实现选药定位；

（2）CC2530无线单片机通过步进电机驱动溶液箱升至合适的高度，配药装置的取药管通过电磁阀孔插入溶液箱相应区域的药液里，进行农药的抽取以便配药所用。

实时配药装置监控节点

流量计传感器模块选用OKD-HZ21WA霍尔流量计传感器模块，安装在抽水管中。配药装置由配制箱和暂存箱组成，配制箱内安装有搅拌器、温度传感器和加热器。配药装置的监控步骤为：

（1）水量和农药量的控制。通过微型水泵、流量计传感器模块和电磁阀控制，将蓄水箱的水和溶液箱内的药液按所需量抽入喷施液配制箱内。

Monitoring of the rotary pesticide selection unit

The stepper motor drives the solution tank of the rotary pesticide selection unit to rotate and select the pesticide type to be sprayed. The stepper motor then uses the 57BYGH module. The P1.0 to P1.2 ports of the CC2530 wireless SCM are connected to the pulse port CLK, direction port DIR, and enabling port EN of the 57BYGH module, respectively. The CC2530 wireless SCM control rotation of the solution tank is in accordance with the commands sent by the PDA controller. The emission heads of 8 laser photoelectric sensors are installed at the bottom of the solution tank, and each head corresponds to a section of the tank. The P0.0 to P0.7 ports of the CC2530 wireless SCM drive the eight relay switches, and their output ports control the corresponding emission head to emit laser. The laser photoelectric sensor uses M12NPN gate transistors such that the laser beam is concentrated and has intensive energy that largely decreases the false ratio. The external interrupt input port INT1 of the CC2530 wireless SCM connects the output port NO of the receiver of the laser photoelectric sensor. When the receiver receives laser signals, the output low level of the NO port triggers external interruption of the CC2530 wireless SCM, so that pesticide selection control is realized. The steps of the pesticide selection control are as follows:

1. The CC2530 wireless SCM drives the corresponding emitter to emit laser on the basis of the commands of the PDA remote controller. The solution tank stops rotating when the receiver receives laser signals. At this point, the solenoid valve installed at the bottom of the areas that correspond to the solution tank is aligned with the pesticide drawing tube of the real-time preparation unit to realize positioning for pesticide selection.

2. With the stepper motor, the CC2530 wireless SCM drives the solution tank to move up or down to an appropriate height. The pesticide drawing tube of the preparation unit is then inserted into the solution of the corresponding section of the solution tank through a solenoid valve hole to draw the pesticide for preparation.

Monitoring of the real-time pesticide preparation unit

The OKD-HZ21WA Hall flow meter sensor module is used and installed in the water drawing tube. The preparation unit consists of a preparation tank and temporary storage tank. A mixer, temperature sensor, and heater are installed in the preparation tank. The preparation unit works as follows:

1. The amounts of water and pesticide are controlled. The water in the water storage tank and the pesticide in the solution tank are drawn through the mini pump, flow meter sensor module, and under the control of the solenoid valve as per the required amount into the
solution preparation tank. The P1.2 port of the CC2530 SCM drives the relay switch to the output power to control the mini pump. The external interruption counter port is connected to the pulse signal output port of the OKD-HZ21WA module, so the metered water is drawn by indirectly measuring the water drawing amount through pulse counting. The P1.0 port of the CC2530 wireless SCM controls the pesticide drawing solenoid valve and realizes quantitative pesticide drawing each time together with eight solenoid valve holes at the bottom of the solution tank.

(2) Pesticide preparation and temperature in the preparation tank are controlled. When the required amounts of water and pesticide are drawn into the preparation tank of the pesticide preparation unit, the CC2530 wireless SCM controls the actions of the mixer through the P1.3 port. The CC2530 wireless SCM also monitors the temperature of the mixture in the preparation tank to thoroughly blend the pesticide solution. The DS18B20 digital temperature sensor is used for the temperature sensor. The CC2530 wireless SCM is also connected with the DQ port of DS18B20 through its P1.4 port to directly read the temperature data measured by DS18B20. The CC2530 SCM also controls the heater mounted at the bottom of the preparation tank through the P1.5 port to heat up the mixture in the preparation tank to the required temperature.

(3) The spraying of the temporary storage tank is controlled. Two level switches are installed in the temporary storage tank to detect the solution height in the tank. The MJ-0825PX mini switches are used for level switches. P2.0 and P2.1 ports of the CC2530 wireless SCM are connected to the two level switches to detect the solution level in the temporary storage tank. When the upper limit level switch in the temporary storage tank detects that the solution level exceeds the upper limit, the CC2530 wireless SCM closes it by controlling the solenoid valve between the preparation tank and the temporary storage tank through the P2.2 port. When the lower limit level switch in the temporary storage tank detects that the solution level is below the lower limit, the CC2530 wireless SCM opens it by controlling the solenoid valve to place the mixed solution into the temporary storage tank. Thus, the nozzle unit can spray in real time and start to prepare the solution for the next round.

**Monitoring node of the nozzle unit**

The nozzle unit of the pesticide spraying machine can spray in all directions. The nozzle height can be adjusted in real time according to the height of the crops to be sprayed. The CC2530 SCM drives the lifting rod through the stepper motor to adjust the nozzle on such rod to an appropriate height according to the wireless control command sent by the PDA remote controller. The P1.0 to P1.2 and P2.0 to P2.5 ports of the CC2530 wireless SCM are then connected to the stepper motor driver. The spraying angle of the nozzle is controlled by four telescopic rods connected to the nozzle. The four rods are divided into two groups that are time-sharing controlled by two motors. The CC2530 wireless SCM controls the four telescopic rods through the driving motor to realize clockwise and counterclockwise flexible spraying.

P1.2端口驱动继电器开关，继电器开关输出端口控制微型水泵的电源。CC2530无线单片机的外部中断计数端口接OKD-HZ21WA模块的脉冲信号输出端口,通过脉冲计数间接测得抽水的流量实现按量抽水的功能。CC2530无线单片机的P1.0端口控制取药电磁阀，并结合溶液箱底部的8个电磁阀孔控制，实现每次定量取用药液。

（2）配制箱内的配药和温度控制。当所需的水量和农药量抽入配药装置的配药箱内后，CC2530无线单片机通过其P1.3端口控制搅拌器的动作。为了喷施药液的充分混合，CC2530无线单片机还进行了配制箱内混合液的温度监控。温度传感器选用DS18B20数字温度传感器。CC2530无线单片机通过其P1.4端口与DS18B20的DQ端口相连接，从而直接读取DS18B20测量的温度数据。CC2530无线单片机通过其P1.5端口控制安装在配制箱底部的加热器工作，使得配制箱内的混合液温度达到所需温度。

（3）暂存箱的喷施控制。暂存箱内安装有2个液位开关用于检测箱内的喷施液高度。液位开关选用MJ-0825PX微型开关，CC2530无线单片机的P2.0、P2.1端口与2个液位开关相连接，用于采集暂存箱内喷施液的液位高度。当暂存箱内的上限液位开关检测到喷施液的液位高于上限值时，CC2530无线单片机通过其P2.2端口控制配制箱和暂存箱之间的电磁阀，使之关闭；当暂存箱内的下限液位开关检测到喷施液的液位小于下限值时，CC2530无线单片机控制配制箱和暂存箱之间的电磁阀，使之开启，从而将配制好的喷施液从配制箱放入暂存箱内，以供喷头装置实时喷施，并同时启动下一轮喷施液的配制。

喷头装置监控节点

农药喷施机的喷头装置可以实现全方位的喷施动作，喷头的高度可以依据所需喷施农作物的高度实时调整。根据PDA遥控器发送的无线控制指令，CC2530无线单片机通过步进电机驱动升降杆动作，使得安装在升降杆上的喷头调整至合适的高度。其中，CC2530无线单片机的P1.0、P1.2、P2.0-P2.5端口与步进电机的驱动器相连接。喷头的喷施角度由4个连接在喷头上的伸缩杆进行控制，伸缩杆分成2组由2个电机进行分时控制。CC2530无线单片机通过驱动电机控制4个伸缩杆从而使实现顺时针和逆时针灵活喷施。
遥控器设计

嵌入式操作系统上开发出具有体积小、开源、运行内存所需存储量小、操作所示，内核架构的位4号全地形移动平台的图形化的嵌入式操作系统，遥控器采用摄像头图像采集模块相互通信。为了直接上移植WinCE6.0和接口组成。

USB两个库文件加入应用程序工程,调用其K9GAG08U0E API RS232嵌入S3C6410遥控器的程序设计通信接口相连,通过所存 储 器 接 成遥控器的电软4容 量 的ZigBee遥控器选用端口与旅L嵌入式控制器、两片共同组成;底板主要由电源模块、4无线单片机的控制节点之间的相互通信。

号全地形移动平台，它是一款功能强大、系统开放、扩展灵活、具有出众越野能力和全天候工作能力的全地形移动平台，能适应沙石、泥土、草地行走，具有60kg负载工作能力。该移动平台预留RS232通信接口，CC2530无线单片机的RXD、TXD端口与旅行家4号全地形移动平台的RS232通信接口相连，通过写入指令控制旅行家4号全地形移动平台行进。

PDA遥控器采用ARM11内核架构的32位S3C6410嵌入式控制器，并结合液晶触摸屏进行设计，具有数据处理能力强、功耗低、界面友好和操控简单的优点。

PDA控制器的电路设计

通为提高电路设计的电磁兼容性和维护的方便性，PDA遥控器采用核心板加底板的设计思路，其结构如图3所示。核心板由S3C6410嵌入式控制、K4X1G163PC-FGC6存存储器接成256MB容量的SDRAM、两片K9GAG08U0E-S存储器接成4GB容量的NAND Flash共同组成；底板主要由电源模块、USB接口、JTAG接口、LCD接口、URAT接口组成。S3C6410嵌入式控制器的URAT接口与ZigBee协调器节点的串口相连，实现与ZigBee控制节点之间的相互通信。

S3C6410嵌入式控制器的IIC接口与Wi-Fi通信模块相连，实现与Wi-Fi摄像头图像采集模块相互通信。为了直观显示和方便操控，PDA遥控器选用AT070TN83V七寸液晶触摸屏，以便实现实时显示和触摸操控。

PDA遥控器的程序设计

PDA遥控器采用微软在WinCE6.0上移植SQLite嵌入式数据库存储专家系统提示数据。Platform Builder软件，自行定制出WinCE6.0图形化的嵌入式操作系统，SQLite具有体积小、开源、运行内存所需存储量小、操作方便等优点，SQLite数据库的实现方式是将sqlite.lib和sqlite.dll两个库文件加入应用程序工程，调用其API函数即可读写数据库。在WinCE6.0嵌入式操作系统上开发出农药喷施机监控系统应用程序，其程序流程如图4所示。

农药喷施机监控系统应用程序的监控界面如图5所示，由选取模块、模式选择模块、行走路线控制模块、摄像头控制模块、喷头装置控制模块和剩余量及温度显示模块组成。
Figure 5 shows that this monitoring system provides all-around monitoring functions by determining the human–machine monitoring interface. The functions of each monitoring module are described as follows:

1. The pesticide selection control module consists of a crop variety selection button, expert system prompt box, drop-down pesticide, or nutrient solution selection list, preparation proportion setting box, and pesticide or nutrient selection indicator light. Before the pesticide spraying machine works, operators determine the variety of pesticide or nutrient solutions and proportion them on the basis of the spraying object, expert system prompt box, and their own experiences.

2. The mode selection module consists of six buttons for fixed distance automatic mode, travel spraying automatic mode, manual mode, cleaning, reset, and stop preparing. The real-time preparation unit is cleaned automatically by clicking the washing button. All units of the pesticide spraying machine are reset by clicking the reset button. The pesticide spraying machine performs spraying in accordance with the pre-set program by clicking the fixed distance automatic mode button or travel spraying automatic mode. The operator controls the pesticide spraying machine by itself by clicking the manual mode button. The pesticide solution preparation tank stops preparing the pesticide by clicking the stop preparing button. The solution temporary storage tank then sprays all the solution inside.

3. The travel route control module consists of five buttons, namely, forward, backward, turn left, turn right, and stop. The operator can control the travel route of the intelligent mobile platform according to the monitoring video transmitted by the image collecting module of the Wi-Fi camera under the manual mode.

4. The nozzle unit control module consists of four buttons, namely, ascending, descending, clockwise, and counterclockwise. The operator can adjust the nozzle height using the ascending and descending buttons under the manual mode.

5. The camera control module adjusts the camera angle using four buttons, namely, upward, downward, leftward, and rightward. The camera shooting and video monitoring are controlled by the shooting and video buttons.

6. The residual amount and temperature display module displays the residual amount of the solution, residual water amount, and temperature in the preparation tank.

By Fig. 5 provided by the human control interface, the monitoring system provides comprehensive monitoring functions. The functions of each module are described as follows:

1. The pesticide selection control module consists of a crop variety selection button, expert system prompt box, drop-down pesticide, or nutrient solution selection list, preparation proportion setting box, and pesticide or nutrient selection indicator light. Before the pesticide spraying machine works, operators determine the variety of pesticide or nutrient solutions and proportion them on the basis of the spraying object, expert system prompt box, and their own experiences.

2. The mode selection module consists of six buttons for fixed distance automatic mode, travel spraying automatic mode, manual mode, cleaning, reset, and stop preparing. The real-time preparation unit is cleaned automatically by clicking the washing button. All units of the pesticide spraying machine are reset by clicking the reset button. The pesticide spraying machine performs spraying in accordance with the pre-set program by clicking the fixed distance automatic mode button or travel spraying automatic mode. The operator controls the pesticide spraying machine by itself by clicking the manual mode button. The pesticide solution preparation tank stops preparing the pesticide by clicking the stop preparing button. The solution temporary storage tank then sprays all the solution inside.

3. The travel route control module consists of five buttons, namely, forward, backward, turn left, turn right, and stop. The operator can control the travel route of the intelligent mobile platform according to the monitoring video transmitted by the image collecting module of the Wi-Fi camera under the manual mode.

4. The nozzle unit control module consists of four buttons, namely, ascending, descending, clockwise, and counterclockwise. The operator can adjust the nozzle height using the ascending and descending buttons under the manual mode.

5. The camera control module adjusts the camera angle using four buttons, namely, upward, downward, leftward, and rightward. The camera shooting and video monitoring are controlled by the shooting and video buttons.

6. The residual amount and temperature display module displays the residual amount of the solution, residual water amount, and temperature in the preparation tank.
RESULTS

The test was performed in June when weeds were flourishing. The test site was the test park of a farm. An intelligent monitoring system was set up based on the structure shown in Figure 2. This system comprises four ZigBee monitoring nodes, a PDA remote controller, and a Wi-Fi camera module. The test mainly includes a packet drop ratio of the ZigBee network and performance test of a PDA controller.

Test of the packet drop ratio of the ZigBee network

Given the test of the packet drop ratio of ZigBee network, command data packets are sent through the PDA remote controller. The data packets received by the ZigBee monitoring node are then counted to determine the data transfer stability of ZigBee network. The test results are shown in Table 1.

The data in Table 1 show that the maximum packet drop ratio of a single node is 0.24%, whereas the average packet drop ratio of the entire ZigBee network is 0.21%. These results show that the wireless transfer of data is highly stable. Each control command is responsively sent to further improve the reliability of data wireless transfer. The ZigBee monitoring node sent responsive signals upon receiving the control command from the PDA remote controller. If the PDA remote controller does not receive the responsive signals, it resends the control command. Through tests of 10,000 wireless control commands sent by the PDA remote controller with this method, the success rate of command sending is determined to be up to 100%.

Performance test of the PDA remote controller

The response time and remote control distance of the monitoring nodes of the pesticide selection unit, real-time preparation unit, nozzle unit, and intelligent mobile platform are measured by sending control commands through the PDA remote controller in the performance test of the PDA remote controller. The test results are shown in Table 2. The data show that the response time of each monitoring node is fast, the PDA remote control can completely control each monitoring node in real time, and the effective control distance is up to 110 m.

ZigBee网络丢包率测试

ZigBee 网络传输丢包率测试，通过 PDA 遥控器发送控制指令数据包，对 ZigBee 监控节点接收的数据包进行统计，得出 ZigBee 网络数据传输稳定性的结论。测试结果如表 1 所示。

从表 1 数据可知，单个节点最大丢包率为 0.24%，整个 ZigBee 网络的平均丢包率为 0.21%，这表明数据的无线传输稳定性高。为进一步提高数据无线传输的可靠性，每条控制指令采用应答式发送。ZigBee 监控节点收到来自 PDA 遥控器的控制指令后发出应答信号，若 PDA 遥控器未收到应答信号，将重新发送控制指令。采用此种方式对 1 万个 PDA 遥控器发送的无线控制指令进行测试，指令发送成功率达 100%。

PDA 遥控器的性能测试

PDA 遥控器的性能测试，就是通过 PDA 遥控器发送控制指令，测试选药装置监控节点、实时配药装置监控节点、喷头装置监控节点、智能移动平台监控节点的响应时间和遥控距离，测试结果如表 2 所示。从表 2 中数据可知，各个监控节点的响应时间快，PDA 遥控器完全可以实时控制各个监控节点，其有效遥控距离可达 110m。
Spraying efficiencies test

Sichuan Province of China belongs to the basin and hilly area. For the pesticide spraying operation, there is no intelligent mechanical equipment suitable for the ground walking, using artificial piggyback operation completed. Spraying efficiencies of the machine, obtained through calculating practical spraying area within a unit of time, are shown in Table 3. According to the data, the spraying efficiency of the spraying machine in time unit is 2~3 times bigger than that in artificial spraying.

Table 1
Packet drop ratio of the ZigBee network

<table>
<thead>
<tr>
<th>ZigBee monitoring node</th>
<th>Sent data packets</th>
<th>Received data packets</th>
<th>Packet drop ratio / %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pesticide selection unit</td>
<td>2880</td>
<td>2874</td>
<td>0.21</td>
</tr>
<tr>
<td>Real-time preparation unit</td>
<td>2880</td>
<td>2875</td>
<td>0.17</td>
</tr>
<tr>
<td>Nozzle unit</td>
<td>2880</td>
<td>2873</td>
<td>0.24</td>
</tr>
<tr>
<td>Average</td>
<td>2880</td>
<td>2874</td>
<td>0.21</td>
</tr>
</tbody>
</table>

Table 2
Performance test of the PDA remote controller

<table>
<thead>
<tr>
<th>Remote control distance / m</th>
<th>Pesticide selection response time / ms</th>
<th>Real-time preparation response time / ms</th>
<th>Nozzle response time / ms</th>
<th>Spraying response time / ms</th>
<th>Intelligent mobile platform response time / ms</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>15</td>
<td>18</td>
<td>16</td>
<td>15</td>
<td>23</td>
</tr>
<tr>
<td>20</td>
<td>18</td>
<td>20</td>
<td>17</td>
<td>17</td>
<td>25</td>
</tr>
<tr>
<td>50</td>
<td>22</td>
<td>22</td>
<td>21</td>
<td>23</td>
<td>28</td>
</tr>
<tr>
<td>80</td>
<td>24</td>
<td>25</td>
<td>23</td>
<td>25</td>
<td>31</td>
</tr>
<tr>
<td>100</td>
<td>27</td>
<td>29</td>
<td>28</td>
<td>26</td>
<td>36</td>
</tr>
<tr>
<td>110</td>
<td>29</td>
<td>32</td>
<td>30</td>
<td>30</td>
<td>45</td>
</tr>
<tr>
<td>120</td>
<td>380</td>
<td>No response</td>
<td>860</td>
<td>710</td>
<td>No response</td>
</tr>
</tbody>
</table>

Table 3
Spraying efficiencies

<table>
<thead>
<tr>
<th>Working environment</th>
<th>Lawn</th>
<th>Greenhouses</th>
<th>Orchard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Artificial piggyback operation / m².h⁻¹</td>
<td>1917</td>
<td>1203</td>
<td>1003</td>
</tr>
<tr>
<td>Machine operation / m².h⁻¹</td>
<td>6018</td>
<td>3527</td>
<td>3012</td>
</tr>
</tbody>
</table>

CONCLUSIONS

An intelligent monitoring system is developed to improve the safety and intelligence of pesticide spraying machines. Focusing on the mechanical structure of the pesticide spraying machine, the ZigBee technology-based design project is proposed. The monitoring node of the rotary pesticide selection unit, monitoring node of the real-time preparation unit, monitoring node of the nozzle unit, Wi-Fi camera image collecting module, monitoring node of the intelligent mobile platform, and PDA controller are also designed.

The graphics-embedded operating system of WinCE6.0 is designed on the PDA remote controller and transplanted with the embedded SQLite database to achieve strong data processing and management capacity. This system employs an LCD touch screen with a friendly human–machine interface that is easy to use and publicize. A dialogue box-based monitoring system program is developed to increase pesticide spraying efficiencies.
本文报告了利用 ZigBee 网络进行喷施自动模式及边走边喷自动模式，手动模式，喷施效率是人工的 2～3 倍。

采用 ZigBee 技术减少了系统布线，使用灵活。ZigBee 网络数据传输稳定，平均丢包率为 0.21%，有效遥控距离达 110m。

致谢

本文受到四川省教育厅自然科学基金项目资助（项目号：No. 12ZA277）。

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THE USE OF DIMENSIONAL ANALYSIS IN STUDYING THE SPRAYING PROCESS THROUGH NOZZLES AT PHYTOSANITARY TREATMENT MACHINES

PREZENTAREA METODEI ANALIZEI DIMENSIONALE ÎN STUDIUL PROCESULUI DE PULVERIZARE PRIN DUZE LA MAŞINILE DE APLICAT TRATAMENTE FITOSANITARE

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Abstract: The quality of phytosanitary treatments performed in crops is largely determined by how substances are sprayed on the plant, by the droplets size, the coverage of the plant and the reduction of the phenomenon of drift. The main elements responsible for the quality of working process of phytosanitary treatment machines are the nozzles, which are the main elements of any sprayers. This explains the great variety of spraying systems. In this paper are detailed some theoretical issues regarding the spraying process through nozzles as the basis for experiments to be carried out using the machine for high precision application of phytosanitary treatments in orchards, MSL. Analysis and modeling of this process is achieved using as main working instrument the dimensional analysis theory.

Keywords: spraying process, nozzles, droplets, dimensional analysis

INTRODUCTION

The gas-liquid two-phase fluid flow is widely found in nature such as, for example, in raindrops fall. In practical applications, an important type of such process is the flow of a two-phase fluid with an initial impulse, which leads to liquid cleavage in droplets.

This spraying process often takes place by passing the liquid through a diffuser - a nozzle. Spraying is the process that leads to the conversion of liquid flow in droplets by passing liquid under pressure through a nozzle. The forces of surface tension of the liquid, which provide it homogeneity, are canceled by internal and external factors.

Figure 1 schematically illustrates the structure of a liquid spray jet.

In the initial zone, liquid fraction is dominant, the liquid being decomposed into bubbles and ligaments (liquid non-spherical particles). In the intermediate, dense spraying zone, liquid fraction has a smaller, but significant share.

Rezumat: Calitatea tratamentelor fitosanitare efectuate în culturile agricole este determinată în mare măsură de modul cum sunt pulverizate substanțele fitosanitare pe plantă, mărimea picăturilor, gradul de acoperire a plantei și reducerea fenomenului de derivă. Principalele elemente responsabile de calitatea procesului de lucru al mașinilor de aplicat tratamente fitosanitare sunt duzele, care se constituie ca elemente principale ale oricărei mașini de stropit. Acest fapt explică și marea diversitate de sisteme de pulverizare. În această lucrare sunt aprofundate unele aspecte teoretice privind procesul de pulverizare prin duze, ca bază pentru experimentările ce vor fi efectuate folosind Mașina pentru aplicarea cu precizie ridicată a tratamentelor fitosanitare în plantățile pomicole, MSL. Analiza și modelarea acestui proces se fac utilizând ca instrument principal de lucru teoria analizei dimensionale.

Cuvinte cheie: proces de pulverizare, duze, picături, analiză dimensională

INTRODUCERE

Curgerea fluidelor bifazice lichid-gaz este întâlnită pe scară largă în natură, ca, de exemplu, în căderea picăturilor de ploaie. În aplicațiile practice, un tip important de astfel de proces este curgerea unui flux bifazic având un impuls inițial, care conduce la scindarea lichidului în picături mici. Acest proces de pulverizare are loc adesea prin trecerea lichidului printr-un ajutaj divergent - o duză. Pulverizarea este procesul care conduce la conversia vânei de lichid în picături, prin trecerea lichidului sub presiune printr-o duză. Forțele de tensiune superficială a lichidului, care îi conferă omogenitatea, sunt anulate de factori interni și externi.

Figura 1 ilustrează schematic structura unui jet de lichid pulverizat.
Here a secondary fragmentation takes place and droplet/droplet interactions, such as collision and coalescence, occur. In the diluted spraying zone spherical well formed droplets, strongly interacting with turbulent air jet are prevailing. In general, the spraying depends on the injection pressure through nozzle, the flow of fluid, the geometric characteristics of the nozzle, the viscosity and density of the liquid.

Fragmentation or hydraulic spraying is accomplished by forcing the passing of liquid through calibrated orifices, called nozzles. In the case of phytosanitary treatment machines fragmentation is achieved by means of:

- hydraulic spraying nozzles with projected jet (either flat or conical directly projected jet, or jet making an impact with a laminar surface, which changes the direction of the jet, i.e. nozzles with indirectly projected jet);
- swirling nozzles, also called tangential nozzles (with helical deflector or swirling pad), where fluid is inducted into a circular motion in a room placed before the calibrated orifice;
- twinjet hydraulic nozzles where jets hit each other, thus achieving dispersion.

Some of the most utilized nozzles (at vineyards and orchards spraying machines) are those tangential with helical deflector and conical jet. The deflector imparts a swirling motion to the liquid. The resulting turbulence splits the jet into droplets that form a cone, when leaving the calibrated orifice. The swirling chamber may be with constant volume or adjustable volume. The swirling chamber volume adjustment is done by shifting the deflector.

Depending on the average droplet size and the amount of liquid applied per unit of surface area, most authors use a classification system of the types of treatment shown in table 1.

<table>
<thead>
<tr>
<th>The diameter of sprayed liquid droplets [µm]</th>
<th>The assignment to grades of fineness</th>
<th>The treatments classification depending on particle fineness</th>
<th>The dose of applied liquid [l/ha]</th>
<th>The treatment classification depending on the volume of applied liquid</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-5</td>
<td>aerosols</td>
<td>atomization</td>
<td>&lt; 0.5</td>
<td>UULV - Ultra Ultra Low Volume</td>
</tr>
<tr>
<td>5-50</td>
<td>mist</td>
<td>atomization</td>
<td>0.5-5.0</td>
<td>ULV - Ultra Low Volume</td>
</tr>
<tr>
<td>50-100</td>
<td>very fine</td>
<td>spraying</td>
<td>5-50</td>
<td>LV - Low Volume</td>
</tr>
<tr>
<td>100-200</td>
<td>fine</td>
<td>aspersion</td>
<td>50-150</td>
<td>MV - Medium Volume</td>
</tr>
<tr>
<td>200-300</td>
<td>medium</td>
<td>aspersion</td>
<td>150-600</td>
<td>HV - High Volume</td>
</tr>
<tr>
<td>300-1000</td>
<td>coarse</td>
<td>aspersion</td>
<td>&gt;600-2500</td>
<td>VHV - Very High Volume</td>
</tr>
</tbody>
</table>

The quantitative distribution of the pulverized liquid is influenced by a number of factors such as the working pressure of the sprayer, the initial speed of the atomized jet, the flow rate of the sprayer, the spraying system used [5].

The diversification of spraying types and of phytosanitary application systems aims to improve the effectiveness of treatment.

**METODOLOGY**

Up to now it was not possible to establish the complex spray laws. Although the phenomenon of fluid decomposition was the subject of a series of theoretical and experimental research in the last 100 years, however a general theory, on which is possible to determine a priori the degree of pulverization for different types of nozzles, features of the liquid and working conditions has not yet developed.

Applying mathematical analysis confines generally to the formulation the problem, i.e. the establishment of

Aici are loc o fragmentare secundară și apar interacțiuni picătură/picătură, cum ar fi coliziunile și coalescența. În zona de pulverizare diluată predomină picăturile sferice, bine formate, care interacționează puternic cu jetul turbulent de aer. În general, pulverizarea depinde de presiunea de injecție prin duză, de debitul de lichid, de carateristicile geometrice ale duzei, de vâscozitatea și densitatea lichidului.

Fragmentația sau pulverizarea hidraulică se realizează prin trecerea forțată a lichidelor de stropit prin orificii calibrate, denumite duze. În cazul mașinilor de aplicat tratamente fitosanitare fragmentația se realizează:

- prin duze de pulverizare hidraulică cu jet proiectat (fie jet plat sau conic direct proiectat, fie jet care face un impact cu o suprafață de lamine, care schimbă direcția jetului, adică duze cu jet indirect proiectat);
- prin duze de turbionare, denumite și duze tangențiale (cu deflector eliceal sau pastilă de turbionare), unde lichidului i se imprimă o mișcare circulară într-o cameră plasată înaintea orificiului calibrat;
- prin duze hidraulice cu două jeturi care se lovesc între ele, realizându-se astfel dispersia.

Unele dintre cele mai utilizate duze (la mașinile de stropit în vini și livezi) sunt cele tangențiale cu deflector eliceal și jet conic. Deflektorul imprimă o mișcare turbionară lichidului. Turbulența rezultată scindă jetaul în picături, care se constituie într-un con, când ies din orificiul calibrat. Camera de turbionare poate fi cu volum constant sau cu volum reglabil. Reglarea volumului camerei de turbionare se face prin deplasarea deflektorului.

În funcție de dimensiunea medie a picăturilor și de cantitatea de lichid aplicată pe unitatea de suprafață, majoritatea autorilor folosesc un sistem de clasificare al tipurilor de tratament prezentat în tabelul 1.
Solving these equations is possible only in a few special cases and with a whole range of simplifying assumptions. A complete analytical solution to the problem of droplet sizes present considerable difficulties for two reasons:

a. There are not accurately known the wavelength and the intensity of oscillations that exist in jet and which depend on the initial conditions of flow through nozzle, the nozzle design, the machining and surface condition, etc.

b. The droplets obtained are the result of a complex process of sprinkling the droplets formed in the substitution area.

For the reasons given above, the possibility of a complete analytical solving of the problem is excluded. Therefore, studying the spraying is done experimentally, and the results, based on the similarity theory, are generalized to similar dynamic systems.

For establishing physical relations, the relationship between the values used for the description of physical phenomena, the dimensional analysis may be used. This method is based on the fundamental theorem of dimensional analysis, Π theorem, of Vaschy-Buckingham.

According to this theorem, the physical processes or physicochemical processes can be described by functions of independent similarity criteria that can be formed of controlling process variables. It is considered that those criteria are independent which can not be expressed through arithmetic combinations of other criteria.

Thus, if a process is determined by n dimensional variables:

\[ X_1, X_2, X_3, ..., X_n \]

it can be expressed by means of a general form criteria function:

\[ f(\Pi_1, \Pi_2, \Pi_3, ..., \Pi_m) = 0 \]

The Π theorem reads as follows: the number of independent criteria from the criteria function is the difference n−r, where n is the number of dimensional variables and r is the rank of the dimensional matrix, which is equal to the number of fundamental values depending on which may be expressed the analyzed variables [6].

In the case of the spraying process through nozzles, dimensional analysis takes into account the following function of m = 7 variables:

\[ f(D, v, \rho_l, d, \eta_l, \sigma, \rho_g) = 0 \] (1)

where:

- \( D \) – nozzle diameter, \( v \) – the relative velocity of the liquid to the surrounding gas, \( \rho_l \) – the liquid density, \( d \) – the droplet diameter, \( \eta_l \) – the dynamic viscosity of the liquid, \( \sigma \) – the surface tension of the liquid, \( \rho_g \) – the gas density
- \( D, v, \rho_l \) are fundamental values.

Dimensionless complexes (independent criteria) are:

\[ \Pi_1 = \frac{d}{D}; \Pi_2 = \frac{\eta_l}{D^2 v^{\alpha_2} \rho_l^{\alpha_3}}; \Pi_3 = \frac{\sigma}{D^4 v^{\alpha_4} \rho_l^{\alpha_5}}; \Pi_4 = \frac{\rho_g}{\rho_l} \] (2)

The dimensional matrix of variables for \( d = 3 \) fundamental values, \( L \) (length), \( M \) (mass), \( T \) (time), is:

\[ \begin{array}{c|ccc|c}
\hline
& L & M & T & \text{Fundamental} \\
\hline
D & 1 & 0 & 0 & \text{Dimensional} \\
v & 0 & 1 & 0 & \text{Dimensional} \\
\rho_l & -1 & 0 & 1 & \text{Dimensional} \\
\eta_l & 1 & 0 & 0 & \text{Dimensional} \\
\sigma & 4 & 0 & 0 & \text{Dimensional} \\
\rho_g & -1 & 0 & 1 & \text{Dimensional} \\
\hline
\end{array} \]

The dimensional analysis of variabilelor pentru \( d = 3 \) mărimi fundamentale, \( L \) (lungime), \( M \) (masă), \( T \) (timp), este:
The dimensionless complex $\Pi_2$ can be put in the form of:

$$\Pi_2 = \frac{\eta_1}{D \rho_1}.$$  

(5)

The solutions obtained are $x_1 = 1$; $x_2 = 1$; $x_3 = 1$ and results:

$$\Pi_2 = \frac{\eta_1}{D \rho_1}.$$  

(5)

The dimensional linear system of equations, expressing the condition of homogeneity, for the dimensionless complex $\Pi_3$, is:

$$\begin{align*}
(\text{L}) & \quad x_1 + x_2 - 3 x_3 = -1 \\
(\text{M}) & \quad x_3 = 1 \\
(\text{T}) & \quad x_2 = 1
\end{align*}$$  

(6)

The solutions obtained are $x_1 = 1$; $x_2 = 2$; $x_3 = 1$ and results:

$$\Pi_3 = \frac{\sigma}{D^2 \rho_1}.$$  

(7)

so that: $\Phi_1(\Pi_1, \Pi_2, \Pi_3, \Pi_4) = 0$ or $\Pi_1 = \Phi_1(\Pi_2, \Pi_3, \Pi_4)$, i.e:

$$\frac{d}{D} = \Phi_2 \left( \frac{\eta_1}{D \rho_1}, \frac{\sigma}{D^2 \rho_1}, \frac{\rho_2}{\rho_1}, \frac{\rho_3}{\rho_1} \right).$$  

(8)

The dimensionless complex $\Pi_1$ can be put in the form of:

$$\Pi_1 = k \Pi_2 \Pi_3^\alpha \Pi_4^\beta.$$  

(9)

Combinations between dimensionless complexes are made, so that appears a physical value, easy to vary in a single complex, i.e. $v$, the relative velocity of the liquid to the surrounding gas. So, dimensionless complexes are combined $\Pi_2$ and $\Pi_3$, to remove $v$, and result the new complexes $\Pi_2$ and $\Pi_3$:

$$\begin{align*}
\Pi_2 &= \frac{\eta_1^2}{D^2 \rho_1} - \frac{\eta_2^2}{D^2 \rho_1} = \frac{\eta_1^2}{D^2 \rho_1}, \\
\Pi_3 &= \frac{\sigma}{D^2 \rho_1}, \quad \frac{\rho_2}{\rho_1}, \quad \frac{\rho_3}{\rho_1}
\end{align*}$$  

(10)

The relation (9) becomes:

$$\Pi_1 = k_1 \Pi_2 \Pi_3^\alpha \Pi_4^\beta.$$  

(12)

but

$$\Pi_4 = \frac{\rho_4}{\rho_1} = \text{const} \Rightarrow k_1 \left( \frac{\rho_4}{\rho_1} \right)^c = k$$  

(13)

and results:

$$\frac{d}{D} = k \left( \frac{\eta_1^2}{D \rho_1 \sigma} \right)^a \left( \frac{\sigma}{D^2 \rho_1} \right)^b$$  

(14)

The scientific literature [4] indicates the following formulas for the size of the average diameter, $d$, of the spraying droplets, obtained by generalizing the results of

$$d = k \left( \frac{\eta_1^2}{D \rho_1 \sigma} \right)^a \left( \frac{\sigma}{D^2 \rho_1} \right)^b D$$  

and results:
experimental measurements, where fluids were water and air.

- for the domain $\eta^2: \rho \sigma d < 0.0333$

$$d = D \left( \frac{\sigma}{\rho \sigma D} \right)^{0.52} \left[ 1.24 + 0.0128 \cdot (\ln \frac{\eta^2}{\rho \sigma D} + 12) \right]$$ (15)

- for the domain $\eta^2: \rho \sigma d > 0.0333$

$$d = D \left( \frac{\sigma}{\rho \sigma D} \right)^{0.52} (2.25 + 0.24 \cdot \ln \frac{\eta^2}{\rho \sigma D})$$ (16)

The experiments to be performed, in 2015, with the Machine for the application with high accuracy of phytosanitary treatments in orchards. MSL (Figure 2) will determine the coefficients $k$, $a$, $b$, which intervene in relation (14), for different phytosanitary substances, varying the velocity of the liquid and the diameter of the nozzles.

In experimentele care urmează a fi efectuate, în anul 2015, cu Mașina pentru aplicarea cu precizie ridicată a tratamentelor fitosanitare în plantățile pomice, MSL (Figură 2) se vor stabili coeficientii $k$, $a$, $b$, care interven în relația (14), pentru diverse substanțe fitosanitare, variind viteza lichidului și diametrul duzelor.

The ultrasonic sensors detect the existence of vegetable mass. The information is transmitted to a programmable logic controller PLC that controls the feeding power-on/off of the spraying device by means of electrovalves. In the absence of vegetable mass the flow of solution is stopped. Depending on the distance that exists between the sensors and the spraying ramp and the speed of the unit equipment, the PLC applies a correction for opening the electrovalves, at the moment when ramp passes the objective to be sprayed [1].

For the determination of droplet diameter will be applied the LDPS (Laser Diffraction Particle Sizing) method, based on laser technology and electronic data processing. Laser diffraction technique is based on the principle that particles passing through a laser beam scatter light at an angle that is directly related to their size. As the particle size decreases, the spreading angle increases logarithmically. The intensity of the light dispersion is also dependent on the size and decreases proportionally to the cross-sectional area of the particle. Therefore, large particles disperse light at small angles, with high intensity, while small particles disperse light at greater angles, but at a lower intensity [9].

Following the experiments will be obtained the shape of equation (14), which describes the variation of droplets diameter. Equation (14) will replace equations (15) and (16), limited by the fact that only water was considered as pulverized fluid and obtained by technical means inferior to modern ones.

Senzori cu ultrasunete sesizează existența masei vegetale. Informația este transmisă unui automat programabil PLC care comanda pomiererea sau întreruperea alimentării dispozitivului de pulverizare, prin intermediul unor electrovalve. În cazul lipsei de masă vegetală fluxul de soluție este oprit. În funcție de distanța existentă între senzori și rampa de stropit, cât și de viteză de înaintare a agregatului echipamentului, PLC-ul aplică o corecție de timp pentru deschiderea electrovalvelor, în momentul când rampa trece prin dreptul obiectivului ce trebuie stropit [1].

Pentru determinarea diametrului picăturilor se va folosi metoda LDPS (Laser Diffraction Particle Sizing), bazată pe tehnica laserului și a prelucrării electronice a datelor. Diffrația cu laser se bazează pe principiul că particulele care trec printr-un fascicul laser împrăștie lumina la un unghi direct proporțional cu mărimea lor. Pe măsură ce dimensiunea particulelor scade, unghiul de împrăștiere crește logaritmic. Intensitatea dispersiei este dependență și de mărimea particulelor și se diminuează proporțional cu suprafața secționării transversale a particulei. Prin urmare, particulele mari dispersează lumina la unghiuri mici, cu intensitate mare, în timp ce particulele mici dispersează lumina la unghiuri mai mari, dar cu o intensitate redusă [9].

În urma experimentărilor se va obține forma ecuației (14), care descrie variația diametrului picăturilor. Ecuatia (14) va înlocui ecuațiile (15) și (16), obținute cu mijloace tehnice inferioare celor actuale, în condițiile limitării dictate de faptul că nu s-a luat în considerare decât apa, ca fluid pulverizat.
CONCLUSIONS
Due to the multiple interactions between droplets and turbulent gas phase, spraying is an extremely complex phenomenon. To describe it, quasi-empirical methods were used until the recent development of digital technology (the exponential growth of computer performance). Technological advances allow a deeper understanding of this phenomenon and, what is relevant, to the development of practical applications. In particular, it is important to know which type of nozzle is suitable for a certain type of spraying and how its performance is affected by liquid properties and operating conditions. Numerical simulation through CFD algorithms (Computational Fluid Dynamics, a branch of fluid mechanics that uses numerical methods and algorithms to analyze and solve problems involving the flow of fluids) allows the study of the process, of the state variables at all spatial and temporal coordinates.

The results of the study conducted on an experimental basis will be presented as generalized. This way of working will allow the setting of very important relations between the average diameter of the droplets, geometric characteristics of the nozzles and physical parameters of the fluid the nozzles spray, relationships that can be the starting point for the optimal sizing of the nozzles.

ACKNOWLEDGMENT
This paper has been financially supported within the project entitled “Horizon 2020 - Doctoral and Postdoctoral Studies: Promoting the National Interest through Excellence, Competitiveness and Responsibility in the Field of Romanian Fundamental and Applied Scientific Research”, contract number POSDRU/159/1.5/S/140106. This project is co-financed by the European Social Fund through Sectoral Operational Programme for Human Resources Development 2007-2013.

REFERENCES

CONCLUZII
Datorită interacțiunilor multiple între picături și faza gazoasă turbulentă, fenomenul pulverizării este deosebit de complex. Pentru a-l descrie s-a apelat, până la dezvoltarea recentă a tehnologiei digitale (creșterea exponențială a performanțelor calculatoarelor), la metode cvasi-empirice. Avansul tehnologic permite o înțelegere mai profundă a acestui fenomen și, ceea ce este relevant, la perfecționarea aplicațiilor practice. În particular, este foarte important să se știe care este tipul de duză definit pentru un anumit tip de pulverizare și cum sunt influențate performanțele acestuia de proprietățile irdului și de condițiile de operare. Simularea numerică prin algoritmi CFD (Computational Fluid Dynamics, rămâie a mecanicii fluidelor ce utilizează metode numerice și algoritmi pentru analiză și rezolvarea problemelor implicate de curgerea fluidelor) permite studierea procesului, a variabilelor de stăre în orice coordonate spațiale și temporale.

Rezultatele studiului pulverizării efectuate pe bază experimentală vor fi prezentate sub formă generalizată. Acest mod de lucru va permite stabilirea unor relații deosebite de importante, între diametrul median al picăturilor, caracteristicile geometrice ale duzelor și parametrii fizici ai fluidului pulverizat, relații care pot constitui punctul de plecare pentru dimensionarea optimă a duzelor.

ACKNOWLEDGMENT

BIBLIOGRAFIE
A NEW METHOD FOR TREE SPECIES ARRANGEMENT IN FARMLAND SHELTERBELTS AND SAND PREVENTION ANALYSIS

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Abstract: Farmland shelterbelts can yield maximum ecological benefits with the smallest occupied area of forests and result in sustainable use of farmland resources. Rapid and efficient planning of farmland shelterbelts at various scales is becoming an urgent task in ecological landscape design. Until now, the problems in studies on farmland shelterbelts combined with wind erosion models are associated with conflicts between scientific and practical requirements. Based on previous research results, a case study was conducted in Yanchi County in north-western China. The primary objectives of this study were to use a new method for the arrangement of tree species and to investigate the effects of sand prevention. In addition, changes in the trends of the input parameters under multiple wind erosion events were analyzed and tested. The results indicated that under a single arrangement of tree species, better shelter protection was provided within the shrub shelterbelt or outside the arbor shelterbelt forest. Under a different arrangement of tree species, shrubs arranged with arbor belts gave little protection on the leeward side. Arbor trees arranged with shrub belts could effectively prevent sand from the windward side, while low trees in the upwind direction provided limited protection. Cumulative percentiles of sand displacement showed that under different arrangements of tree species, the sand prevention benefit was better than that of a single tree species. In addition, the experimental error was less than 3.00% and there was close correlation between percentiles of sand displacement under multiple wind erosion events, indicating a preferable simulation effect.

Keywords: farmland shelterbelt, exponential model, summation curve method, wind erosion

INTRODUCTION

Shelterbelts are artificial barriers used to reduce wind velocity. In history they have been used to protect homes and enhance the agricultural landscape [1]. As an important type of shelterbelts, farmland shelterbelts can increase animal and plant species and enhance the ecological function of agricultural systems. Furthermore, it can protect soils from erosion forms, and boosts crop yields [5, 15]. Therefore, the construction of farmland shelterbelts plays a significant role in achieving sustainable development. So far, researches related to the farmland shelterbelt have paid more attention to the structure and protective effects of shelterbelts combined with the existing wind erosion models at a small scale.

Studies on the structure of farmland shelterbelt systems focused mainly on forest structural characteristics and their relationship with meteorological variables. In recent years, various methods and studies showed that establishing multi-band arbor trees and...
Wind erosion models include theoretical and empirical models. A theoretical model is based on the fluid mechanics principle, with a strong scientific nature founded on the laws of physical movement of sand and provides a superior explanation. The disadvantage and difficulty in developing physical-based models of sand displacement results from the high degree of complexity and randomness, which is a characteristic feature of the mechanical processes of erosion and sediment transport. Hence, the goal of a complete and applicable theoretical model seems unreachable under the given circumstances. Empirical models include the Wind Erosion Equation (WEQ) and the Revised Wind Erosion Equation (RWEQ) models. Different from the theoretical models, empirical models are able to quantify the external factors with minimum assumptions and simple calculations, and provide a wider scope of application. However, with these models, the transport mass must increase without limits for average soil erosion to remain constant for large farm fields; this does not agree with the theory that wind has a limited capacity to transport sand material. This may be true for large farm fields, i.e., there is an increase in transport mass due to the dust carried in suspension, but this portion is relatively small compared with the proportion being transported in suspension, saltation, and creep. While the wind may pick up the surface fine material, the total transport cannot increase without limit [4, 12]. Therefore, empirical models are fundamentally flawed.

At present, scientists and policy makers plan and design farmland shelterbelt forest systems at large scales, i.e., soil erosion control and desertification prevention, from a protection function perspective. Consequently, the rationality of shelterbelt patterns at the landscape scale is key for shelterbelt construction and management. However, the data required for these methods are not easy to obtain, and the methods themselves are difficult to operate, leading to the failure of farmland shelterbelt establishment. Therefore, forestry planners need a reasonable, simple, and easy to operate sand control method for the large-scale construction of farmland shelterbelt forests. New methods should overcome the parameter uncertainties and computational complexities in theoretical models as well as the physical defects in empirical models [2]. Meanwhile, a physically-based wind erosion model coupled with empirical functions and methods needs to be developed.

The objective of this study was to use the existing typical farmland shelterbelts as examples to apply a new method to quantitatively analyze the effects of sand prevention and dynamics of sand movement under different arrangements of tree species. In addition, changes in the trends of the input parameters under multiple wind erosion events were analyzed to test their stability and applicability. Our results will provide useful information for supporting the management of farmland shelterbelt forest systems.

MATERIAL AND METHOD

Experimental site

The experimental site was located at the Ningxia Yanchi Research Station of the State Forestry Administration (between 37°04′N and 38°10′N, and 106°300′E and 107°410′E, with an altitude of 1,354 m above sea level) covering an area of approximately 6,700 km². The annual precipitation averages 287 mm.
(1950–2010). Mean annual potential evaporation is 1273 mm. Mean annual temperature is approximately 8.1 °C. The prevailing wind is mainly from the northwest, and wind speed averages 3.0 m/s. The landscape is a typical transitional zone; the terrain changes from the Loess to the Ordos plateau. The soils are primarily dark loessial soil, eolian sandy soil, and sierozem soil. The vegetation type varies from dry steppe to desert grassland species [6]. The farmland shelterbelt system in the Yanchi semi-arid area is mainly distributed in the flat drought farmland and wind erosion plough land.

**Tree species selection**

A survey on the structure of the farmland shelterbelt was conducted in 2009 [14] and 2012. The results of this investigation are as follows:

- **Shrub shelter forest:** This is a 17-year pure, band shelter forest of *Hedysarum scoparium*. The shelterbelt length and width is 150 m and 40 m, respectively. The average tree height is 2.8 m, and average tree crown width is 1.5 m×2.0 m; *Salix psammophila* is a pure, band shelter forest. The direction of the forest belt runs from northeast to southwest. The length and width of the shelterbelt is 200 and 10 m, respectively, with an average tree height of 2.8 m.

- **Arbor shelter forest:** This is a 30-year pure band shelter forest of *Populus bolleana* Lauch; the forest belt direction runs from northeast to southwest; the shelterbelt is 200 m long and 50 m wide with a plant spacing of 4.0 m×4.0 m. The average tree height is 12 m, average diameter at breast height is 0.22 m, average tree crown width is 7.5 m×8.0 m, and average under branch height is 2.5 m. The porosity is 60%; The *Pinus sylvestris* var. mongolica stand is at the initial stage of growth. This is a 7-year, mesh shelterbelt forest, with a northeast to southwest direction. The shelterbelt length is 70 m, with a width of 50 m, and a plant spacing of 1.2 m×1.5 m. The average tree height is 2.8 m, average diameter at breast height is 0.27 m, and canopy density is 40%.

Dry farming farmland surrounds the shelterbelt forests. Except for the *Populus bolleana* Lauch forest, the porosity of the tree belts range from 20% to 40%. The survival rate of the shelter forest is determined by the width of the shelterbelt [13] considering the semi-arid and arid climate and the restrictions of land utilization and water resources. Therefore, this article only focuses on the width of the shelter forest (at this time, the protective direction is perpendicular to the wind direction) when determining its influence on wind erosion. In addition, it was assumed that the shelterbelt was complete without any damage and there were no dead trees in the forest. In order to simplify the calculation process, an arrangement of two tree species was considered, and a maximum protective width of 100 m was used.

**Model description**

The simulation functions used to characterize the non-uniform displacement of eroded particles were the rational function, simplified Gaussian function and exponential function. Among these three models, the rational function model is limited by mathematical calculations, and the Gaussian function can only simulate the unidirectional distance. For this study, we adopted the exponential model due to its advantages of applicability and reliability in data simulation.

The exponential model has been described by Lobb et al. [10]. The exponential model used to simulate the non-uniform displacement of eroded particles under multiple wind erosions is:

(1950–2010)，年均蒸发量 1273mm，年均气温约为 8.1°C。主风向为西北风，平均风速为 3.0m/s。地貌景观属于交替区域，地貌从黄土高原变化至鄂尔多斯平原。土壤类型为黑土士、风沙土和灰钙土，植被类型从干草原变化至荒漠植被[6]。盐池县沙区农田防护林主要分布在农田集中的平缓干旱沙地和风蚀沙地。

**防护林树种选择**

农田防护林林分结构调查时间为 2009 年[14]和 2012 年，调查结果如下:

- **灌木防护林：** 花棒 17 年生纯林，带状防护林，长 150m，宽 40m，平均树高为 2.8m，平均冠幅为 1.5m×2.0m；沙柳纯林，带状防护林，林带呈东北-西南走向，带长 200m，带宽 10m，平均树高为 2.8m。

- **乔木防护林：** 新疆杨 30 年生纯状纯林，林带呈东北-西南走向，带长 200m，带宽 50m，株行距为 4.0m×4.0m，平均树高为 12m，平均胸径为 0.22m，平均冠幅为 7.5m×8.0m，平均枝下高为 2.5m。林带疏密度为 60%。樟子松林分处于生长初期，为 7 年生网状防护林，林带呈东西—南北走向，带长 70m，带宽 50m，株行距为 1.2m×1.5m，平均树高为 2.8m，平均胸径为 0.27m，郁闭度为 40%。

各防护林带周围为平坦开阔的沙质旱作农田。除新疆杨林外，其它防护林疏密度在 20%到 40%。防护林带宽度是决定防护林存活率的重要决定因素[13]。考虑到在半干旱、干旱地区气候条件和受制于土地利用率、水资源限制，因此，本文只针对防护林带宽度（此时防护林方向与风向成垂直方向）对风蚀作用的影响分析，并假定防护林带无破损、树木无死亡情况出现，为了简化计算过程，对 2 种树种进行配置组合，最大防护距离为 100m。

**模型描述**

模拟功能可以模拟可蚀性颗粒的不均匀分布状态，有：有理函数模型、简化的高斯模型和指数模型。在这三种模型，有理函数模型在数理学计算上存在局限性。高斯模型只能模拟风沙流在单一水平下的移动距离。本文采用指数模型，优点是在数据模拟、预测拥有更好的适用性和可靠性。

本文采用 Lobb[10]对指数模型的描述，可模拟连续风蚀下可蚀性颗粒的的不均匀移动距离分布，公式为:
The summation curve method was used to quantify the sand prevention effect. The methods used to calculate the summation curve are described by Lobb and Kachanoski [8, 9, 11]. In this paper, the summation curve method was improved for application to wind erosion studies. Eroded particles under wind erosion events were measured using established methods, i.e., the estimated eroded particle distribution for a series of sequential hypothetical sand sources with a length exceeding the maximum distance to which particles were transported was used to generate a summation curve to calculate the mean eroded particle movement in the windblown direction (Fig. 1a). Using the summation curve method, the mean eroded particle distance per unit width and the average eroded depth \( (D_w) \) was calculated using the following equation (2):

\[
D_w = \int_0^\infty (1 - c_i) dx, \ [m]
\]

The summation curve was used to quantify the dispersion of the eroded particles. Three steps were used in this process. First, the areas above and below the summation curve, delineated by \( x = 0 \), were used to calculate \( u_{s1} \):

\[
u_{s1} = \sqrt{\int_0^\infty c x^2 dx + \int_0^\infty (1 - c_i)x^2 dx - \int_0^\infty (c x dx)^2} / C, \ [m]
\]

Second, the areas above and below the summation curve, delineated by \( x = D_w \), were used to calculate \( u_{s2} \) (Fig. 1b):

\[
u_{s2} = \int_0^\infty (1 - c_i) dx, \ [m]
\]

Third, the cumulative percentiles of the eroded particles amount were calculated. \( D_{W50} \), \( D_{W75} \), and \( D_{W95} \) correspond to the 50th, 75th, and 95th cumulative percentiles of the amount of eroded particle displacements respectively (Fig. 1b).

To characterize the general form of the distribution of eroded particles, \( u_{s1} \) and \( u_{s2} \) were expressed as relative measures of \( D_w \):

\[
u_{s1,2} = 100 \times \frac{u_{s1,2}}{D_w}, \ [%]
\]

where: \( C_w \) is the total amount of sand, \( x \) is the sand displacement distance (m), \( C^T(x) \) is the amount of sand at \( x \) after wind erosion, and \( D^W \) is the ratio of the windblown depth and eroded soil depth, with a value of 1. \( D_w \) is the wind erosion model coefficient (defined as an average sand displacement distance (m)).

This model assumes that the extent of sand translocation is infinite (the series of distributions is summed to generate a summation curve, \( c \)); this extent is described experimentally as the extreme point at which applied eroded particles can be measured above background levels. The data generated by the exponential model can be used with the summation curve method to quantify the sand prevention effect.

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\]

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\[
u_{s2} = \int_0^\infty (1 - c_i) dx, \ [m]
\]

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\[
u_{s1,2} = 100 \times \frac{u_{s1,2}}{D_w}, \ [%]
\]

式中, \( C_w \) 为风沙总量, \( x \) 为风沙移动距离 (m), \( C^T(x) \) 为风蚀后在 \( x \) 距离处的风沙量, \( D^W \) 为吹蚀深度与可蚀性土壤层深度之比, 值为 1; \( D_w \) 为风蚀模型系数 (定义为风沙平均移动距离 (m))。

指数模型假定风沙移动量是趋于无限的 (累积比例量为 \( C_w \)), 并描述在风力作用下所有被吹蚀的颗粒移动距离大于起始位置处。将指数方程产生的模拟数据代入到累积曲线方法中, 可以对防沙效果进行定量分析。

累积曲线方法: 累积曲线方法由 Lobb 和 Kachanoski[8,9,11]提出, 本文中, 累积曲线方法被改进以应用于风蚀研究中。在风蚀作用下, 采用累积量计算方法, 例如, 在风蚀方向下, 假设一系列相同的风沙源被风蚀, 直到可蚀性颗粒移动至最大距离, 此时对风蚀方向下的可蚀性颗粒量累积加和计算, 得到累积曲线 (图 1a)。因此, \( D_w \) 代表颗粒物在平均风蚀宽度和深度下的平均移动距离, 计算公式 (2):

\[
D_w = \int_0^\infty (1 - c_i) dx, \ [m]
\]

累积曲线方法可以用于量化可蚀性风沙颗粒分布过程, 分为三步计算过程: 第一步从 \( x = 0 \) 处计算风沙颗粒分布过程, 得到 \( u_{s1} \):

\[
u_{s1} = \sqrt{\int_0^\infty c x^2 dx + \int_0^\infty (1 - c_i)x^2 dx - \int_0^\infty (c x dx)^2} / C, \ [m]
\]

第二步, 当风蚀颗粒移动至平均移动距离 (\( x = D_w \)), \( u_{s2} \) 计算公式 (图 1b):

\[
u_{s2} = \int_0^\infty (1 - c_i) dx, \ [m]
\]

第三步, 风沙量累积百分数计算, \( D_{W50}, D_{W75}, D_{W95} \) 和 \( D_{W95} \) 分别代表累积百分数 50%, 75%, 90% 和 95% 的风沙量移动距离（图 1b）。

区分对颗粒物一般性分布过程的描述, 可将计算出的 \( u_{s1} \) 和 \( u_{s2} \) 与实际输出值 \( D_w \) 比较, 得到计算误差 \( u_{s1,2} \) （%），公式为:

\[
u_{s1,2} = 100 \times \frac{u_{s1,2}}{D_w}, \ [%]
\]
The first and second steps still take the general form of the distribution of the amount of sand particles based on the empirical results. Consequently, for the actual calculations, \( u^*_1 \) and \( u^*_2 \) should equal 100% of \( D_W \) and 50% of \( D_W \), respectively.

\( D_W \) can also be converted directly to mass, \( D_M \) (kg/m), which is the eroded particle mass per unit width:

\[
D_M = s \rho D_W, \quad [\text{kg/m}]
\]

where: \( \rho \) is bulk density (kg/m\(^3\)). \( s \) is wind erosion width (m).

Fig. 1 - Summation Curve Method. a) Sand source: sand before wind erosion is indicated by the dotted line (\( L_P = 1.00 \) m); sand after wind erosion is indicated by the distribution line below; the summation curve represents the accumulation of sand (\( D_W = 0.50 \) m; top line above). b) Dispersion is indicated by \( D_{W50}, D_{W75}, D_{W90}, \) and \( D_{W95} \), i.e., the cumulative percentile of the particles along the path of 50%, 75%, 90%, and 95% displacement, respectively. Arrows represent sand movement to a distance of \( D_W \) where \( u^*_2 \) was calculated.

The magnitude of the undulations on the summation curve, \( \varepsilon \) (m), was calculated over a distance equal to \( L_P \) (m), beyond the distance to which the eroded particles were observed, \( L_S \) (m). The coefficient of the experimental error and translocation variability (\( \varepsilon^* \)) was estimated as:

\[
\varepsilon^* = \left( \int_{L_S}^{L_S+L_p} \left[ 1 - c_l \right] dx \right) \frac{D_M}{D_W + L_P} \times 100, \quad [%]
\]

where:
- \( L_P \) is sand source (m), \( L_S \) is maximum sampling distance (m).

Theoretically, the summation curve should increase steadily from \( x = 0 \) to its maximum at \( L_S + L_P \) and then decrease steadily to a value of zero. However, the summation curves generated from experimental data are not smooth; rather, they undulate (Fig. 2a). These undulations are a result of experimental errors. Therefore, experimental errors exist. \( \varepsilon \) is a measure of the inherent variability in translocation (Fig. 2b). Hence, \( \varepsilon^* \) is referred to as the experimental error.

式中 \( D_W \) 为风沙源距离（m），\( L_S \) 为最大风沙采样距离（m）。理论上，累积曲线从 \( x = 0 \) 处上升，直到移动至最大距离 \( L_S + L_P \)。然后平稳下降至 0。然而，源于实验数据得到的曲线方程并非是一条平滑的直线，相反，会产生波动（图 2a）。这些波动是由于实验内部误差造成的，因此，实验误差一直存在，由于 \( \varepsilon \) 为实验内部系统性存在结果（图 2b）。所以 \( \varepsilon^* \) 可认定为是实验误差。
Fig. 2 - Experimental error demonstration: a) Sand source: sand before wind erosion is indicated by the dotted line ($L_P=1.00 \, m$, $D_W=0.50 \, m$); b) $\epsilon$ for the summation curve method, represented by the hatched area ($L_P=1.00 \, m$, $L_S=5.70 \, m$).

$D_W$ was calculated under different tree species arrangements using the following:

$$D_W = \frac{D_{W-\text{tree species A}} + D_{W-\text{tree species B}}}{n}, \, [m]$$

where:

$D_{W-\text{tree species A}, B}$ is the average sand displacement distance ($m$) of the shelter tree species A and B. The value of $D_W$ was determined as the mean of $D_{W-\text{tree species A}}$ and $D_{W-\text{tree species B}}$.

**RESULTS**

*Outside forest sand source parameter input selection*

In this study, it was assumed that all sand particles originated from outside the forest (bare sandy land, no shelter forest) and were distributed within the farmland shelterbelts. Therefore, we defined the outside forest farmland as sand sources and the shelter belts as storage sinks. This paper focuses on sand with a moving distance less than or equal to 100 m; therefore, the sand source parameter input should ensure that the average sand moving distance is greater than 50 m (the boundary between tree species A and B), and that the largest moving distance exceeds 100 m from the outer boundary. Here, the diameter of the outside forest sand source was set as 100 m, the sampling point interval was 1 m, the sand bulk density was 1100 kg/m$^3$ and the wind erosion depth was 0.0010 m. The distribution pattern of the eroded particles was simulated by applying the exponential model, and then the $D_W$ value was obtained using the summation curve method. The optimal parameter was selected when $D_W$ was 60 m, 50% of the accumulated amount of sand concentrated around a distance of 50 m, and the largest moving distance exceeded 100 m (Fig. 3).

式中

$D_{W-\text{tree species A}, B}$ 是防护林树种 A 和 B 的林内风沙平均移动距离（m）。总 $D_W$ 的计算为防护林树种 A 和 B 的风沙移动距离的平均值。

**结果**

*林外风沙源参数输入选择*

本文假定所有风沙颗粒来自于林外（裸沙地，无防护林），并最终分布在农田防护林内。因此，林外裸沙地设为源，防护林内为汇。本研究只考虑 100 m 范围内的风沙移动走向。因此，在林外风沙源参数输入上，应确保风沙源风沙移动平均距离大于 50m（树种 A 和 B 的配置边界），外边界最大移动距超过源内 100m。在本文中，设定林外风沙源直径距离为 100m，采样点为 1m，风沙容重为 1100kg/m$^3$。土壤层率为 0.0010m。指数方程提供风沙分布模拟值，代入到累计曲线方法中，得到各参数 $D_W$ 输出值。图 3 为参数筛选后得到最佳参数输入值，当 $D_W$ 为 60m 时，50%的累积风沙量集中于 50m 处，最大移动距离超过 100m（图 3）。
Effects of different arrangements of shelterbelt tree species

Previous studies indicated that the ventilation coefficients of *Hedysarum scoparium*, *Salix psammophila*, and *Pinus sylvestris* var. *mongolica* shelter forests belonged to a tight structure with ventilation coefficients of 0.2. In contrast, the *Populus bolleana* Lauche shelter forest had a loose structure with a ventilation coefficient of 0.3 [7]. The effective sand prevention distances (outside forest) were 0.5 H for *Hedysarum scoparium*, 1 H for *Salix psammophila*, 4 H for *Populus bolleana* Lauche, and 2 H for *Pinus sylvestris* var. *mongolica*. The effective sand prevention distances (inside forest) were 4 H, 2 H, 0.5 H, and 1 H for *Hedysarum scoparium*, *Salix psammophila*, *Populus bolleana* Lauche, and *Pinus sylvestris* var. *mongolica*, respectively [14].

Thus, the value of the sand moving distance within the *Populus bolleana* Lauche shelter forest was set at 6 m. The $D_W$ values of *Hedysarum scoparium*, *Salix psammophila*, and *Pinus sylvestris* var. *mongolica* were set at 2 m, 4 m, and 8 m, respectively, according to different ventilation coefficients, and $L_P$ was 1 m, and the sand sampling point was 0.1 m.

Under the single arrangement of tree species, the shrub shelter forest could not prevent sand movement outside the forest belt, but effectively prevented sand movement within the forest belt (table 1). The arbor forest effectively prevented wind erosion outside the forest. However, such a prevention effect was not obvious inside the forest.

The results of different tree species arrangements indicated that when the shrub tree species was arranged with the arbor tree species, there were vast quantities of sand accumulation on the lee side of the shelterbelt. Although the sand prevention effect was better than a single tree species, the effect was insignificant. An arbor forest with shrub tree species can effectively prevent most of the sand on the windward side, but was
associated with a higher calculation error. However, short
arbor trees with shrub tree species such as *Pinus sylvestris* var. *mongolica* could not provide effective
protection to external sand sources.

The numerical procedures used to calculate eroded particle displacement resulted in errors. Under a single
tree species arrangement, the *Pinus sylvestris* var. *mongolica* shelter forest showed the highest error of
1.40%. Under a different tree species arrangement, the *Populus bolleana* Lauche shelter forest was associated
with the highest error of 2.97%. The main reason for
these errors is that sand loss was calculated using the
exponential model. In this research, the calculation error
was controlled within 3.00% under conditions where was
assumed that experimental errors were negligible and the
results were satisfactory.

For the hypothetical data, \( u_{S1} \) and \( u_{S2} \) were lower
than the average \( D_w \). This is due to the fact that these
measures relate to the general form of the distribution of
eroded particles. As the form of the distribution
approached that of a step, \( u_{S1} \) approached a value of
100% and \( u_{S2} \) approached a value of 50%, which agree
with the previous equations mentioned above.

![Table 1](image)

<table>
<thead>
<tr>
<th>Tree species arrangement</th>
<th>( D_w ) input</th>
<th>( D_w ) output</th>
<th>( u_{S1} )</th>
<th>( u_{S2} )</th>
<th>( \varepsilon )</th>
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<tr>
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<td>7.99</td>
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<td>37.08</td>
<td>1.40</td>
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<td>1.34</td>
</tr>
</tbody>
</table>

* H represents *Hedysarum scoparium*, S represents *Salix psammophila*, B represents *Populus bolleana* Lauche,
P represents *Pinus sylvestris* var. *Mongolica*

Amount of eroded particle dispersion (50%, 75%,
90%, and 95%) expressed as percentiles of cumulative
translocation can provide useful information for
understanding wind erosion and the dynamics of sand
movement.

Figure 4 shows that greater sediment deposition
occurred on the lee side of the arbor trees, and the
potential of wind erosion was higher than with shrub tree
species. Complete shelter belts (tall trees), such as
*Populus bolleana* Lauche, had the greatest sand
prevention effect, while incomplete shelter belts (short
trees), such as *Pinus sylvestris* var. *Mongolica*, did not
exhibit a clear sand prevention effect. In general, the
combination of different tree species showed a better
sand prevention effect than a single shelter forest.

风沙量百分数移动分布（50%，75%，90%和95%）能
为更好理解风蚀作用和风沙移动的动态过程提供有效
信息。

图 4 表明，乔木林在背风处严重积沙，并且其潜在风蚀
率要高于灌木树种。完整的防护林带（高大的乔木树种）
，如新疆杨防护林对于风沙防治效应效果最为明显，
但是不完整的防护林带（低矮的乔木树种），如樟子松防
护林，防治风沙效果并不明显。总体来说，不同树种组合
下的防治风沙效果要好于单一树种下的防护林配置。
Sand loss was estimated using the exponential model. In general, small amounts of sand loss are associated with a low experimental error in the summation curve method. Figure 5 shows that there was a positive correlation between sand loss and the $D_W$ input. Sand loss with Pinus sylvestris var. mongolica was 3 times that of a single tree species and 6 times that of different tree species arrangements. But this difference was considered insignificant. In theory, only when the $D_W$ value exceeds the maximum distance ($L_S$) will calculation results generate significant error [3]. Therefore, $L_S$ should be set as far as possible. In addition, for accurate measurement of sand displacement, $L_P$ should be set as short as possible, at least 1 m, and the sand sampling interval should be set to least 0.1 m to filter out this undulation (error). Consequently, a smoother summation curve will be generated, which can provide better results.

风沙损失量

指数方程用来估算风沙损失量。一般而言，较小的损失量带入到累计曲线方法中产生误差也较小。图 5 看出，$D_W$ 输入值与损失量成一定程度的正相关。樟子松树种配置上风沙的损失量分别是单树种损失量的 3 倍和不同树种配置损失量的 6 倍。但是差异并不显著。理论上，只有当 $D_W$ 值超过最大的距离 $L_S$ 时，计算结果会造成较大误差 [3]。因此 $L_S$ 值应尽量设置较远。另外，为准确计算风沙移动距离，$L_P$ 应设置较小，至少为 1m，并且风沙采样点设置至少为 0.1m，这样可以过滤掉波动带来的实验误差。因此，计算得到的累计曲线会更加平滑，可提供较为理想的实验结果。
Multiple wind erosion process analysis

Wind erosion can significantly affect the underlying surface. For the purpose of long-term planning of sand prevention, it is essential to analyze these effects under multiple wind erosion events. As discussed above, the exponential function can simulate the distribution of eroded particles under a continuous wind erosion process, and the summation curve method can determine the dynamics of sand movement. Therefore, the data generated by the exponential model can be understood as the process of sand movement under continuous wind erosion events or multiple years of wind erosion. In this paper, Pinus sylvestris var. mongolica and Hedysarum scoparium trees were selected to demonstrate the process of sand movement under 5 continuous wind erosion events. Figure 6 shows that under a constant $D_W$ parameter input, the output values were stable; a small amount of sand loss did not affect the simulation results. Linear regression analysis indicated that there was strong correlation between sand movements under multiple wind erosion events, whereas $R^2$ decreased with an increase in the cumulative percentage. Theoretically, during multiple wind erosion events, the cumulative percentage of the sand moving distance should show a decreasing trend due to the shelter forest controlling the wind effect. In general, the summation curve is stable and accurate, and can be used as a mid- or long-term protective model.

Fig. 6 - Analysis of multiple wind erosion events. (a, b) Sand source (inside forest) changing trend (using Hedysarum scoparium as an example) and linear relationship of the $D_{505}$, $D_{755}$, $D_{905}$, and $D_{955}$ values. (c, d) Sand source (inside forest) changing trend (using Pinus sylvestris var. mongolica as an example) and linear relationship of the $D_{505}$, $D_{755}$, $D_{905}$, and $D_{955}$ values.
CONCLUSIONS
The ultimate goal of wind erosion research is to establish erosion models that can predict particle erosion losses at different temporal and spatial scales. In general, the scientific and practical explorations of wind erosion studies are rather limited; therefore, it is necessary to rebuild the theoretical based method for a wider application.

Based on former studies, this paper proposed a new method of analysing the effects of sand prevention in a shelterbelt forest. Because it is difficult to obtain accurate data, this paper used general conclusions from previous studies as estimates. The results indicated that experimental errors were well controlled and the conclusions drawn from the final analysis indicate that this method can provide direction and idea for shelterbelt management.

Compared with the empirical model, the summation curve method accounts for the fundamental theories of physical principles of blown sand and sedimentation processes. In addition, the theoretical model is more complicated than the summation curve due to the numerical calculations. Thus, the summation curve is the best method.

In the actual calculation and application, the summation curve method has two advantages. The first is that the input parameters are simple; the second is that this method can be used at different scales. Therefore, the summation curve can be applied to a wider scope when assessing farmland protection forest.

Considerable work needs to be conducted in future research. In this study, the assessment method was based on a single direction (width of the belts). However, different areas vary with respect to the topography, land use, degree of wind erosion and other factors, and these factors interact with each other. Therefore, it is necessary to establish a classification standard in future studies.

An additional decision factor in the design of optimal farmland shelterbelt systems involves the water requirements of the tree species because water is a limited resource and may be the main factor that prevents long-term maintenance of farmland shelterbelt systems in arid or semi-arid regions. Further studies are required to determine the water consumption of shelter forest tree species and the local water resources to explore the best afforestation density and shelterbelt forest structure.

ACKNOWLEDGEMENT
This work was supported by the National Basic Research Program of P. R. China (2013CB429906); National "Twelfth Five-Year" Plan for Science & Technology Support (2012BAD16B02); The Commonweal Project of State Forestry Administration of P. R. China (201304325)

REFERENCES

讨论与结论
风蚀研究最终目标是建立能够预测不同时间尺度和不同地表类型的风蚀模型。一般而言，过去对风蚀研究的探索兼顾科学性和实用性较少。因此，重新构建具有理论基础与更广泛适用性的风蚀模型势在必行。

本文在现有防护林研究基础上，加入了新的研究方法，分析了防护林防治风沙效果。因为计算所需要的精确数据获取难度大，故本文采用前人研究中的一般结论进行估算。研究结果表明，实验误差被较好的控制，并且最终分析得到的结论可以为防护林建设管理提供新的研究方向和思路。

对比经验模型，累积曲线方法采用了风沙吹蚀沉降的基础物理模型。另外，理论模型较累积曲线方法在数理计算上要更加复杂。因此累积曲线方法要优于以上模型。

实际计算、应用上，累积曲线方法具有两方面优势，一是输入参数简单；二是可以应用至各个尺度。因此，累积曲线方法可以应用至更大范围内的农田防护林评估。

下一步需要进行的工作是，本文只考虑单一方向的风蚀效应（防护林带的宽度）。然而，不同地区的地形、土地利用、风蚀率和其他相关因子也不尽相同，并且这些因子相互作用影响。因此未来的工作需要将这些因子进行分类研究。

另外，需要考虑的因素是在设计最优化合理的农田防护林时将农田防护林树种的水分利用情况考虑进来，因为在干旱和半干旱地区，受干旱水资源限制，水分是阻碍农田防护林系统长期维持的主要因素。未来工作也需要结合防护林各树种蒸腾耗水规律和当地水资源条件，研究探讨最佳防护林造林密度和结构。

致谢
国家重点基础研究发展计划项目（2013CB429906）、“十二五”国家科技支撑计划项目（2012BAD16B02）、国家林业局公益性行业科研专项（201304325）。

参考文献
[4] Fryrear D.W., Bilbro J.D., Saleh A., Schomberg H.,

Abstract: The study has found a continuing beneficial impact of electromagnetic treatments on seeds of Bulgarian tomato varieties: Милйана, Пловдивска каротина, Водолей F₁, IZK Alya and Ideal after 365 days storage to sowing at a voltage between the electrodes U=12 kV and duration of impact ≈35 s. The stimulating effect on germination energy and laboratory germination increase compared to that of control seeds of 1.25 to 15%.

Keywords: pre-sowing electromagnetic treatments, tomato seeds, germination energy, laboratory seed germination

INTRODUCTION

Tomato is a traditional vegetable crop for the territory of Bulgaria. There is a close relation between high and qualitative yields and sowing qualities of the seeds [3]. The germination energy and germination are ones of the most important features of the seeds. The low germination energy is a reason for slower initial rate of root and hypocotyl growth for tomato seed germination as well as later for germination in field conditions. The sowing rate is determined depending on the seed germination [7]. Alternative, ecological pure methods and technologies for stimulation of the sowing properties of the seeds by their treatment in electric [12], magnetic [1.9] and electromagnetic [11] fields are being searched. Positive effect of the laboratory (5…12%) and field germination (16…20%) of cabbage seeds after electromagnetic treatment [2] has already been recorded.

A peculiarity of the Bulgarian tomato seeds variety after electromagnetic pre-sowing has been established and it depends on the duration of the electromagnetic impact and duration of storage prior to planting [4]. The longer the duration of seed stays (12 days) from treatment to sowing and the higher value of applied voltage of treatment (12 kV) is, a stimulating effect on the seed quality in the studied tomato varieties has been found.

The favourable pre-sowing electromagnetic impact on the tomato seeds from variety Милйана is retained after stay prior to sowing of 365 days. It is of interest whether the impact of the pre-sowing electromagnetic treatments would be retained after longer stay in seeds from other tomato varieties [4].

The purpose of the study is to establish the effect of pre-sowing electromagnetic treatment and duration of storage on the sowing qualities of the seeds from Bulgarian tomato varieties.
MATERIAL AND METHOD

The object of the study are the seed qualities from the accepted Bulgarian tomato varieties Milyana, Plodivska karotina, Vodoley F1, IZK Alya and Ideal, described in our previous investigation [4]. The seeds have been subject to electromagnetic treatment and have then stayed for 365 day prior to sowing.

As in other similar studies [5, 13] the pre-sowing electromagnetic treatments were performed in the AC corona discharge field between the electrodes (blade-plate). The adopted controlled factors of impact for this study were also the voltage between the electrodes U (kV) and the duration of treatment \( \tau \) (s). The experiment planning matrix [10] with two controlled factors on two levels (type 2\(^2\)) of pre-sowing treatment is presented in Table 1.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Voltage, U</th>
<th>Duration of impact, ( \tau )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>+1</td>
<td>12</td>
</tr>
<tr>
<td>2</td>
<td>-1</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>+1</td>
<td>12</td>
</tr>
<tr>
<td>4</td>
<td>-1</td>
<td>6</td>
</tr>
<tr>
<td>Control</td>
<td>untreated</td>
<td></td>
</tr>
</tbody>
</table>

After treatment the seeds were kept in packing paper in a dry and dark storeroom. After 365-day storage i.e., on February the 7th 2014 the seeds from each variant of impact were set in 4 replications with 20 seeds in each replication according to the adapted methods by ISTA [6], for germination in Petri dishes in thermostat at temperature of 25°C and relative humidity of 95%. Untreated seeds for the relevant varieties were used as a control.

The following sowing qualities of the seeds were studied: germination energy – g.e. (%) and laboratory germination – g. (%) being read on 5-th and 14-th day, respectively after seed set for germination. For greater comparability the data from each variant of treatment is presented as percentage in relation to that of the control (%/c).

The obtained data was processed statistically by variation [8] and regression analysis [10].

RESULTS

The results for germination energy and laboratory germination of the seeds untreated in the electromagnetic field are given in Table 2.

<table>
<thead>
<tr>
<th>Sowing qualities</th>
<th>Variety</th>
<th>Milyana</th>
<th>Plodivska karotina</th>
<th>Vodoley F1</th>
<th>IZK Alya</th>
<th>Ideal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germination energy, %</td>
<td>( \bar{x} \pm \text{sd} )</td>
<td>81.25</td>
<td>88.75</td>
<td>83.75</td>
<td>32.50</td>
<td>90.00</td>
</tr>
<tr>
<td></td>
<td>( \pm \text{sd} )</td>
<td>± 3.75</td>
<td>± 4.27</td>
<td>± 3.75</td>
<td>± 3.22</td>
<td>± 3.74</td>
</tr>
<tr>
<td></td>
<td>CV%</td>
<td>9.23</td>
<td>9.62</td>
<td>8.96</td>
<td>19.86</td>
<td>7.86</td>
</tr>
<tr>
<td>Germination, %</td>
<td>( \bar{x} )</td>
<td>87.50</td>
<td>92.50</td>
<td>90.00</td>
<td>76.25</td>
<td>93.75</td>
</tr>
<tr>
<td></td>
<td>( \pm \text{sd} )</td>
<td>± 4.79</td>
<td>± 3.23</td>
<td>± 3.54</td>
<td>± 4.27</td>
<td>± 2.39</td>
</tr>
<tr>
<td></td>
<td>CV%</td>
<td>10.94</td>
<td>6.98</td>
<td>7.86</td>
<td>11.20</td>
<td>5.11</td>
</tr>
</tbody>
</table>
In further studies these results are accepted for 100% and the data from the other crops is reduced to them. The variety IZK Alya demonstrates the lowest percentage of germination energy and laboratory germination in comparison to the remaining studied varieties. This is cherry type tomato variety which seeds are the smallest amongst the studied seeds, with the lowest absolute weight being probably a reason for lower sowing qualities of the seeds compared to the other varieties included in the study. In 2013 it was established that the germination energy and the laboratory germination of the seeds from variety IZK Alya are 33.75% and 91.25%, respectively [4]. The sowing qualities of the control seeds are g.e.=32.5% and g.=76.5% after stay of 365 days. These values are lower than those obtained in 2013 that are 33.75% and 91.25%, respectively. The laboratory germination and germination energy decrease with increase of the seed age that is both species and variety peculiarity.

The analysis of data given in Table 2 shows that in comparison with 2013, a decrease of g.e. in the control seeds of the other tomato varieties in 2014 is observed but it is within the range of (5…10)%, but of g. – (2…12)%.
The results from the study for germination energy and laboratory germination of the seeds from all varieties treated in electromagnetic field according to the variants in Table 1 and stay 365 days prior to sowing in 2014 are presented in Figure 1. The results were given as percentage in relation to the ones from the control (%/c). The analysis demonstrates that for varieties Milyana, Plovdivska karotina and IZK Alya a dominant positive impact on g.e. and g. after treatment of the seeds by variant 1 (U=12 kV, τ=35 s) is obtained. This effect is kept for 365 days after electromagnetic treatment as for Milyana g.e.=109.23%/c and g.=105.71%/c and for variety Plovdivska karotina g.e.=109.86%/c and g.=108.11%/c.

The established low natural (for seed from the control) g.e. and g. in variety IZK Alya have the highest impact from the electromagnetic treatments among the mentioned two varieties. The values of the two studied parameters, obtained after treatment of the seeds from this variety by variant 1 and stay for a period of 365 days prior to sowing are g.e.=146.15%/c and g.=116.39%/c. This is significantly more than the observed parameters of the above mentioned varieties Milyana and Plovdivska karotina.

The seeds form variety Vodoley F1 show a slight increase of the two observed parameters after treatment by variant 1. After stay for a year the values are g.e.=101.49%/c and g.=102.78%/c.

It was established that after treatment of the seeds from variety Ideal by variant 1 and stay of 365 days prior to sowing, the germination energy is slightly depressed. It is 98.61%/c towards the control. The peculiarity for this variety is that the read laboratory germination is g.=104.00%/c.

The above could be explained with variety peculiarity of the individual seeds when the other factors of influence and conditions are identical.

Figure 1 also shows that after seed treatment with the parameters of the other variant there is a depression of the germination energy and laboratory germination in different degrees, for different variants of treatment, in different tomato varieties. An exception was established in variant of treatment 3 (U=12 kV and τ=5 s) where the seeds of variety Ideal demonstrated the highest value of their response after pre-sowing treatment. Germination

![Fig. 1 – Germination energy and seed laboratory germination of electromagnetic treated seeds after 365 days length of storage](image-url)
energy for this variety is $g.e.=109.72\%$ and $g.e.=101.33\%$. The similar situation was observed in variety Пловдивска каротина. The values read for the seeds of this variety, treated by variant 3 are $g.e.=107.04\%$ and $g.e.=108.11\%$.

The established repression of the germination energy or laboratory germination of the seeds can be due to the combination of the factors levels, prolonged stay of the seeds within 365 days and their variety peculiarity.

The analysis of the statements made in [4, 5, 13] show a regularity of the impact of the pre-sowing treatment. It could be concluded that after pre-sowing electromagnetic treatment in values of the controlled factors by variant 1 ($U=12$ kV and $\tau=35$ s) and longer stay of the seeds (12 or 365 days), dominating positive responses were obtained followed by increases in the germination energy and laboratory germination of the seeds.

According to the data from Table 1 the experiment that was conducted is with two controlled factors of influence: the applied voltage between the electrodes $U$ (kV), accepted as coded quantity $x_1$ and duration of the impact, $\tau$ (s) – $x_2$. This gives a possibility to calculate the equations of regression of the studied parameters germination energy and laboratory germination being given in $\%$. All equations are from the following type [10]:

$$\hat{Y} = b_0 + b_1 \cdot x_1 + b_2 \cdot x_2 + b_1b_2 \cdot x_1 \cdot x_2$$

(1)

According to the established values (in $\%$) of the particular observed parameters, the following equations of regression are obtained:

for variety Милана:
- germination energy
  $$\hat{Y}_{g.e.} = 99,615 + 5,000 \cdot x_1 + 1,925 \cdot x_2 - 2,690 \cdot x_1 \cdot x_2$$
  (2)
- laboratory germination
  $$\hat{Y}_{g.l.} = 98,320 + 4,535 \cdot x_1 - 1,680 \cdot x_2 + 4,535 \cdot x_1 \cdot x_2$$
  (3)

for variety Пловдивска каротина:
- germination energy
  $$\hat{Y}_{g.e.} = 103,167 + 5,282 \cdot x_1 + 0,352 \cdot x_2 + 1,058 \cdot x_1 \cdot x_2$$
  (4)
- laboratory germination
  $$\hat{Y}_{g.l.} = 105,067 + 3,042 \cdot x_1 - 1,012 \cdot x_2 - 1,012 \cdot x_1 \cdot x_2$$
  (5)

for variety Водолей $F_1$:
- germination energy
  $$\hat{Y}_{g.e.} = 101,120 - 1,865 \cdot x_1 - 1,120 \cdot x_2 - 0,375 \cdot x_1 \cdot x_2$$
  (6)
- laboratory germination
  $$\hat{Y}_{g.l.} = 99,305 + 1,390 \cdot x_1 + 2,085 \cdot x_2$$
  (7)

for variety ИЗК Алия:

КВ и $\tau=5$ s) семената на сорт Идеал са показали най-високи стойности на реакцията си от предсеитбената обработка. При тях $k.e.=109.72\%$, а $k.e.=101.33\%$. Подобно е положението и при сорт Пловдивска каротина. За неговите семена, обработени по вариант 3, са отчетени $k.e.=107.04\%$ и $k.e.=108.11\%$.

Констатационите потискане на кълняемата енергия, или лабораторната кълняемост на семената може да се отдае на съчетанието на нивата на факторите, продължителността престой на семената от 365 денонощия и тяхната сортова особеност.

Анализът на изложенията, направени в [2, 3, 9] показва закономерност на въздействието на предсеитбените обработки. Последното се заключава в това, че след предсеитбена електромагнитна обработка при стойности на управляемите фактори по вариант 1 ($U=12$ kV и $\tau=35$ s) и по-продължителен престой на семената (12 или 365 денонощия) се получават доминиращи положителни реакции, а с това и повишение на кълняемата енергия и лабораторната кълняемост на семената.

Съгласно табл. 1 проведеният експеримент е с два управляеми фактора на въздействие: приложеното напрежение между електродите $U$ (kV), възприет като кодирана величина $x_1$ и продължителност на въздействието, $\tau$ (s) – $x_2$. Това дава възможност да се пресметнат уравненията на регресия на изследваните параметри кълняемата енергия и лабораторна кълняемост, които са представени в $\%$. Всички уравнения са от типа [7]:

$$\hat{Y} = b_0 + b_1 \cdot x_1 + b_2 \cdot x_2 + b_1b_2 \cdot x_1 \cdot x_2$$

(1)
The examination that was performed demonstrates that all equations are adequate since the calculated criteria of Fisher are smaller than their critical values and the coefficients of the regression equations are significant according to the criterion of Student [10].

The analysis of the equations (2)...(11) shows that the size of the coefficients in front of the coded factor \( x_1 \) are significantly higher compared to the other in the particular equations. This is an indication that the degree of influence of the factor voltage \( U \) of treatment of seeds is greater compared to that of the duration of impact \( \tau \). This is confirmed by the higher values of germination energy and laboratory germination of the seeds treated in \( U=12 \) kV that have been reached.

The values of the coefficients \( \hat{c}_i \) for variety \( \text{IZK Alya} \) are the greatest compared to the other equations – for example for \( g.e. \) (8) the value is 10,615. In this case it was found that the germination energy is the highest - 146,15%/g. (Figure 1). The coefficient in front of factor \( x_1 \) in the equation (9) for laboratory germination is 7,785, i.e. the effect of voltage on this parameter is slightly than that for the germination energy. It was established that for the laboratory germination of the seeds from variety \( \text{IZK Alya} \) is 116,39%/c in variant 1 \((U=12 \text{ kV and } \tau=35 \text{ s})\) i.e. it is lower than the germination energy reached by the seeds (Figure 1). The values of the coefficient in front of \( x_1 \) in (9) however are the highest compared to the coefficients in the equations for laboratory germination of the rest of varieties.

The coefficients in front of the coded factor \( x_1 \) (voltage \( U \)) are the smallest in the equations (7) and (11) -1,390 and 1,997 for germination of the varieties \( \text{Vodoley F1} \) and \( \text{Ideal} \). According to the data obtained and Figure 1 was established that the laboratory germination of the mentioned varieties, for example in variant 1 is102,78%/g and 104,00%/g, respectively. These values correlate with the size of the coefficients in front factor \( x_1 \).

The impact of the factor duration of treatment \( \tau \), with coded kind \( x_2 \), on the germination energy and laboratory germination is smaller compared to that of the factor voltage \( U \). The last fact is proven by the values in front of the coefficients \( x_2 \) in the equations (2)...(11). The coefficient in front \( x_2 \) are with negative value (-1,680 and -1,150) for variety \( \text{Ideal} \) in the equation (10) and smaller -0,410 in the equation (9) for variety \( \text{IZK Alya} \).
-1.012, respectively) in equations (3) and (5) only for varieties *Milyana* and *Plovdivska karotina*. The analysis of the equations demonstrates that these coefficients are the smallest compared to similar ones. This could be explained with variety peculiarity of the seeds from varieties *Milyana* and *Plovdivska karotina*.

The interaction between the factors voltage *U* and duration of treatment *τ* could be found and analyzed from the values in front the coefficients *x₁* and *x₂* . The results obtained for germination energy and laboratory germination of the tomato seeds from the mentioned varieties after stay of 365 days from treatment to sowing, correlate with those in variety *Milyana* [4], whose seeds have stayed for 12 days from treatment to sowing in laboratory conditions. The treatment with parameters of variant 1 (*U* = 12 kV and *τ* = 35 s) could be recommended as the most efficient for stimulation of the germination energy and laboratory germination of tomato seeds.

CONCLUSIONS

The study found an extended favourable impact of the pre-sowing electromagnetic treatment (in specified values for the controlled factors) on the seeds from Bulgarian tomato varieties *Milyana*, *Plovdivska karotina*, IZK *Alva* *F₁* and *Ideal* after 365 days of stay to sowing.

An increase of the germination energy (*g.e.*) and laboratory germination (*g.*) of the seeds towards the control (untreated) seeds was established after presowing electromagnetic treatment in the corona discharge field with parameter of the controlled factors: voltage between the electrodes *U* = 12 kV and duration of the impact *τ* = 35 s and after one year stay of the seeds to their sowing. The increase is as follows: for variety *Milyana* – *g.e.* = 109,23% and *g.* = 105,71%, for variety *Plovdivska karotina* – *g.e.* = 109,86% and *g.* = 108,11%, for variety *Ideal* – *g.e.* = 98,61% and *g.* = 104,00%, and for variety *Vodoley F₁* – *g.e.* = 101,49% and *g.* = 102,78%.

It was established that in low values of the controlled factors of electromagnetic treatment: voltage between the electrodes *U* = 6 kV and period of impact *τ* = 5 s and after one year stay of the seeds to their sowing, a depression of the observed laboratory parameters is observed in which the germination energy and laboratory germination reach 95%/c.

It was found that in the calculated equations, the coefficient of regression in front of the coded value *x₁* of the controlled factor of impact voltage *U* are with higher values compared to these in front of the coded value of the factor duration of treatment *x₂*, that demonstrates the greater influence of the voltage on the effect of the presowing treatment.

Electromagnetic treatment with parameters: voltage *U* = 12 kV and duration of the treatment *τ* = 35 s could be recommended as the most efficient for stimulation of the germination energy and the germination of the seeds from Bulgarian tomato varieties.

коефициентите пред *x₁* са с отрицателна стойност (съответно -1,680 и -1,012). Анализът на уравненията показва, че тези коефициенти са най-малките в сравнение с другите подобни. Описаното може да се обясни със сортовата особеност на семената от сортове *Milyana* и *Plovdivska karotina*.

Взаимодействието между факторите напрежение *U* и продължителност на обработката *τ* може да се констатаира и анализира от стойностите пред коефициентите *x₁* и *x₂*. Получените резултати за кълняема енергия и лабораторна кълняемост на семената от домати на споменатите сортове, след престой от обработката до засяването им 365 денонощия напълно корелират с тези при сорт *Milyana* [2], чиито семена са престояли 12 денонощия от обработката до засяването в лабораторни условия. При това обработката с параметрите на вариант 1 (*U* = 12 kV и *τ* = 35 s) може да се препоръчва като най-ефективна за стимулиране на кълняемата енергия и лабораторна кълняемост на семената от домати.

ИЗВОДИ

След 365 денонощия престой до засяването е констатирано продължаващо благотворно въздействие на предсеитбените електромагнитни обработки при определени стойности на управляемите фактори върху семена от български сортове домати: *Milyana*, *Plovdivska karotina*, IZK *Alva*, *Vodoley F₁* и *Ideal*.

След предсеитбените електромагнитни обработки в полето на коренен разряд с параметри на управляемите фактори: напрежение между електродите *U* = 12 kV и продължителност на въздействието *τ* = 35 s, и след едногодишен престой на семената до засяването им е установено увеличаване на кълняемата енергия (*g.e.*) и на лабораторната кълняемост (*g.*) спрямо контролните семена както следва: за сорт *Milyana* – *g.e.* = 109,23%/k и *g.* = 105,71%/k, за сорт *Plovdivska karotina* - *g.e.* = 109,86%/k и *g.* = 108,11%/k, за сорт *Ideal* - *g.e.* = 98,61%/k и *g.* = 104,00%/k и за сорт *Vodoley F₁* - *g.e.* = 101,49%/k и *g.* = 102,78%/k.

Установено е, че при ниските стойности на управляемите фактори на електромагнитна обработка: напрежение между електродите *U* = 6 kV и продължителност на въздействието *τ* = 5 s, и след едногодишен престой на семената до засяването им се получава потискане на наблюдаваните лабораторни параметри, при което кълняемата енергия и лабораторната кълняемост достигат до 95%/k.

Констатирано е, че в пресметнатите уравнения, коефициентите на регресия пред кодираната стойност *x₁* на управляемия фактор на въздействие напрежение *U* са с по-големи стойности от тези пред кодираната стойност на фактора продължителност на обработката *x₂*, което показва по-голямото влияние на напрежението върху ефекта от предсеитбената обработка.

Електромагнитна обработка с параметри: напрежение *U* = 12 kV и продължителност на обработката *τ* = 35 s може да се препоръчва като най-ефективна за стимулиране на кълняемата енергия и кълняемостта на семената от българските сортове домати.
REFERENCES
INTRODUCTION

Driving sieves used for cleaning the agricultural crop seeds can be performed with different mechanisms, of rod-handle type, eccentric, or vibrating motors with balance weight type. Therefore, the separating surface vibrating movement is transmitted to particles of material, which gives a certain state of sieving process, able to achieve the passage of small particles through sieve holes.

The sieve driving mechanism was designed so that it mainly ensures a circular alternative movement, measured at the edge of the sieve, from one hand, and from the other- the neutral oscillation position in which the connecting of the length is fixed to operating mechanism (of swinging saw type).

The driving mechanism is made of an electric engine of alternative current of 710 W and a driving system of worm gear and oscillating slideway, \((3, 3', 6, 8 \text{ fig.1)}) with acting button placed eccentrically on spiral wheel of mechanism transmission, \([1, 2])

The lift of oscillating slideway of driving system is of 16 mm, the slideway arm \(3\) being articulated by a spherical joint to arm \(7\) fixed with sieve \(1\), placed in radial direction to cone base cercle. The experimental stand is endowed with a system of regulating the oscillating movement parameters, namely the oscillation frequency, \(F\) and oscillation amplitude, \(A\).

The oscillation frequency can be modified from electric engine by varying the electric current parameters, and oscillation amplitude can be modified by changing the arrangement position of driving mechanism comparing to sieve radial arm, articulated between them by spherical articulation \(6\), \(\text{fig.1).}\)

Keywords: cone-shaped sieve, oscillating movement, Labview program

Abstract: There were performed experimental researches on vibration of a conical sieve with vertical axle equiangularly suspended by three thin elastic cables both at upper and lower part. The sieve driving was made by a driving mechanism with oscillating slide way through a connecting arm rigidly fixed at conical sieve edge and spherically articulated at the mechanism rod. The paper presents the components of acquisition program and describes the vibrations parameters for several geometrical and functional variants of driving mechanism. Results presented and utilization method of LabView program can be a model for the researchers studying vibrations of equipment working surfaces from agriculture and food industry.

Keywords: cone-shaped sieve, oscillating movement, Labview program

Utilization of Labview Program for Acquiring and Processing the Vibrations of an Oscillating Cone-Shaped Sieve with Vertical Axle Used for Cleaning the Agricultural Crops Seeds

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INTRODUCERE

Acţionarea sitelor utilizate la curăţarea seminţelor cultivurilor agricole se poate realiza cu mecanisme din cele mai diverse, de tip bielă-manivelă, de tip excentric, motoare vibratoare cu contragreutăţi, etc. Astfel mişcarea vibratoorie a suprafeţelor de separare se transmite particulelor de material, ceea ce împrejmă o anumită stare de cernere materialului capabilă să realizeze trecerea particulelor mici prin orificiile sitei.

O sită cu suprafaţă de separare conică exterioră, suspendată în trei puncte echidistante, atât la partea de sus, cât şi la partea de jos, cu cabluri metalice elastice flexibile, a fost utilizată la curăţarea seminţelor de rapiţă de corpuri străine mari. Mecanismul de acţionare al sitei a fost astfel conceput încât să asigure în principal o mişcare circulară alternativă cu o anumită amplitudine, măsurată la marginea sitei conice, de o parte şi de cealaltă a poziţiei neutre de oscilaţie în care este fixat un braţ de legătură de lungime \(d\), la mecanismul de acţionare (de tip ferăstrău pendular). Mecanismul de acţionare este compus dintr-un motor electric de curent alternativ cu puterea de 710 W şi un sistem de acţionare de tip mecanic roată melcată cu culisă oscilantă, \((3, 3', 6, 8 \text{ fig.1)}) cu butonul de acţionare dispus excentric pe roata melcată a transmisiei mecanismului, \([1, 2])

Cursa culisei oscilante a sistemului de acţionare este de \(16\) mm, braţul culisei \(3\) fiind articulate prin articulaţia sferică la braţul \(7\) rigidizat cu sita \(1\) dispus pe direcţie radială la cercul de bază al conului. Standul experimental este prevăzut cu posibilitatea reglării parametrilor mişcării oscillante, şi anume a frecvenţei de oscilaţie, \(F\) şi a amplitudinii oscilației, \(A\).

Frecvenţa de oscilație se poate modifica de la motorul electric prin variarea parametrilor curentului electric, iar amplitudinea oscilației se poate modifica prin schimbarea poziției de dispunere a mecanismului de acționare în raport cu brațul radial al sitei, articulate între ele prin articulația sferică \(6\), \(\text{fig.1).}\)

Rezumat: Au fost realizate cercetări experimentale privind vibraţia unei site conice cu ax vertical suspendată echiunghiular a trei cabluri elastice subţiri atât de la partea de sus cât şi la partea de jos. Acţionarea sitei s-a făcut cu un mecanism de acţionare cu culisă oscilantă printr-un braţ de legătură fixat rigid de marginile sitei conice şi articulat sferic la biela mecanismului. În lucrare se prezintă componentele programului de achiziţie şi se descriu parametrii vibraţiilor pentru mai multe variante geometrico-funcţionale ale mecanismului de acţionare. Rezultatele prezentate şi modul de utilizare a programului Labview pot fi luate ca model de alţi cercetători ai vibraţiilor suprafeţelor de lucru ale utilajelor din agricultură şi industria alimentară.

Cuvinte cheie: sită conică, mişcare oscilantă, programul Labview
MATERIAL AND METHOD

Sieve movement is limited by metallic cables elasticity, which do not seem to be extendible, but due to their very small displacements, the movement can be considered mostly oscillating around sieve central axle. Therefore, for experimental researches of vibrations and process have been used oscillating frequencies of 250, 520, 790 osc/min and amplitudes (3.58; 3.74; 3.91; 4.10 mm), by modifying the distance \( d \) at values 480, 460, 440 and 420 mm.

By eccentric tangential layout of arm joint of driving mechanism to cone-shaped sieve, it performs approx. circular oscillations, related to cone vertical axle.

Fig. 1 – Scheme of experimental stand with suspended conical sieve [6]

1. conical sieve with circular holes; 2. supplying hopper; 3. driving mechanism with spiral wheel and oscillating slideway; 3’. arm of oscillating slideway; 4. collecting box of separated material; 5. metallic suspension cables; 6. spherical joint; 7. radial connecting arm to sieve driving mechanism, 8. worm pinion

For performing the experimental vibrations determinations, a measuring chain comprising the following devices, was used:

1) National Instruments data acquisition system with the following characteristics:
   - 24-bit resolution
   - sampling rate of 50 kS/s,
   - 4 simultaneous analogous input channels,
   - dynamic domain 102 dB, input domain +/- 5 V
   - USB 2.0 interface for computer connecting
2) four accelerometers Brüel & Kjær 4508B with magnetic fixing system and by metallic clamp, each with magnetic connecting fixing cable;

MATERIAL ŞI METODĂ

Deplasarea sitei este restricţionată de elasticitatea cablurilor metalice, care par inextensibile, dar datorită deplasărilor foarte mici ale acestora mişcarea poate fi considerată preponderent oscilantă în jurul axei centrale a sitei.

1) Pentru cercetările experimentale de vibraţii şi de proces au fost utilizate frecvenţe de oscilaţie de 250, 520, 790 osc/min şi amplitudinile (3,58; 3,74; 3,91; 4,10 mm), prin modificarea distanţei \( d \) la valorile 480, 460, 440 şi 420 mm.

Prin dispunerea excentrică, tangenţială a articulaţiei braţului mecanismului de acţionare la sita conică, aceasta realizează oscilaţii aproximativ circulare faţă de axa verticală a conului.

Pentru efectuarea determinantelor de vibraţii experimentale s-a utilizat un lanţ de măsură compus din următoarele dispozitive:

1) placă de achiziţie de date Naţional Instruments având următoarele caracteristici:
   - rezoluţie de 24 biţi
   - rată de eșantionare de 50 kS/s,
   - 4 canale simultane de input analog, domeniu dinamic 102 dB, domeniu de input +/- 5 V
   - interfaţă USB 2.0 pentru conectare la calculator
2) patru accelerometre Brüel & Kjær 4508B cu sistem de fixare magnetic şi prin clemă metalică, fiecare cu cablu de conectare, de fixare magnetic;
3) computer with Labview data acquisition and processing;

For performing the measurements, the 4 accelerometers used were placed two by two, diametrically opposed to sieve centre, able to determine the vibrations both on tangential direction and radial direction (fig.1).

Mounting scheme corresponds to specialty literature indications related to acquisition of vibration signals of circular oscillating surfaces. [4, 5].

Accelerometers 2 and 4 have the possibility to determine the parameters of vibrations comparing to radial direction from cone base (sieve), while the accelerometers 1 and 3 can determine vibration parameters according to tangential direction.

In figure 2 is shown the block scheme of measuring chain used for determining variations of accelerations and speed measured by the 4 accelerometers, respectively the signal spectra.

It comprises the vibration transducers (1), located two by two diametrically opposed, on the separating surface of sieve with oscillating movement, the signal amplifier (2), National Instruments acquisition system (3), for acquiring the signals from the 4 transducers and laptop (5), for processing the data acquired.

In order to trace the acquired signals, a printer which may be connected to laptop (5), can be also used.

Processing the experimental data was achieved with Labview program. Signals acquired were processed and transformed into acceleration units (m/s²), for being integrated in order to obtain the speed values of sieve points on the sieve where transducers were placed.

In fig. 3 is shown the structure of LabView written program for processing the signals acquired by the 4 accelerometers.

Block “Read From Measurement File” (fig.3) represents the data acquisition board, the signal registered by the four accelerometers being cached by it.

Blocks “Simulate Signal” are introduced for generating four steady signals (one for each accelerometer), necessary to correct the errors introduced by accelerometers: when nothing is measured, accelerometers still indicate a constant small acceleration but other than zero (noted with \( a_0 \)).

As a result, for each signal measured, a constant signal equal to \(-a_0\) is generated, which is added to measured signal, for restoring zero value.

After registering the signal in data acquisition board and corrected in "Simulate Signal" blocks, it was multiplied by 9.81 - gravity acceleration.

Multiplication by 9.81 is performed because the signal acquired is measured in g units (gravity acceleration), and

3) calculator with soft de achiziţie şi prelucrare de date Labview;

Pentru realizarea măsurătorilor cele 4 acelerometre folosite au fost amplasate două câte două diametral opus faţă de centrul sitei având posibilitatea determinării vibraţiilor atât pe direcţie tangenţială, cât şi pe direcţie radială, (fig.1).

Schema de montare corespunde cu indicaţiile din literatura privind achiziţia semnalelor de vibraţii ale suprafeţelor cu mişcare oscillantă circulară, [4, 5].

Acelerometrele 2 şi 4 au posibilitatea determinării parametrilor vibraţiilor după direcţia radială la baza conului (sitei), în timp ce acelerometrele 1 şi 3 au posibilitatea determinării parametrilor vibraţiilor după direcţie tangenţială.

În figura 2 este prezentată schema bloc a lanţului de măsură utilizat pentru determinarea variatiilor acelerărilor şi vitezelor măsurate de cele patru acelerometre, respectiv spectrele de semnal.

Aceasta cuprinde traductoarele de vibrații (1), amplasate două câte două diametral opus, pe suprafața de separare a sitei cu mișcare oscillantă, amplificatorul de semnal (2), placa de achiziție de date Național Instruments (3), pentru achiziția semnalelor de vibrații de la cele patru traductoare, și calculatorul laptop (5), pentru prelucrarea datelor achiziționate.

În vederea trasării semnalelor achiziționate se poate utiliza și o imprimantă ce poate fi conectată la calculatorul laptop (5).

Prelucrarea datelor experimentale s-a realizat cu programul Labview. Semnalele achiziționate au fost prelucrate și transformat în unități de accelerație (m/s²), care apoi au fost integrate în vederea obținerii valorilor vitezelor punctelor de pe sită în care au fost amplasate traductoarele.

În fig. 3 este prezentată structura programului scris sub LabView pentru prelucrarea semnalelor achiziționate de către cele patru acelerometre.

Blocul “Read From Measurement File” (fig.3) reprezintă placa de achiziție de date, semnalul înregistrat de cele patru acelerometre fiind captat de acesta.

Blocurile “Simulate Signal” sunt introduce pentru a genera patru semnale constante (câte unul pentru fiecare acelerometru), necesare pentru a corecta eroirile pe care le introduc accelerometrele: când nu se măsoară nimic, accelerometrele indică totuși o accelerație constantă, mică, dar diferită de 0 (notată \(a_0\)).

Drept urmare, pentru fiecare semnal măsurat, se generează un semnal constant, egal cu \(-a_0\), care se adună la semnalul măsurat, pentru a restabili valoarea zero.

După ce semnalul a fost înregistrat în placa de achiziție de date și corectat în blocurile “Simulate Signal” s-a multiplicat cu 9,81, accelerația gravitațională.

Înmulțirea cu 9,81 este efectuată pentru că semnalul achiziționat este măsurat în unități de g (accelerația...
in subsequent processing, it should be expressed in S.I. (m/s²) units, [7].

FFT (Fast Fourier Transform) function from program structure calculates and displays the signal spectrum.

For each of four accelerometers a FFT block is used, so four signals.

Frequencies and amplitudes of harmonic components (of Acosωt or Asinωt type which the periodic signal is made of) are obtained by means of spectra. These frequencies and amplitudes give information on oscillating (vibrating) system movement, in this case on suspended conical oscillating sieve movement.

Data measured are generally affected by different types of errors, determined by causes such as: apparatus calibration (sensors, acquisition board etc); numerical processing methods (numerical integral, decimal number truncating etc).

Such errors determine periodical phenomena that lead to measured periodical signals, but which are displaced comparing to zero line (fig.4.a), or even non periodical signals (fig.5.a). Therefore, appears the necessity of gravitaţională), iar în prelucrările ulterioare este nevoie ca el să fie exprimat în unităţi S.I. (m/s²), [7].

Funcţia FFT (Fast Fourier Transform) din structura de program calculează şi afişează spectrul semnalului. Pentru fiecare din cele patru acelerometre se utilizează câte un bloc FFT, deci patru semnale. Frecvenţele şi amplitudinile componentelor armonice (de tip Acosωt sau Asinωt din care se compune semnalul periodic) se obţine cu ajutorul spectrelor. Aceste frecvenţe şi amplitudini dau informaţii despre mişcarea sistemului oscilant (vibrator), în cazul de faţă despre mişcarea sitei conice oscilante suspendate.

Data măsurate sunt în general afectate de diferitele tipuri de erori, datorate unor cauze precum: etalonarea aparatelor (senzori, placă de achiziţie etc); metode de prelucrare numerică ( integrală numerică, trunchiere a numerelor cu zecimale etc).

Astfel de erori fac ca fenomene periodice să conducă la semnale măsurate periodice, dar deplasate faţă de linia de zero (fig.4.a), sau chiar neperiodice (fig.5.a). Drept urmare, apare necesitatea corectării valorilor măsurate,
correcting the measured values, by repositioning comparing to zero line (fig. 4.b) or by tilting the middle line (fig.5.b).

**Correction of „0” degree**, aims to place again the measured data related to zero line.

Data measured are replaced by data corrected:

\[
 y_{\text{cor}} = y_{\text{max}} - a
\]

\[
 y_0 = a
\]

**Fig. 4 – Example regarding the correction of „0” degree [2, 3]**

Value of correction parameter is determined from the condition of minimizing the average square meter error [5]:

\[
 \varepsilon(a) = \sum_{i=1}^{n} (y_i - a)^2
\]

This condition is equal to derivative annulation

\[
 \frac{d\varepsilon}{da} = 0
\]

From where, the correction parameter results

\[
 a = \frac{\sum_{i=1}^{n} y_i}{n}
\]

**Correction of „1”degree**

Correction of „1” degree aims to „make the horizontal the middle line. Data measured are replaced by the corrected ones:

\[
 y_{\text{cor}} = y_{\text{max}} - at - b
\]

**Fig. 5 – Example regarding correction of „1”degree**

Values of correction parameters \(a\) and \(b\) are determined from condition of minimizing the average square meter error

\[
 \varepsilon(a,b) = \sum_{i=1}^{n} (y_i - at_i - b)^2
\]

This condition is equivalent to annulations of partial derivatives

\[
 \frac{d\varepsilon}{da} = 0, \quad \frac{d\varepsilon}{db} = 0
\]
\[
\frac{\partial \varepsilon}{\partial a} = 0 ; \quad \frac{\partial \varepsilon}{\partial b} = 0
\]  

The correction parameters are obtained

\[
a = \frac{\sum_{i=1}^{n} t_i \sum_{i=1}^{n} y_i - n \sum_{i=1}^{n} t_i y_i}{\left( \sum_{i=1}^{n} t_i \right)^2 - n \sum_{i=1}^{n} t_i^2}
\]

\[
b = \frac{\sum_{i=1}^{n} t_i^2 \sum_{i=1}^{n} y_i - n \sum_{i=1}^{n} t_i^2 y_i}{\left( \sum_{i=1}^{n} t_i \right)^2 - n \sum_{i=1}^{n} t_i^2}
\]

In fig 6, are presented the signals and spectra appropriate to four accelerometers mounted on cone-shaped sieve surface

\[f_2 = 8.6 \text{ Hz și brațul } d_1 = 480 \text{ mm}\]

\[f_2 = 8.6 \text{ Hz și } d_3 = 420 \text{ mm}\]

**Application example**

By means of acquisition system achieved and Labview written program, vibration signals were acquired at the four accelerometers, placed on sieve separation surface.

**Exemplu de aplicație**

Cu ajutorul sistemului de achiziție realizat și a programului realizat în Labview, au fost achiziționate semnale de vibrații, la cele patru accelerometre, poziționate pe suprafața de...
Two accelerometers acquire the signal on arm direction, and the other two on a direction perpendicular to arm connected to driving mechanism rod.

Determinations for no-load run have been performed for oscillation frequency of \( f_2 = 8.6 \) Hz, for three different lengths of sieve arm, while the determinations for load run have been made with rape seeds for three oscillating frequencies \( (f_1 = 4.1 \) Hz, \( f_2 = 8.6 \) Hz, \( f_3 = 13.1 \) Hz) and three different lengths of sieve arm \( (d_1 = 480 \) mm, \( d_2 = 460 \) mm, \( d_3 = 420 \) mm).

Based on analysis of oscillation signal acquired and shown in fig 6, the oscillation sinusoidal variation for the four accelerometers is found out. The variation can be very well noticed at accelerometer 1 mounted near the sieve arm, which gets the signal on tangential direction (perpendicular on oscillating average position direction of sieve arm).

For no-load running, the amplitude of signal acquired at the oscillating frequency of \( f_2 = 8.6 \) Hz, is inversely proportional, as value, to length of sieve arm \( d \). Thus, at accelerometer 1, the oscillation acceleration reaches maximum values, of 100 m/s\(^2\), the general oscillation being of sinusoidal type with minimum disturbances related to elastic suspension system and sieve own vibration.

The bigger the arm’s length is, the smaller will be the sieve acceleration size, reaching values under 50 m/s\(^2\) at an arm’s length of 480 mm, but with more profound disturbing vibrations superposed on the general oscillation.

At accelerometer 3, which acquires the signal always on tangential direction (perpendicular to sieve arm) placed at a bigger distance comparing to operating point, the general oscillation, even though of sinusoidal type, is not anymore so evident as at accelerometer 1, being much more flatten, but also in this very case, the oscillation acceleration size decreases with sieve’s arm length increment from average values of approx.100 m/s\(^2\) to values under 50 m/s\(^2\), for an arm’s length of 420 mm.

It has been also found out the existence of oscillations determined by other factors than the oscillation printed on driving mechanism.

At accelerometers 2 and 4 acquiring the signal on radial direction (namely, in parallel with sieve’s arm) placed at about the same distance from the operating point, the general sinusoidal oscillations are not so visible as at accelerometers 1 and 3, and disturbing vibrations are stronger.

But, it has been noticed the same tendency of reducing the sieve oscillation acceleration size along with arm’s length increasing, namely diminishing the sieve movement amplitude.

CONCLUSIONS

For the sieve presented, with suspension wires length of 240 mm on top and 180 mm under the sieving surface, with sieve diameter of 410 mm and a tilting cone generator to horizontal surface of 8\(^\circ\), the acceleration of sieve had values of \( \pm 150 \) m/s\(^2\) for the arm connected to the driving mechanism of \( d=480 \) mm. When the arm’s length \( d \) decreases, the sieve accelerations are modified, reaching values of \( \pm 300 \) m/s\(^2\) on tangential direction and \( \pm 200 \) m/s\(^2\) on radial direction, which demonstrates a better movement on tangential direction and a quicker falling of seeds.

The oscillating movement of separating surfaces is characterized by its basic parameters: oscillations frequency and amplitude; at the same time, other parameters related to the process and material features have to be taken into account: sieves tilting angle, separare a sitei. Două acceleromètre achiziţionează semnalul pe direcția brațului, iar celelalte două, pe o direcție perpendiculară pe brațul de legătură cu tija mecanismului de acționare.

Determinările la mersul în gol au fost efectuate numai pentru frecvența de oscilație \( f_2 = 8.6 \) Hz, iar trei lungimi diferite ale brațului sitei, în timp ce determinările la mersul în sarcină au fost efectuate cu semnire de rapiță pentru trei frecvențe de oscilație \( (f_1 = 4.1 \) Hz, \( f_2 = 8.6 \) Hz, \( f_3 = 13.1 \) Hz) și trei lungimi diferite ale brațului sitei \( (d_1 = 480 \) mm, \( d_2 = 460 \) mm, \( d_3 = 420 \) mm).

Pe baza analizei semnalelor de accelerăție achiziționate și prezentate în fig 6, se constată variația sinusoidală a oscilațiilor pentru cele patru accelerometre. Aceasta este profund vizibilă la accelerometrul 1 montat în apropierea brațului sitei care achiziționează semnal pe direcție tangențială (perpendiculară pe direcția poziției medii de oscilație a brațului sitei).

Pentru mersul în gol, amplitudinea semnalelor achiziționate, la frecvența de oscilație \( f_2 = 8.6 \) Hz, este invers proporțională, ca valoare, cu lungimea brațului sitei \( d \). Astfel la accelerometrul 1, mărimea accelerației oscilației atinge valori maxime, de ordinul a 100 m/s\(^2\), oscilația generală fiind de tip sinusoidal cu perturbații minore legate de sistemul elastic de suspendare și vibrația proprie a sitei. Cu cât lungimea brațului crește, cu atât mărimea accelerării sitei scade, până la valori sub 50 m/s\(^2\) la o lungime a brațului de 480 mm, dar cu mai profuse vibrații perturbatoare suprapuse este oscilația generală.

La accelerometrul 3, care achiziționează semnalul tot pe de direcția tangențială (perpendiculară pe brațul sitei) aflat însă la o distanță mai mare față de punctul de acționare, oscilația generală, deși este evident de tip sinusoidal, nu mai este la fel de pronunțată ca la accelerometrul 1, fiind mult mai aplatizată, dar și în acest caz, mărimea accelerării oscilației, descrește cu creșterea lungimii brațului sitei, de la valori medii de circa 100 m/s\(^2\) la valori sub 50 m/s\(^2\), pentru o lungime a brațului de 420 mm.

Se constată, de asemenea, existența oscilațiilor perturbatoare cauzate de alți factori decât oscilația imprimată de mecanismul de acționare.

La accelerometrele 2 și 4 care achiziționează semnal pe direcție radială (adică paralel cu brațul sitei) aflate, aproximativ la aceeași distanță față de punctul de acționare, oscilațiile sinusoidale generale nu mai sunt așa de vizibile, ca la accelerometrele 1 și 3, iar vibrațiile perturbatoare sunt mult mai pronunțate.

Se constată, însă, aceeași tendință de scădere, a mărimea accelerării oscilației sitei, cu creșterea lungimii brațului, adică cu scăderea amplitudinii deplasărilor sitei.

CONCLUZII

Pentru sita prezentată, cu lungimi ale firelor de suspendare de 240 mm deasupra și 180 mm sub suprafața de cernere, cu diametrul sitei de 410 mm și o înclinare a generației conului față de suprafața orizontală de 8\(^\circ\), accelerăția sitei a avut valori de \( \pm 150 \) m/s\(^2\) pentru un braț de legătură cu mecanismul de acționare de \( d=480 \) mm. În situația în care lungimea brațului d scade, accelerățiile sitei se modifică la valori de \( \pm 300 \) m/s\(^2\) pe direcție tangențială și la valori de \( \pm 200 \) m/s\(^2\) pe direcție radială, ceea ce arată o mișcare mai bună pe direcție tangențială și o căderă mai rapidă a semnșilor.

Mișcarea oscilatoare a suprafețelor de separare este caracterizată prin parametri săi de bază: frecvența oscilațiilor și amplitudinea oscilației; trebuie avut în vedere și alți parametri care țin atât de proces, cât și de caracteristicile materialului ce trebuie prelucrat : unghiul
friction coefficients, optimum sieving speed and limit speed imposed by passing through sieves, particles interactions with sieving surfaces, processing power consumption, dimensions and shape of separating holes.

In order to avoid the inefficient sieving areas, restrictions related to sieve binding or a symmetrical driving system, should be introduced. There is also the possibility of operating by means of a generator of vibrations with non-balanced masses, which should be placed on symmetry axe of sieve.

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de înclinare a sitelor, coeficienții de frecare, viteza optimă de cernere și viteza limită impuse de trecerea prin site, interacțiunile dintre particule, interacțiunile cu suprafețele de cernere, consumul energetic la prelucrare, dimensiunile și forma orificiilor de separare.

Pentru a evita zonele cu cernere ineficientă, ar trebui, cumva introduse restricții în ceea ce privește legarea sitei sau o acționare simetrică. Există, de asemenea, posibilitatea acționării cu ajutorul unui generator de vibrații cu mase neechilibrate care să fie plasat pe axa de simetrie a sitei.

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THEORETICAL RESEARCH ON DETERMINING THE VIBRATIONS ISOLATION DEGREE OF A VIBRATING SEPARATOR

CERCETĂRI TEORETICE PRIVIND DETERMINAREA GRADULUI DE IZOLARE A VIBRAȚIILOR PENTRU UN SEPARATOR VIBRATOR

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Abstract: Mechanical vibrations occur in any system where there are motors for driving mechanisms or inertial elements elastically supported. The presence of mechanical vibrations is generally harmful because of their effects. Depending on the complexity of the machine, characterized by the distribution of weight and flexible system configuration, the parameters of vibration isolation can be determined only on the basis of a model able to reproduce the dynamic behavior of the machine. This paper presents the scheme for calculating the parameters of vibration isolation from a vibrating separator equipped with metal elastic elements.

Keywords: degree of isolation, vibration, calculation scheme, elastic element, vibrating separator

INTRODUCTION

The vibrations analysis of mechanical systems is necessary to determine the causes of their occurrence, the ways to reduce the absorbed energy, or to control the vibration and reduce noise. The failure or breakage phenomena of elastic systems made from different materials are very complex and differ fundamentally from static cases to variable cases. Fatigue is strongly localized and occurs in areas of high stress and strain of various parts or structures.

In order to model and analyze properly a problem of fatigue, it should, previously, determine the sequences of variable stress that can produce - or not - damage to the structure. The protection against vibration increases the lifetime of vibrating equipment thus ensuring reduced costs for maintenance and repairs. A vibrating system consists of the actual structure to which distributed masses (according to a certain law) and / or concentrated masses, are attached. Any structure is capable, under the action of causes with dynamic character (time-varying), to perform relative movement around an equilibrium position. This phenomenon is due to the fact that the structure possesses inertial properties (concentrated and distributed masses) and elastic elements (defined by flexibility or stiffness). Using on larger scale of the equipment with vibratory motion in the milling industry is due to significant increase in productivity of sorting and separation process of impurities from the cereal seeds mass, from this category being part the vibrating separator for removing stones from cereal seeds mass (Figure 1).

The stone separator SP-00 is used to separate impurities from cereal seed mass, that combines the principle of separation based on the difference in specific weight (through the movement of vibration of sieve) and separation by their aerodynamic properties (through the action of air currents).
MATERIAL AND METHOD

Based on the analysis of structural and functional structure of the vibrating separator shown in Figure 1, it is therefore necessary to study the dynamic model of calculation. The vibrating separator is modeled in Figure 2 to meet simultaneously, the technical performance (including the vibration parameters of work), and vibration isolation parameters of parts which need to be protected.

MATERIAL ŞI METODĂ

Pe baza analizei structurii constructive și funcționale a separatorului vibrator din Figura 1, rezultă necesitatea studierii modelului dinamic de calcul. Separatorul vibrator este modelat în Figura 2 pentru a satisface simultan, atât performanțele tehnice (inclusiv parametrii vibrațiilor de lucru), cât și parametrii izolării vibrațiilor părților ce trebuie protejate.

Given the system in Figure 2, the differential equations of motion are [4]:

\[
\begin{align*}
\frac{d^2 x}{dt^2} + 2 \cdot \eta_x \frac{dx}{dt} + p^2_{x}x &= \frac{M_0 \cdot R \cdot \omega^2}{M + M_0} \cos \omega t \\
\frac{d^2 y}{dt^2} + 2 \cdot \eta_y \frac{dy}{dt} + p^2_{y}y &= \frac{M_0 \cdot R \cdot \omega^2}{M + M_0} \sin \omega t
\end{align*}
\]  

(1)

where, the damping factors have the expressions:

\[
\eta_x = \frac{c_x}{2(M + M_0)}; \eta_y = \frac{c_y}{2(M + M_0)}
\]  

(2)

and the system’s own pulsations have the expressions:

\[
p_x = \sqrt{\frac{k_x}{M + M_0}}; p_y = \sqrt{\frac{k_y}{M + M_0}}
\]  

(3)

Because own vibration is damped down rather quickly in the transitional regime, in this case, it presents practical interest only the operating stationary regime (forced vibration). The solutions of equations (1) corresponding to stationary regime (forced vibration) have the form [4]:

\[
\begin{align*}
x &= A_x \cdot \cos(\omega t - \varphi_x) \\
y &= A_y \cdot \sin(\omega t - \varphi_y)
\end{align*}
\]  

(4)
where the amplitudes of motion are:

\[
\begin{align*}
A_x &= \frac{M_0 \cdot R}{M + M_0} A_{0x} \\
A_y &= \frac{M_0 \cdot R}{M + M_0} A_{0y}
\end{align*}
\]  

(A\(_x\) and A\(_y\) being the amplification factors and \(\varphi_x\) and \(\varphi_y\) the initial stages).

Vibrating separators work in stationary regime in post resonance (\(\omega >> \rho\)) passing under stationary regime through resonance (resonance pulsations are determined with relations (3)). Under the functioning conditions in post resonance regime (when damping system can be neglected), the amplitudes of motion are given by the relation [4]:

\[
A_x = A_y = A = \frac{M_0 \cdot R}{M + M_0}
\]

\[
(\text{\(A_x\) \text{and} \(A_y\) \text{fiind factorii de amplificare, iar \(\varphi_x\) \text{și} \(\varphi_y\) fazele inițiale})}
\]

In the case of functioning regime in post resonance, the effect of damping being insignificant, in order to obtain vibrations of the sieve casing as circular trajectory, the elastic constants of the elastic system, by the two directions, should to be equal. So, in this case the value of \(k_y\) adopted equal to that of the \(k_x\) is given by [4]:

\[
k_y = p_y^2 (M + M_0)
\]

The parameters that determine the performance of vibration isolation are the transmissibility \(T\) and the degree of isolation of vibrations \(I\). The two parameters are complementary, and the relation is: [1]

\[
I = (1 - T) \cdot 100 \quad [\%]
\]

For a vibratory separator leaning against metal elastic elements, with small viscous damping, modeled as a system with one degree of freedom in vertical translation, the \(T\) parameter has the form: [1]

\[
T = \frac{F_{Tr} \cdot \frac{1 + (2 \cdot \zeta \cdot \Omega)^2}{(1 - \Omega^2)\zeta \cdot \Omega^2}}{F_0}^{1/2}
\]

where: \(F_{Tr}\) is the force transmitted through the elastic element of \(k\) constant and through viscous damping element; \(F_0\) is the amplitude of the disturbing force; \(\Omega\) is the report of pulsations, defined by the relation \(\Omega = \omega / \rho\); \(\zeta\) is a fraction of critical damping.

The variation of parameters \(T\) and \(I\) is given by the report of pulsations \(\Omega\) and \(\zeta\) parameter shown in Figure 3.

\[\text{Fig. 3 – The variation of transmissibility T and degree of isolation I function of report of pulsation} \quad \Omega = \omega / \rho \text{ and fraction of critical damping } \zeta \quad \text{Variatia transmisibilitatii T \& a gradului de izolare I funcție de raportul pulsărilor } \Omega = \omega / \rho \text{ \& a fracțiunea din amortizarea critică } \zeta \]
For design calculations, it is more convenient to use the static arrow due to the action of weight \( m \cdot g \).

Thus, the own pulsation of the system can be expressed as [1]:

\[
p = \sqrt{\frac{k \cdot g}{m \cdot g}} = \sqrt{\frac{g}{m \cdot g}} \frac{k}{\delta_{st}}
\]

With the nomogram in Figure 4 can be determined the degree of isolation according to the static arrow and vibration frequency (the frequency of the disturbing force). In the nomogram field are plotted two types of oblique lines, the first line (dashed line) represents natural frequency of the system and the rest of lines (solid lines) represent the degree of vibration isolation.

RESULTS

Based on the calculation scheme previously presented, we presented a calculation example for determining the degree of vibration isolation for a vibrating separator, in our case, SP-00. Because the determination of elastic constant of the entire system is more difficult to perform, in this example, we will determine the calculation of constant elasticity of elastic system of springs and used it in calculation example.

First of all it must be determined the spring constant of the coil springs system. According to STAS 12243/2-86, the coil spring, used in the construction of the vibrating separator SP-00, has the following dimensions:

- the spiral diameter \( d = 7 \text{ mm} \);
- the outer diameter of the winding, \( D = 50 \text{ mm} \);
- number of turns, \( n = 9.5 \).

Using relation (2) is determined the spring constant of a coil spring:

\[
k_1 = \frac{G \cdot d^4}{8 \cdot n \cdot D^2} = \frac{8100 \cdot 7^4}{8 \cdot 9.5 \cdot 50^2} = 2.05 \text{ [kgf/mm]}
\]

\( \rightarrow k = 4 \cdot k_1 = 8.2 \text{ [kgf/mm]} \) (elastic constant of coil springs system)

According to [3], the determined circular trajectory amplitude is \( A_x = A_y = A = 2.5 \text{ [mm]} \), and frequency \( \nu = 960 \text{ [osc./min]} \), in accordance with (6), \( M_0 = 14 \text{ [kg]} \), where the eccentricity \( R = 120 \text{ [mm]} \).

RESULTATE

Pe baza schemei de calcul prezentată anterior, am prezentat un exemplu de calcul pentru determinarea gradului de izolare al vibrațiilor pentru un separator vibrator, în cazul nostru, SP-00. Pentru că determinarea constantei elastice a întregului sistemului este mai dificil de efectuat, în acest exemplu de calcul vom determina constanta de elasticitate a sistemului elastic de arcuri și o vom folosi în exemplul de calcul.

Mai întâi, trebuie determinată constanta de elasticitate a sistemului de arcuri elicoidale. Conform STAS 12243/2 – 86, arcul elicoidal, folosit în construcția separatorului vibrator SP – 00, prezintă următoarele dimensiuni:

- diametrul spirei, \( d = 7 \text{ mm} \);
- diametrul exterior de înfășurare, \( D = 50 \text{ mm} \);
- numărul de spire, \( n = 9.5 \).

Cuv ajutorul relației (2) se stabilește constanta elastică unui arc elicoidal:

\[
k_1 = \frac{G \cdot d^4}{8 \cdot n \cdot D^2} = \frac{8100 \cdot 7^4}{8 \cdot 9.5 \cdot 50^2} = 2.05 \text{ [kgf/mm]}
\]

\( \rightarrow k = 4 \cdot k_1 = 8.2 \text{ [kgf/mm]} \) (constanța elastică a sistemului de arcuri elicoidale)

Conform [3], amplitudinea traiectoriei circulare determinată este \( A_x = A_y = A = 2.5 \text{ [mm]} \), și frecvența \( \nu = 960 \text{ [oscil/min]} \), conform (6), \( M_0 = 14 \text{ [kg]} \), unde excentricitatea \( R = 120 \text{ [mm]} \).
The pulsation of oscillation, $\omega$ is:

$$\omega = 960 \text{ [osc./min]} \quad \rightarrow \quad \frac{960 \cdot 2 \cdot \pi}{100.53} = 10 \text{ [s}^{-1}]$$

The mass of the vibrating part of the separator (without the material load from the sieve, negligible compared to the mass vibrating system) is about 250 [kg], and the mass of generators vibration, $M_0 = 14$ [kg].

With the relation (7) $p = \sqrt{\frac{k}{M + M_0}} = 17.66$ [s$^{-1}$] → in accordance with (10), $\delta_{s\alpha} = \frac{g}{p^2} = 31.45$ [mm]

Using the static arrow of the coil spring, 31.45 [mm] and the frequency of oscillation of the stone separator, 960 [rot/min], the degree of isolation $I$ of the generated vibrations can be identified in the nomograph of Figure 4.

Fig. 5 – The degree of isolation for the vibrating separator, SP-00

It results in a degree of isolation $I = 95 \pm 99\%$, as shown in Figure 5. With the relations (7) and (8) is calculated exactly which is the value of the degree of isolation for the vibrating separator SP-00. First, we calculate the vibration transmissibility $T$, noting that the percentage of critical damping, $\zeta$, is 0 for a transmissibility of $T < 1$ (as shown in Figure 3), and $\Omega = \frac{\omega}{p} = 5.69$:

$$T = \left[ \frac{1 + (2 \cdot 0.569)^2}{(1 - 0.569)^2 + (2 \cdot 0.569)^2} \right]^{1/2} = 0.032$$ (12)

According to (8), it results a degree of isolation:

$$I = (1 - 0.032) \cdot 100 = 96.8\%$$ (13)

CONCLUSIONS

For most of the vibrating separators, the dynamic and reliability parameters are determined by the presence in the structure of the machine, of the vibratory elements.

To calculate the parameters for the isolation of vibrations, it must, first, to establish the equations of motion of the elastic system and the systems own pulsations that can be determined on the basis of a dynamic model of the vibrating separator.

Rezultă un grad de izolare $I = 95 \pm 99\%$, așa cum este arătat în figura 5. Prin intermediul relațiilor (7) și (8) se calculează cu exactitate care este valoarea gradului de izolare pentru separatorul vibratoare SP-00. Mai întâi se calculează transmisibilitatea $T$ a vibrațiilor, cu menționarea că, fracțiunea din amortizarea critică, $\zeta$, este 0 pentru o transmisibilitate $T < 1$(așa cum reiese din Figura 3), iar raportul $\Omega = \frac{\omega}{p} = 5.69$:

$$T = \left[ \frac{1 + (2 \cdot 0.569)^2}{(1 - 0.569)^2 + (2 \cdot 0.569)^2} \right]^{1/2} = 0.032$$ (12)

Rezultă, conform (8) un grad de izolare

$$I = (1 - 0.032) \cdot 100 = 96.8\%$$ (13)

CONCLUZII

Pentru cea mai mare parte a separatoarelor vibratoare, parametrii dinamici și de fiabilitate sunt determinații de prezența, în structura mașinii, a elementelor vibratoare.

Pentru a calcula parametrii de izolare a vibrațiilor, trebuie, mai întâi, stabilite ecuațiile mișcării sistemului elastic și pulsațiile proprie ale sistemului, care pot fi determinate pe baza unui model dinamic al separatorului vibratoare.
Based on the calculation of parameters of vibration isolation, the degree of isolation on the nomogram of a vibrating separator, and the resonant zone that should be avoided, are identified.

In order to have small force $F_1$, transmitted, it is necessary that the report $\Omega = \omega / p$ should be as high as possible. Therefore, its own pulsation $p$ shall be as small as possible, which can be achieved by using springs with a low spring constant.

Given the fact that in this article we performed a calculation example only for the elastic coil springs system, it is therefore necessary, to have in the future, experimental results on the determination of elastic constants of the whole system.

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Pe baza calcului parametrilor de izolare a vibrațiilor, se identifică pe nomogramă gradul de izolare al unui separator vibrator, precum și zona de rezonanță care trebuie evitată.

Pentru a avea forța transmisă $F_1$, mică, este necesar ca raportul $\Omega = \omega / p$ să fie cât mai mare posibil. Pentru aceasta, pulsiația proprie $p$, trebuie să fie cât mai mică, ceea ce se poate realiza prin utilizarea unor arcuri cu o constantă elastică mică.

Dat fiind faptul că în acest articol am efectuat un exemplu de calcul doar pentru sistemul elastic de arcuri elicioidale, rezultă necesitatea unor rezultate experimentale viitoare privind determinarea constantelor elastice și ale întregului sistem.

BIBLIOGRAFIE

EXPLAINING THE PHENOMENON OF SEPARATION INTO FRACTIONS OF A MIXTURE OF PARTICULATE MATTER BY APPLYING THE PRINCIPLE OF MINIMUM ENERGY

EXPLICAREA FENOMENULUI DE SEPARARE ÎN FRAŢII A UNUI AMESTEC DE PARTICULE MATERIALE ÎN BAZA APLICĂRII PRINCIPIULUI ENERGIEI MINIME

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Abstract: The paper explains, on the basis of the minimum power principle, the phenomenon of layering a mixture of material particles (especially seeds of cereals) maintained under an oscillating motion, with or without the action of an air stream. This phenomenon of separation into fractions is also generalized on a mass of particles with the same specific weight, but with different sizes, an untreated aspect, in this form, in the specific literature.

Keywords: minimum energy principle, seed mixture, unstable technical system, unstable equilibrium, vibrating flat surface, equivalent pyramid, fluidized bed

INTRODUCTION

The great majorities of agricultural products, but also those resulting from various industries, represent mixtures consisting of material particles with different physico-mechanical features [3, 6].

Their processing through different separation methods is made in order to bring them at the level of the conditions imposed by standards, the norms imposed in consumption or the requirements of prior processing and storage operations [4].

Filtering [1] is a process of separation in more fractions (three, four etc.) according to specific criteria (dimension, weight, color etc.), regarding components of the same nature of an agricultural products mixture found in the same state of granulation, fragments etc. (seeds, potato tubers, fruit etc.).

Filtering is made for obtaining uniform fractions as size, shape, weight etc., for the prior processes such as: sowing with machines provided with special distribution machinery, industrial processing, packaging etc., to be conducted easier, more accurately and with a greater performance, or for commercial purpose [2].

Filtering machines are built and work according to different principles, depending on the product to be filtered and the filtering criterion [5]. Thus, the majority of seeds can be filtered depending on their dimension by way of sifters or sorters.

Sifters with circular orifices filter the seeds according to width (the average size), those with elongated orifices filter the seeds according to density (the maximum size).

Given the specific weight and the aerodynamic resistance, the seeds can be filtered by means of air stream (pneumatic filtering), water or some type of solutions (hydraulic filtering), or air vibrator masses.

The air vibrator mass is a part of a seed filtering machine depending on the specific mass, consisting of a sifter with vibratory motion, under which one or more fans creating an air stream passing through the sifter’s orifices can be found, operating upon the seeds, without detaching them of the sifter’s surface, though. The sifter is sloped both lengthwise and transversely. Due to the vibratory motion and the air stream’s action, the seeds...
filter according to the specific weight, being separately collected.

The Minimum Energy Principle

It is known that it within an elementary filtering system (screen, sifter etc.) there is a mixture of objects relatively uniform in dimensions but with different specific weights (such as pebbles, lead shots, corn grains), and subject to oscillatory motion, these will stratify in such a way that the objects with the bigger specific weight (the lead shots) will occupy the inferior part, and the other components will occupy the following positions, stratifying according to their specific weight, in downward direction [3].

This type of placing is based on the “minimum energy principle” of an unstable technical system, according to which the objects will stratify in such a way that the potential energy of the system to be minimal. By virtue of this principle, a solid object, found in unstable equilibrium, will seek to occupy a stable position, whereas a mixture of solid objects or immiscible liquids, subject to an oscillatory motion of a certain amplitude and frequency, will separate in fractions.

MATERIAL AND METHOD

The stratification phenomenon of the material particles (especially of seeds) is carried by applying a continuous oscillatory motion to the seeds mass. In some cases, the oscillatory motion of the surface with seeds is accompanied by the action of an air stream which crosses the material layer subject to filtering, in a downward or upward direction.

In the case of filtering systems without air stream, the seeds’ stratification can take place in the following cases:

- the seeds have relatively uniform dimensions, but different specific weights ($\gamma_1, \gamma_2, ..., \gamma_i, ..., \gamma_n$);
- the seeds have irregular dimensions, but the same specific weight;
- the seeds have irregular dimensions and different specific weights, but their dimensions are inversely proportional with their specific weights (particles with small dimensions have bigger specific weights, and those with bigger dimensions have smaller specific weights).

In the case of filtering systems with an air stream, the above cases are admissible only if also taking into account the direction of the air stream, whose direction is chosen suitably to the filtering process.

The following cases can thus be identified:

- the seeds have relatively uniform dimensions and different specific weights, and the air stream is directed upwards;
- the seeds have irregular dimensions and the same specific weight, and the air stream is directed downwards;
- the seeds have irregular dimensions and different specific weights (their dimensions are inversely proportional with their specific weights), and the air stream is directed downwards.

a) The case where $d_i = k$ (constant), $\gamma_i \neq k$

If the seeds have relatively uniform di dimensions and their specific weights are then different, when taking into account the mass of two seeds categories of a given volume, the seeds which have bigger specific weight will also have a bigger mass:

$$m_1 = \frac{\gamma_1 V}{g}; \quad m_2 = \frac{\gamma_2 V}{g}; \quad \gamma_1 \geq \gamma_2; \quad m_1 \geq m_2$$

Principiul energiei minime

Este cunoscut faptul că, dacă într-un sistem elementar de sortare (ciur, sârăci etc.) avem un amestec de corpuri de dimensiuni relativ uniforme, dar de greutăţi specifice diferite (de ex. pietricele, alici de plumb, boabe de porumb etc.) şi le supunem unei mişcări de oscilaţie, acestea se vor stratifica astfel încât greutatea specifică cea mai mare (alicele de plumb) vor ocupa partea inferioară, iar celelalte componente vor ocupa poziţiile următoare, stratificându-se după greutatea specifică, în sens descrescător al acesteia [3].

Acest mod de dispune re are la bază „principiul energiei minime” a unui sistem tehnic nestabilizat, conform căruia corpurile se vor stratifica astfel încât energia potenţială a sistemului să fie minimă. Astfel, un corp solid, aflat în echilibrul instabil, va tinde să ocupe o poziţie stabilă, iar un amestec de corpuri solide sau lichide nemiscibile, supus unei mişcări oscilatoare de o anumită amplitudine şi frecvenţă, se va separa în fracţii.

MATERIAL ŞI METODĂ

Fenomenul de stratificare a particulelor materiale (în particular a seminţelor) se realizează prin împrăştierea unei mişcări de oscilaţie întreunătă masei de seminţe. În unele cazuri, mişcarea de oscilaţie a planului pe care se află seminţele este însoţită de acţiunea unui curent de aer care străbate, în sens ascendent sau descendent, stratul de material supus sortării.

La sistemele de sortare fără prezenţa unui curent de aer, stratificarea seminţelor poate avea loc în următoarele cazuri:

- seminţele au dimensiuni $d_1, d_2, ..., d_i, ..., d_n$ relativ uniforme, dar greutăţi specifice ($\gamma_1, \gamma_2, ..., \gamma_i, ..., \gamma_n$) diferite;
- seminţele au dimensiuni neuniforme, dar aceeaşi greutate specifică;
- seminţele au dimensiuni neuniforme şi greutăţi specifice diferite, dar dimensiunile acestora sunt în raport invers proportional cu greutăţile lor specifice (particulele de dimensiuni mici au greutăţi specifice mai mari, iar cele de dimensiuni mari au greutăţi specifice mai mici). La sistemele de sortare în prezenţa unui curent de aer, la fiecare din cazurile de mai sus se ţine seama de influenţa curentului de aer, al cărui sens se alege convenabil procesului de sortare.

Se disting, astfel, următoarele cazuri:

- seminţele au dimensiuni relativ uniforme şi greutăţi specifice diferite, iar curentul de aer are sens ascendent;
- seminţele au dimensiuni neuniforme şi aceeaşi greutate specifică, iar curentul de aer are sens descendent;
- seminţele au dimensiuni neuniforme şi greutăţi specifice diferite (dimensiunile lor sunt în raport invers proportional faţă de greutăţile lor specifice, iar curentul de aer are sens descendent.

a) Cazul $d_i = k$ (constant), $\gamma_i \neq k$

Dacă seminţele au dimensiuni di relativ uniforme, iar greutăţile lor specifice sunt diferite atunci, dacă se consideră masa a două categorii de seminţe dintr-un volum dat, seminţele care au greutatea specifică mai mare vor avea şi masa mai mare:

$$m_1 = \frac{\gamma_1 V}{g}; \quad m_2 = \frac{\gamma_2 V}{g}; \quad \gamma_1 \geq \gamma_2; \quad m_1 \geq m_2$$

(1)
The mass of seeds subject to filtering in an oscillatory motion stratifies based on the "minimum energy principle".

b) The case where \( d_i \neq k; \gamma_i = k \)

We assume that for a given volume we have material particles of a certain dimension; for another volume, equal to the first volume, we have particles with another dimension. We want to illustrate that for equal volumes, the particles with smaller dimensions fill better the area where they can be found.

In order to simplify this, we will consider the particles have a spherical shape.

Let us consider \( R \) being the radius of a particle. In one unity of volume shaped as a square pyramid (fig. 1), with the base side being a multiple of \( R \), an \( N \) number of spheres will be able to fill the volume.

If on the square’s base side of the pyramid we have “\( n \)” spheres, then the number of spheres from the inferior stratum will be \( n^2 \). On the side of the second row we will have “\( n-1 \)” spheres, and the number of spheres from this second row will be \( (n-1)^2 \) etc.

The total number of spheres from the entire pyramid will be:

\[
N = n^2 + (n-1)^2 + (n-2)^2 + \ldots + 3^2 + 2^2 + 1^2 = \frac{n(n+1)(2n+1)}{6}
\]

For \( n = 6 \) spherical particles with the \( R \) radius, it results \( N = 91 \), with their volume:

\[
V = N \cdot \frac{4\pi R^3}{3} = 91 \cdot \frac{4\pi R^3}{3} = 381.18R^3
\]

The height of the pyramid can be calculated based on the following relationship:

\[
H = 2R + (n-1) \cdot h
\]

where \( h \) is the distance, vertically measured, between the centers of the spheres displayed on two adjacent horizontal layers.

The height “\( h \)” can be determined if considering another pyramid, the latter having its peaks in the centers of 5 adjacent spheres (fig. 1). It results from the right triangles \( O_3O_4 \), \( O_3O_5 \) and \( A_5O_5 \) that:

Masa de semințe supusă sortării, aflată în mișcare de oscilație, se stratifică pe baza „principiului energiei minime”.

b) Cazul di ≠ k; \( \gamma_i = k \)

Să admitem că, într-un volum dat, avem particule materiale de o dimensiune oarecare; într-un alt volum, egal cu primul, avem particule de o altă dimensiune. Vrem să demonstrăm că, la volume egale, particulele de dimensiuni mai mici umplu mai bine spațiul în care se află.

Pentru simplificare, să considerăm că particulele au forma sferică.

Fie \( R \), raza unei particule. Într-o unitate de volum în formă de piramidă pătrată (fig.1), cu latura bazei multiplu de \( R \), va intra un număr \( N \) de sfere.

Dacă pe latura pătratului de bază al piramidei avem „\( n \)” sfere, atunci numărul de sfere din stratul inferior va fi \( n^2 \). Pe latura celui de-al doilea rand vom avea „\( n-1 \)” sfere, iar numărul de sfere din acest al doilea rand va fi \( (n-1)^2 \) etc.

Numărul total de sfere din întreaga piramidă va fi:

\[
N = n^2 + (n-1)^2 + (n-2)^2 + \ldots + 3^2 + 2^2 + 1^2 = \frac{n(n+1)(2n+1)}{6}
\]

Pentru \( n = 6 \) particule sferice de rază \( R \), rezultă \( N = 91 \), iar volumul lor:

\[
V = N \cdot \frac{4\pi R^3}{3} = 91 \cdot \frac{4\pi R^3}{3} = 381.18R^3
\]

Înălţimea piramidei se poate calcula pe baza următoarei relaţii:

\[
H = 2R + (n-1) \cdot h
\]

unde \( h \) este distanţa, măsurată pe verticală, dintre centrele sferelor dispuse în două straturi orizontale alăturate.

Înălţimea „\( h \)” se determină considerând o altă piramidă, aceasta din urmă având vârfurile în centrele a 5 sfere alăturate (fig.1). Din triunghiurile dreptunghice \( O_3O_4 \), \( O_3O_5 \) şi \( A_5O_5 \), rezultă:
and the angle with the biggest slope of the lateral sides of the pyramid:

\[ \alpha = \arctan \frac{R \sqrt{2}}{2R} = \arctan \frac{\sqrt{2}}{2} = \frac{\pi}{4} \quad (6) \]

It results that:

\[ H = 2R + (n - 1)R \frac{\sqrt{2}}{2} = R \left[ 2 + (n - 1) \frac{\sqrt{2}}{2} \right] \]

For \( n = 6 \), it results that:

\[ H = 2R + (6 - 1)R \frac{\sqrt{2}}{2} = 5.535R; \quad V = \frac{2}{9} \pi R^3 \cdot 6 \cdot (6 + 1)(2 \cdot 6 + 1) = 381.18R^2 \quad (7) \]

We now assume we have a square pyramid, with the same base side and the same slope of the lateral sides, but consisting of spheres with the radius \( r = R/2 \). In the pyramid formed of spheres with the radius \( r \) there will be \( N_I \) spheres:

\[ N_I = (2n)^2 + (2n - 1)^2 + (2n - 2)^2 + \ldots + 3^2 + 2^2 + 1^2 = \frac{2n(2n + 1)(4n + 1)}{6} = \frac{n(2n + 1)(4n + 1)}{3} \]

For \( n = 6 \), it results that:

\[ N_I = \frac{6(2 \cdot 6 + 1)(4 \cdot 6 + 1)}{3} = 2 \cdot 13 \cdot 25 = 650 \]

The volume of the spheres with the radius \( r \) will be:

\[ V = N_1 \cdot \frac{4\pi r^3}{3} = N_1 \cdot 4\pi \left( \frac{D}{2} \right)^3 = 340.34R^3 \quad (9) \]

and the height of the pyramid consisting of these spheres will be:

\[ H_1 = 2r + (2n - 1)h - R + (12 - 1) \frac{r \sqrt{2}}{2} = R \left[ 1 + \frac{11\sqrt{2}}{4} \right] = 4.889R \quad (10) \]

Let us consider \( V_R \) the volume of a square pyramid capturing all the balls of radius \( R \):

\[ V = a^2 \cdot H = (6R)^2 \cdot 5.535R = 199.26R^3 \quad (11) \]

where \( a \) is the base side of the pyramid.

Similarly, the volume of the pyramid capturing all the balls of radius \( r \) will be:

\[ V = a^2 \cdot H = (6R)^2 \cdot 4.889R = 176.004R^3 \quad (12) \]

Let us now consider \( \varepsilon \) the ratio of the two square pyramids capturing all the small balls, as well as all the larger balls:

\[ \varepsilon = \frac{V_1}{V_2} = \frac{177.004R}{199.26R} = 0.8833 = 88.33\% \quad (13) \]

It thus results that the balls of radius \( r = R/2 \) fill in a smaller volume than the balls of radius \( R \), from which it also results that the irregular particles shaped quasi-spherically, of the same specific weight, can stratify on an animated densimetric mass with an oscillatory motion.

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motion. Stratification will be made reversely to their dimensions, with the smallest particles filling the inferior part of the seeds layer subject to filtering.

c) The case where $d_{i} \neq k, \gamma_{i} \neq k; d_{i}$ is inversely proportional to $\gamma_{i}$

This case has an obvious explanation. Based on the phenomenon analyzed at b), here will also participate, accordingly, the specific weights of the particles.

d) The case of an upward vertical air stream; $d_{i} = k; \gamma_{i} \neq k$

Having discussed case a) evidenced that the filtering of uniform dimensioned seeds and with different specific weights is possible even without the influence of an air stream.

In the case of a vertical air stream, this has a different effect on the seeds only if it acts upwards, compared to when it acts downwards.

It is important to determine the direction of the air stream favorable to filtering. In this sense, we will consider that upon a homogenous spherical material particle with the radius $R$ and the density $\rho = \gamma/g$, an upwards vertical air stream will operate. Upon the particle (fig. 2), the dynamic pressure will operate, and subsequently the force:

$$P_{dn} = c \cdot \rho_{a} \cdot \frac{v_{a}^{2}}{2}$$

where $c$ is a coefficient of aerodynamic resistance, $\rho_{a}$ – air density and $v_{a}$ – the speed of air.

\[ F = c \cdot \rho_{a} \cdot \frac{v_{a}^{2}}{2} \cdot \pi R \]  

where $c$ is a coefficient of resistance aerodynamic, $\rho_{a}$ – densitatea aerului, iar $v_{a}$ – viteza aerului.

Reversely, upon the particles will operate the gravity force $G = mg$, where $m$ is the mass of the particle. If the forces $F$ and $G$ virtually have equal values, when operating reversely, their resultant is zero, and the particle will receive a fluidized state, favorable to free movement under minimal impulses. Obviously, upon the particle with the density, $\gamma_{1} > \gamma$, a $G > F$ force will operate, and the fluidized action of the air stream is less definite. If the forces $F$ and $G$ work in the same direction, the fluidization of the fractions from the seeds layer subject to filtering is hampered, so the downwards direction of the air stream is not indicated.

CONCLUSIONS

The stratification phenomenon of the material particles is carried by applying a continuous oscillatory motion to the seeds mass. In some cases, the oscillatory motion of the surface with seeds is accompanied by the action of an air stream which crosses the material layer subject to filtering in a downward or upward direction.

Applying minimum energy principle, in the paper

În sens invers dimensiunilor lor, particulele cele mai mici ocupând partea inferioară a stratului de semințe supus sortării.

c) Cazul $d_{i} \neq k, \gamma_{i} \neq k; d_{i}$ invers proporțional cu $\gamma_{i}$

Acest caz este evident. În baza fenomenului analizat la punctul b) participă, în consens, și greutățile lor specifice.

d) Cazul unui curent de aer vertical ascendent; $d_{i} = k; \gamma_{i} \neq k$

Punerea în discuție a cazului a) a evidențiat faptul că sortarea semințelor de dimensiuni practic uniforme și de greutăți specifice diferite este posibilă chiar și fără influența unui curent de aer.

În cazul existenței unui curent de aer vertical, acesta are asupra semințelor acțiune diferită în situația în care lucrăza în sens ascendent, față de situația în care lucrăza în sens descendent.

Este important să determinăm sensul curentului de aer favorabil sortării. Pentru aceasta, să considerăm că asupra unui particule materiale sferice omogene, de rază $R$ și densitate $\rho = \gamma/g$, acționează un curent de aer vertical ascendent. Asupra particulei (fig. 2) acționează presiunea dinamică, respectiv forța.

CONCLUZII

Fenomenul de stratificare a particulelor materiale se realizează prin imprimarea unei mișcări de oscilație întreținute masei de semințe. În unele cazuri, mișcarea de oscilație a planului pe care se află semințele este însotită de acțiunea unui curent de aer care străbate, în sens ascendent sau descendent, stratul de material supus sortării.

În cadrul lucrării s-a explicat, în baza principiului energiei minime, fenomenul de stratificare a unor
has been explained the stratification phenomenon of some material particles (especially of seeds) in the case where a fluidization of the fractions from the layer of seeds, subject to filtering, takes place or not.

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particule materiale (în particular a seminţelor) în situaţia în care are loc sau nu, fluidizarea fracţiilor din stratul de seminţe supus sortării, sortarea după greutatea specifică fiind un caz particular ai stratificării particulelor.

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EXPERIMENTAL RESEARCHES UPON THE DOSING ACCURACY OF TECHNICAL DOSAGE EQUIPMENT DESIGNED FOR AGRIFOOD PRODUCTS

CERCETĂRI EXPERIMENTALE PRIVIND ACURATETEA DOZĂRII PENTRU ECHIPAMENTUL TEHNIC DE DOZARE DESTINAT PRODUSELOR AGROALIMENTARE

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Abstract: The researches which results are herein presented, tackle the dosage process optimization in small and medium-sized enterprises. The dosing technical equipment DTE performs two main functions:
- automated setting of product flow rate for a programmed value and maintaining this value within certain pre-set limits, by respecting the regulations in force concerning the dosage precision imposed for this equipment type;
- automated control of quantities of products passing through the dosage equipment in a certain period of time. In this paper, are presented this equipment experimental tests, the working qualitative indexes determined, by emphasizing the advantages of using this equipment type in small and medium-sized milling enterprises, in rural area.

Keywords: dosage, agricultural products, milling units, automated control, PLC.

INTRODUCTION

The field of systems and equipment for weighing, dosing and packaging agri food products is one of the fields with a high economic impact in Romania (especially in the last years), but also in the industrially developed countries. Modern weighing and automated dosing devices represent ingenious technical solutions that comprise fields from both the mechanics and electronics, being characterized by a high precision and sensitivity according to several papers from the specialty literature. [1, 2, 3, 4, 8].

Usually, operations involving direct action on the processed material are exclusively done by mechanical mechanisms or components, but also the command and dosage adjustment operations are frequently done by mechanical systems, the electronic systems having a surveillance and fine adjustment role as described in the paper [5, 9].

Technological operations of weighing and dosing are not independent in the manufacturing process of products, but are integrated into various technological processes, so that the result of the operation does not emerge distinctively, but cumulated in the resulted final product, and as a result, the quality of the dosage/weighing directly influencing the quality of the final product. [6, 7].

In the milling process in different points of the mill's technological flow, technical equipment used for weighing the grains that enter the processing and the finished products and by-products are provided.

Aligned with the most modern equipment in the field and encompassing innovative constructive solutions, the Dosing Technical Equipment DTE (fig. 1), developed at INMA Bucharest has a direct applicability in small and medium capacity milling units, and can be interleaved in their technological flow in several points of processing quantitative information, but also in combined fodder monitoring and fine adjustment role concerning the dosage precision imposed for this equipment type; and encompassing innovative constructive solutions, the Dosing Technical Equipment DTE (fig. 1), developed at INMA Bucharest has a direct applicability in small and medium capacity milling units, and can be interleaved in their technological flow in several points of processing quantitative information, but also in combined fodder surveillance and fine adjustment role concerning the dosage precision imposed for this equipment type;

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Rezumat: Cercetările ale căror rezultate sunt prezentate în acest articol au ca subiect optimizarea procesului de dozare în unitățile produsive de mică și medie capacitate.

Echipamentul tehnic de dozare ETD realizează două funcții principale:
- reglarea automată a debitului de produs la o valoare programată și menținerea acestei valori înconjurând limitele prescrise, cu respectarea normativelor referitoare la precizia de dozare pentru aceste tipuri de echipamente;
- gestionarea automată a cantităților de produse ce trec prin echipamentul de dozare, cu respectarea limitelor de prelucrare.

În această lucrare sunt prezentate investigațiile experimentale ale acestui echipament, indicii calitativi de lucru determinați cu evidențierea avantajelor utilizării acestui tip de echipament tehnic în fluxul unităților de morărit sătești de mică și medie capacitate.

Cuvinte cheie: dozare, produse agricole, unități de morărit, control automat, PLC.

INTRODUCERE

Domeniul sistemelor și echipamentelor de cântărire, dozare și ambalare pentru produsele agroalimentare este unul din domeniile de mare impact economic în România (mai ales în ultimii ani), dar și în tările dezvoltate din punct de vedere industrial.

Dispozitivele moderne de cântărire și dozare automată sunt soluții tehnice ingenioase ce cuprind domeniul atât din mecanică cât și din electronică fiind caracterizate printr-o precizie și sensibilitate înaltă conform mai multor lucrări din literatura de specialitate [1, 2, 3, 4, 8].

De regulă, operațiile ce presupun acțiunea directă asupra materialului prelucrat sunt efectuate în exclusivitate de mecanisme sau componente mecanice, însă și operațiile de comandă și reglaj al dozării sunt efectuate de multe ori de sisteme mecanice, cele electronice având rolul de supraveghere și reglaj fin după cum se arată în lucrarea [5, 9].

Operațiile tehnologice de cântărire și dozare nu sunt independente în procesul de fabricație al produselor, ci se integrează în procese tehnologice diverse, astfel încât rezultatul operației nu apare distinct, ci cumulat în produsul final rezultat, iar ca urmare, calitatea dozării / cântării influențând direct calitatea produsului final. [6, 7]

În cadrul procesului de măcinare în diferite puncte ale fluxului tehnologic din mori sunt prevăzute echipamente tehnice pentru cântărirea cerealelor din în procesul de prelucrare, precum și a produselor finete și a subproduselor obținute.

Alinat celor mai moderne utile din domeniul și înglobând soluții constructive inovatoare, Echipamentul tehnic de dozare ETD (fig.1) conceput la INMA București, are aplicativitatea directă în cadrul unităților de morărit de mică și medie capacitate putând fi intercalat în fluxul tehnologic al acestora în diverse puncte de prelucrare a informației cantitative, cât și în cadrul unor fabrici de
factories, where several dosing technical equipment can be connected and through a central computer, several recipes can be achieved.

MATERIAL AND METHOD

In a technological flow, the Dosing Technical Equipment DTE performs two main functions:
- automatic adjustment of the flow of product to a programmed value and maintaining that value within certain preset limits, in compliance with regulation on dosing precision for this type of equipment;
- automatic management of the quantities of products that pass through the dosing equipment in a certain time.

Mainly, the work process is carried out this way (fig.2):
- the dosed product flows through a pipe (pos. 2) provided at the end with a mobile flap actuated by using an electric command by an electric actuator (pos. 9);
- the product stream dimensioned by the flap falls from a certain height directed through a channel on an inclined plate (pos. 3);
- the inclined plate constitutes the end of a lever that transmits the impact force to a tensometric dose (pos. 7);
- the tensometric dose transforms the impact force into material flow, sending an impulse to the automation system;
- the electric impulse is processed and based on the programming, the automation system makes the comparison, recording and displaying of measured flow and managed values;
- the mobile flap, depending on the command it receives, increases or decreases the product flow in order to stabilize it.

In principal, procesul de lucru se desfășoară astfel (fig. 2):
- produsul de dozat afluează printr-o pâlnie de dirijare (poz. 2) prevăzută la capăt cu o clapetă mobilă (poz. 8) acționată prin comandă electrică de către un actuator electric (poz. 9);
- jetul de produs dimensionat de clapetă, cade de la o anumită înălțime dirijat printr-un canal pe un plan de impact (poz.3);
- planul de impact constituie capătul unei pârghii care transmite forța de impact unei doze tensiométrice (poz. 7);
- doza tensiometrică transformă forța de impact în debit de material, transmițând un impuls instalăției de automatizare;
- în instalația de automatizare se prelucrează impulsul electric și în funcție de programare se efectuează compararea, înregistrarea și afișare debitului măsurat și a valorilor gestionate;
- clapeta mobilă, în funcție de comanda ce o primește mărește sau micșorează fluxul de produs pentru stabilizarea lui.
The operating terminal (seen in fig.3) acts as graphical user interface. It communicates with the installation’s PLC on a dedicated RS422 serial communication interface.

Using the settings, the working parameters for DTE are set (reference flow, weight counter) and product management data are viewed (total amount of material and measured current flow).

The analyzed dosing equipment constitutes an application of dynamics postulates. Thus, it is known that a particle’s mass impulse \( m \) and speed \( v \) is:

\[
\vec{H} = m \cdot \vec{v}
\]

and that the \( \vec{H} \) vector is tied to the \( \vec{P} \) vector of the resultant forces applied to the mobile point, through the equation:

\[
\frac{d\vec{H}}{dt} = \vec{P}
\]

Also, the impulse of a points system is written:

\[
\vec{H} = \sum_i H_i = \sum_i m_i \vec{v}_i ; \text{ this vector } \vec{H} \text{ can be regarded as the impulse of a fictive point with the mass } M = \sum_i m_i, \text{ and the speed equal with the speed of the center of mass (weight). Thus, we have the impulse variation in the time interval } (t_a, t_b):
\]

\[
M_B \vec{v}_c(t_B) - M_A \vec{v}_c(t_A) = \vec{S} = \int_{t_a}^{t_b} \sum_i s \, dt
\]

\[
\sum m_i \cdot \vec{v}_c(t_B) - \sum m_i \cdot \vec{v}_c(t_A) = \vec{S}
\]

It results that the impulse is zero, the exterior forces will have a constant value and vice versa.

Therefore, we are constructively and functionally looking to achieve the solution \( \vec{S} = 0 \).

In order to achieve that, it was constructively imposed that \( H = \) vertical particle falling height \( H = \) constant, resulting that \( v = \) constant because \( v = \sqrt{2gh} \) for any particle \( (v_1 = \text{const.}) \). It results:

\[
\sum m_i \cdot (V_c(t_B) - V_c(t_A)) = \sum m_i \cdot (V_c(t_B) - V_c(t_A))
\]

\[
V_c(t_A) = V_c(t_B)
\]

\[
\sum m_i - \sum m_i = \sum m_i - \sum m_i
\]

It results that for this, \( M_B = M_A \) therefore it is

Terminalul de operare (vezi fig.3) îndeplineşte funcţia de interfaţă grafică cu utilizatorul. Acesta comunica cu PLC-ului instalării pe o interfaţă dedicată de comunicaţie serială RS422.

Prin setări se stabilesc parametrii de lucru ai ETD (debit de referinţă, contor de masă) şi se vizualizează datele de gestiune (cantitate totală de material şi debit curent măsurat).

Echipamentul tehnic de dozare supus analizei constituie o aplicaţie a unor postulate ale dinamicii. Astfel, se știe că impulsul unei particule de masă \( m \) şi viteza \( v \) este:

\[
\vec{H} = m \cdot \vec{v}
\]

şi că vectorul \( \vec{H} \) este legat de vectorul \( \vec{P} \) al rezultantei forţelor aplicate punctului mobil, prin ecuaţia:

\[
\frac{d\vec{H}}{dt} = \vec{P}
\]

De asemenea, impulsul unui sistem de puncte se scrie: \( \vec{H} = \sum_i H_i = \sum_i m_i \vec{v}_i \); acest vector \( \vec{H} \) poate fi privit că impulsul unui punct fictiv cu masa \( M = \sum_i m_i \) şi viteza egală cu viteza centrului de masă (de greutate). Astfel, vom avea variaţia impulsului în intervalul de timp \( (t_A, t_B) \):

\[
M_B \vec{v}_c(t_B) - M_A \vec{v}_c(t_A) = \vec{S} = \int_{t_A}^{t_B} \sum_i s \, dt
\]

\[
\sum m_i \cdot \vec{v}_c(t_B) - \sum m_i \cdot \vec{v}_c(t_A) = \vec{S}
\]

Rezultă că dacă varianța de impuls este zero, forţele exterioare vor avea o valoare constantă și invers. Astfel, s-a căutat constructiv și funcțional să se realizeze soluția \( \vec{S} = 0 \).

Pentru aceasta, constructiv s-a impus \( H \) = înaltimea de cădere a particulelor pe verticală \( H=\text{const.} \). rezultând \( \vec{v}=\text{const.} \) pentru că \( v = \sqrt{2gh} \) pentru orice particulă \( (v_1 = \text{const.}) \).Rezultă:

\[
\sum m_i \cdot (V_c(t_B) - V_c(t_A)) = \sum m_i \cdot (V_c(t_B) - V_c(t_A))
\]

\[
V_c(t_A) = V_c(t_B)
\]

\[
\sum m_i - \sum m_i = \sum m_i - \sum m_i
\]

Rezultă că pentru aceasta \( M_B = M_A \) deci
ultimately constant with the flow.

Functionally, it was searched that the instant value taken by the tensometric dose and sent to the PLC, compared with a reference value – resulted from calibration and related adjustments – to be constant. If not, by comparing it to the reference value, actions will be taken through the electric actuator on the mobile flap to adjust the flow.

Taking into consideration that the equipment should only take the impulse and the material has to flow as smoothly as possible, an inclined plan was built to serve as an impact receptor (pos.3, fig. 2).

The inclination value $\xi \alpha$ has to be bigger than the fall limit $\xi$, the $\xi$ when the products start to roll $\alpha_{min} < \alpha$.

This value $\alpha_{min}$ is determined from the transport speed formula where the kinetic energy variation is equaled with the mechanical work of the forces acting on the material.

Therefore, we have the formula:

$$G \cdot \frac{(v - v_0)^2}{2} = GH - G \cos \alpha \cdot \frac{h}{\sin \alpha} \cdot f$$

where:
- $G$ = material weight, kgf.;
- $g$ = gravity acceleration, m/s$^2$;
- $v$ = transport speed, m/s;
- $h$ = falling height, m;
- $\alpha$ = falling angle, degrees;
- $f = \tan \rho$ - friction coefficient, depending on the friction angle of the material on the inclined plan.

When $v_0 = 0$ it results:

$$\frac{v^2}{2g} = h(1 - \tan \alpha)$$

$$v = \sqrt{2gh(1 - \cot \alpha)}$$

at limit $\nu=0$ for $\tan \alpha = \frac{tgp}{g}$

RESULTS

The testing of the experimental model of DTE equipment was made at INMA, in laboratory and exploiting conditions, using its own experimental methods, carrying out the following activities: preliminary checks, initial technical expertise, experimenting operating without load, calibrating the weighing system, checking the functioning of the automation installation in simulated mode, experimenting operating under load.

For the experiments in working conditions were used agricultural products such wheat seeds and bran. The dosing error ($\varepsilon_2$) was determined with the following relation [3]:

$$\varepsilon = \frac{|Qp - Qc|}{Qp} \cdot 100 \%$$

where: $Qp$ - programmed flow, t/h;
$Qc$ – calculated flow, t/h.

constant debitului în ultimă instanță.

Funcțional s-a cătut ca valoarea instantanee preluată de doză tensiometrică și transmisă PLC-ului, unde, comparată cu o doză de referință – rezultat al etalonării și a reglajelor aferente – să fie constantă. Dacă nu, prin compararea față de valoarea de referință se va acționa prin intermediul actuatorului electric asupra clapetei mobile de reglare a debitului.

Având în vedere că echipamentul de dozare trebuie să preia doar impulsul, iar materialul trebuie să se scurgă cât mai rapid, s-a construit un plan înclinat ca receptor de impact (poz.3, fig.2).

Valoarea $<\alpha$ de înclinare a planului trebuie să fie mai mare decât $<\alpha$ limită de cădere, $<\alpha$ la care produsele încep să se rostogolească $\alpha_{min} < \alpha$.

Această valoare $\alpha_{min}$ se determină din formula vitezei de transport unde variația energiei cinetice o egalăm cu lucrul mecanic al forțelor ce acționează asupra materialului.

Astfel avem formula:

$$G \cdot \frac{(v - v_0)^2}{2} = GH - G \cos \alpha \cdot \frac{h}{\sin \alpha} \cdot f$$

unde:
- $G$ = greutatea mat. în kgf.;
- $g$ = accelerația gravitațională 9,81 m/s$^2$;
- $v$ = viteză de transport, în m/s;
- $h$ = înălțimea de cădere, în m;
- $\alpha$ = unghiul de cădere, în grade;
- $f = \tan \rho$ - coeficient de frecare, în funcție de unghiul de frecare al materialului pe planul înclinaț.

Când $v_0 = 0$ se obține:

$$\frac{v^2}{2g} = h(1 - \tan \alpha)$$

$$v = \sqrt{2gh(1 - \cot \alpha)}$$

REZULTATE

Încercarea modelului experimental al echipamentului tehnic de dozare s-a realizat în cadrul INMA în condiții de laborator și de exploatare, utilizând o metodică de experimentare proprie fiind efectuate următoarele tipuri de activități: verificări preliminare,expertiza tehnică inițială, experimentări de funcționare în gol; calibrarea sistemului de cântărire, verificarea funcționării instalației de automatizare în regim simulat, experimentări de funcționare în sarcină.

Pentru experimentări în condiții de exploatare s-au folosit ca materie primă produse agricole precum semințe de grâu și târâță. Eroarea de dozare ($\varepsilon_2$) s-a determinat cu relația [3]:

$$\varepsilon = \frac{|Qp - Qc|}{Qp} \cdot 100 \%$$

unde : $Qp$ – debit programat, t/h;
$Qc$ – debit calculate, t/h.
The calculation formula for $Q_c$ is:

$$Q_c = \frac{M_p}{T_p} \cdot 3600 \text{ [t/h]}$$

(12)

where: $M_p$ – sample weight, kg; $T_p$ - sample duration s.

Table 1

<table>
<thead>
<tr>
<th>Sample</th>
<th>Programmed flow ($Q_p$) [t/h]</th>
<th>Sample duration ($t_p$) [s]</th>
<th>Sample weight ($M_p$) [kg]</th>
<th>Calculated flow ($Q_c$) [t/h]</th>
<th>Dosing error ($\varepsilon_d$) [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>1</td>
<td>1</td>
<td>17,200</td>
<td>1,032</td>
<td>3.20</td>
</tr>
<tr>
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<td>1,026</td>
<td>2.60</td>
</tr>
<tr>
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<td>1,035</td>
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<td>2,058</td>
<td>2.90</td>
</tr>
<tr>
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<td>2,064</td>
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</tr>
<tr>
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<td>1,974</td>
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<tr>
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<tr>
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<td>2.70</td>
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<tr>
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<tr>
<td>II</td>
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</tr>
<tr>
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<td>2.30</td>
</tr>
<tr>
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</tr>
</tbody>
</table>

Figure 4 shows the dosing error variation depending on the sample weight on sample duration of 30 seconds.

![Graph showing dosing error variation](image)

In figura 4 este arătată variația erorii de dozare în funcție de masa probei la o durată de probei de 30 secunde.

CONCLUSIONS

Continuous flow dosage of finished agricultural products is a complex and important operation for the destination and future processing of those products. This operation is made using the Dosing Technical Equipment DTE integrated in different technological flows in small and medium capacity milling units and also in unit making concentrated fodder, in several points of processing the quantitative information, according to the programming of the electronic unit [1].

Through the constructive and functional solutions adopted following the experimental tests, it was found that the Dosing Technical Equipment DTE offers a series of advantages such as:

- **CONCLUZII**

Dozarea în flux continuu a produselor agricole finite este o operație tehnologică complexă și important pentru destinația ulterioară a acestor produse. Această operație se realizează utilizând echipamentul tehnic de dozare ce poate fi integrat în fluxul tehnologic al unităților de morărit de mică și medie capacitate cât și în cadrul unor fabrici de nutrețuri combine în diverse puncte de prelucrare a informației cantitative, în concordanță cu unitatea electronică de programare [1].

Prin soluțiile constructive și funcționale adoptate în urma investigațiilor experimentale s-a constatat că Echipamentul tehnic de dozare ETD prezintă următoarele avantaje:
- high dosing precision;
- adjusting the product flow to a programmed value;
- automated management of product quantities throughout the whole technological flow;
- easy maintenance and exploiting;
- visualizing the product feed through the transparent tube of the feeding funnel;
- hermetic connection to the piping of the technological installation where it is integrated;
- modern design;
- reduced specific material and energy consumption.

We can therefore conclude that the use of automated weighing and dosing technological operation bring a growth in the economical efficiency of the productive unit and have an immediate impact on the management of the processed product.

ACKNOWLEDGEMENT
The experimental model of Dosing Technical Equipment DTE was achieved in the NUCLEU Program.

REFERENCES

- precisie de dozare ridicată;
- reglarea debitului de produs la o valoare programată;
- gestionarea automată a cantităților de produs pe întregul parcurs al fluxului tehnologic;
- întreținere și exploatare facile;
- vizualizarea alimentării cu produs prin tubul transparent al pâlniei de alimentare;
- racordarea etanșă la tubulatura instalației tehnologice în care se integrează;
- design modern;
- consumuri specifice de materiale și energie reduse.

Putem concluziona deci, că utilizarea tehnologiilor de cântărire și dozare automată aduc cu sine o creștere a eficienței economice și au un impact imediat asupra managementului produselor procesate.

MULTUMIRI
Modelul experimental al Echipamentului tehnologic pentru cântărire și gestionare automată ECGA a fost realizat în cadrul Programului NUCLEU.

BIBLIOGRAFIE
INVESTIGATION OF THE STABILITY OF THE TORSORIAL VIBRATIONS OF A SCREW CONVEYER UNDER THE INFLUENCE OF PULSE FORCES

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Abstract: The aim of the research is to analyze the influence of pulse forces on non-linear torsorial vibrations of a screw conveyer.

The methodology is based on the combination of the methods by Bubnov-Halorkin and Van der Pol. With the help of this methodology we have developed the so called equations of a standard form for the case of pulse forces action.

A mathematical model of the torsorial vibrations of a screw conveyer under the influence of pulse forces is presented. It has been determined, that there is a jump pattern of change of the amplitude-frequency characteristics of the torsorial vibrations of a screw conveyer. Resonance torsorial vibrations of a screw conveyer under the influence of pulse forces have been considered. Torsorial vibrations of a screw conveyer have been investigated in case, when the moment of resistance forces is proportional to the relative angular velocity, and the moment of pulse forces is approximated by a non-linear function. It has been determined, that in such a case the influence of pulse forces becomes apparent only in the change of frequency of the vibrations of a screw conveyer. The amplitude-frequency characteristics of the torsorial vibrations of a screw conveyer of different geometrics have been presented.

Keywords: screw conveyer, torsorial vibrations, pulse forces

INTRODUCTION

Conveyor transport and technological mechanisms are widely used in different branches of industry, including mining industry, for the transportation of bulk and lump material. The efficiency of the operation of many bays, shops and the whole enterprises depends on their reliable functioning. Screw conveyers can be characterized by the simplicity of their design and, consequently, high reliability, easiness of operation and adjustment when used in automated systems and by being ecologically-friendly to the environment because of their hermeticity [2], [4], [5]. High speed screw conveyers are used for all-purpose loading and unloading complexes, which are designed to transport load on horizontal, declining and vertical routes. The existing methods are based on a number of theoretical and experimental investigations as well as on the analysis of the statistical data on the results of their exploitation. In order to provide the reliability and the quality of the technological processes performed by conveyer mechanisms, it is necessary to take into account the dynamic vibrations, caused by outside power factors and the peculiarities of the functioning of screw conveyers.

The fundamentals of the designing and the investigation of screw conveyers were layed by such scientists as A.M. Grigoryev [5], B.M. G levko [2], R.M. Rohatynskyi [2], V.S. Loveikin [6], R.B. Gevko [4] and

Résumé: L’objectif de la recherche est d’analyser l’influence des forces impulsionnelles sur les vibrations torsorielles non linéaires d’un convoyeur à vis.

La méthodologie est basée sur la combinaison des méthodes de Bubnov-Halorkin et de Van der Pol. Nous avons développé les équations sous forme standard pour le cas d’actions de forces impulsionnelles.

Un modèle mathématique des vibrations torsorielles d’un convoyeur à vis sous l’influence des forces impulsionnelles est présenté. Nous avons déterminé que l’effet des forces impulsionnelles se manifeste seulement par des modifications de la fréquence des vibrations du convoyeur à vis.

Les caractéristiques amplitudonégolettes des vibrations torsorielles d’un convoyeur à vis ont été étudiées, lorsque le moment de résistance est proportionnel à la vitesse angulaire relative, et le moment des forces impulsionnelles est approximé par une fonction non-linéaire. Nous avons déterminé que dans ce cas, l’influence des forces impulsionnelles se manifeste seulement par des modifications de la fréquence des vibrations du convoyeur à vis.

Les caractéristiques amplitudonégolettes des vibrations torsorielles d’un convoyeur à vis de différentes géométries ont été présentées.

Mots-clés : convoyeur à vis, vibrations torsorielles, forces impulsionnelles.

INTRODUCTION

Les convoyeurs transport et mécanismes technologiques sont largement utilisés dans différentes branches d’industrie, y compris l’industrie minière, pour le transport de matériaux en poudre et en bloc. L’efficacité de l’opération de nombreuses baies, magasins et d’entiers entiers dépend de leur fonctionnement fiable. Les convoyeurs à vis peuvent être caractérisés par la simplicité de leur conception et, conséquemment, la fiabilité haute, l’aisance d’exploitation et d’ajustement quand utilisés dans des systèmes automatisés et sont écologiquement amicaux envers l’environnement en raison de leur hermeticité [2], [4], [5]. Les convoyeurs à vis à hauts vitesses sont utilisés pour des complexes d’affrétement et déchargement, qui sont conçus pour transporter le chargement sur des chemins horizontaux, en pente et verticaux. Les méthodes existantes sont basées sur un certain nombre de méthodes théoriques et d’investigations expérimentales ainsi que sur l’analyse des données statistiques sur les résultats de leur exploitation. Afin de garantir la fiabilité et la qualité des processus techniques réalisés par les mécanismes de convoyeurs, il est nécessaire de prendre en compte les vibrations dynamiques, causées par des facteurs de puissance extérieurs et les particularités de l’exploitation des convoyeurs à vis.

Les fondements du conçue et l’investigation des convoyeurs à vis étaient déposés par des scientifiques tels que A.M. Grigoryev [5], B.M. Glevko [2], R.M. Rohatynskyi [2], V.S. Loveikin [6], R.B. Gevko [4] and
The development of the theory of vibrations was elaborated by V.S. Loveikin [6], L.Q. Chen [1] and other. In case of forced vibrations, in other words those vibrations, which are caused by the influence of periodical forces, the frequency of which is altering in time, the amplitude of vibrations and the dynamic stress essentially depend on the frequency of the forcing power. When the above mentioned frequencies are the same, or when the frequency of forcing power approximates the frequency of natural oscillations in a screw conveyor and in case of low damping, resonance is developing [7,3], that is the amplitude of vibrations which is increasing rapidly. Such a rise in the amplitude causes an essential increase of a twist angle or deflection of a conveyor. With the increase of angle or linear deformations, the dynamic stress in the working bodies of screw conveyers increases as well. In this case, dynamic stress (resonance) depends both on inside factors (physical and mechanical parameters of a screw conveyor, its geometrics etc.) and on the outside ones. The outside factors include the angle speed of the rotation of a conveyor and the value of outside disturbing forces for flexural [3] and torsorial vibrations [7].

**MATERIAL AND METHOD**

General results, presented in papers [7,3], are used for the investigation of the influence of pulse forces on the torsorial vibrations of a screw conveyor. A screw conveyor rotates about an axis, making torsorial and flexural vibrations. In many cases the last ones cause short-lasting periodical influence on torsorial vibrations. The question is about the contact of a screw and a casing, transportation of bulk loads of relatively large sizes and other. A mathematical model of the torsorial vibrations of a screw conveyor for the above mentioned influence of outside immediate forces is the following differential equation

\[
I \frac{d^2 \theta}{dt^2} + \frac{\partial}{\partial x} \left( GJ \frac{\partial \theta}{\partial x} \right) = Q \left( 0, \frac{\partial \theta}{\partial x}, \frac{\partial \theta}{\partial t} \right) + \sum_{n=1}^{\infty} Q \left( 0, \frac{\partial \theta}{\partial x}, \frac{\partial \theta}{\partial t} \right) \sum_{j=-\infty}^{\infty} \delta \left( t - (t_j + \tau) \right),
\]

where \( \theta(x,t) \) - twist angle of a screw conveyor, \( I \) - linear moment of inertia of a screw conveyor about a strain-free axis, \( G \) - shear modulus of the material of a screw conveyor, \( J \) - equatorial moment of the cross-section of a screw conveyor, \( \delta(...) \) - Dirac function, which acts periodically over a period of \( \tau \) at time moments \( t_j \), \( Q \left( 0, \frac{\partial \theta}{\partial x}, \frac{\partial \theta}{\partial t} \right) \) - function, which characterizes the intensity of pulse forces action at the time moments mentioned.

If the properties of \( \delta \)-function are used:

\[
f(t) \delta(t) = f(0) \delta(t),
\]

\[
\sum_{j} \delta(t - j\tau) = \frac{u}{\pi} \left[ \frac{1}{2} + \sum_{j=1}^{\infty} \cos j\omega t \right];
\]

\[
\int_{-\infty}^{t} \delta(t) dt = \begin{cases} 1, & t > 0, \\ 0, & t \leq 0, \end{cases}
\]

де \( \theta(x,t) \) - кут закручення шнека, \( I \) - погонний момент інерції шнека відносно нездеформованої осі, \( G \) - модуль зсуву матеріалу шнека, \( J \) - екваторіальний момент поперечного перерізу шнека, \( \delta(...) \) - функція Дірака, яка діє періодично із періодом \( \tau \) у моменти часу \( t_j \), \( Q \left( 0, \frac{\partial \theta}{\partial x}, \frac{\partial \theta}{\partial t} \right) \) - функція, яка характеризує інтенсивність дії імпульсних сил у вказані моменти часу.

Якщо використати властивості \( \delta \) – функції:
the system of differential equations (1) after the averaging is as follows:

\[
\frac{da}{dt} = -\frac{\mu}{a_0} \left\{ F_{\alpha_0}^i (a) + \frac{\nu}{2\pi} \sum_{j=1}^n F_{\beta_{\alpha_0}}^i (0) \right\},
\]
\[
\frac{d\phi}{dt} = -\frac{\mu}{\alpha a_0} \left\{ F_{\alpha_0}^i (a) + \frac{\nu}{2\pi} \sum_{j=1}^n F_{\beta_{\alpha_0}}^i (0) \right\},
\]

where \( \nu = \frac{2\pi}{\tau} \), \( \omega_\phi \) – frequency of the vibrations in a screw conveyer.

If it is technically considered, the fact that the above mentioned equations can be integrated, then the dynamic process of a screw conveyer can be shown as

\[
\theta(x,t) = a(t) X(x) \cos(\omega_\theta t + \phi(t)),
\]

In (5) the amplitude of torsorial vibrations \( a(t) \) and its phase \( \psi = \omega_\theta t + \phi(t) \) are determined by the system (4).

The indicated solution will be the first approximation to the task stated. In order to describe a jump pattern of change for the main parameters of the torsorial vibrations of a screw conveyer, it is necessary to find its first improved approximation. In order to find it, we assume, that the solution of the differential equations (4) is the functions \( a = a(t) \) and \( \psi = \psi(t) \). Then, the first “improved” approximation of the parameters \( a \) and \( \psi \) is represented as follows

\[
a_{\text{impr}} = a - \frac{\mu}{a_0} \left\{ \frac{\nu}{2\pi} \sum_{j=1}^n F_{\alpha_0}^i (a) \sigma(t,j) + \frac{\nu}{2\pi} \sum_{j=1}^n \sum_{n}^{n} \frac{-F_n^{\alpha_0} (a) \cos(n\psi) + F_n^{\alpha_0} (a) \sin(n\psi)}{n \omega_\theta} + \right\},
\]
\[
\psi_{\text{impr}} = \psi_0 + \frac{\varepsilon}{\alpha a_0} \left\{ \frac{\nu}{2\pi} \sum_{j=1}^n F_{\alpha_0}^i (a) \sigma(t,j) + \frac{\nu}{2\pi} \sum_{j=1}^n \sum_{n}^{n} \frac{F_n^{\alpha_0} (a) \cos(n\psi) + F_n^{\alpha_0} (a) \sin(n\psi)}{n \omega_\theta} + \right\},
\]

То система диференційних рівнянь (1) після усереднення набуває вигляду

де \( \nu = \frac{2\pi}{\tau} \), \( \omega_\theta \) – частота власних коливань шнека.

Якщо формально вважати, що вказані рівняння вдається зінтегрувати, то динамічний процес шнеку представляється у вигляді

\[
\theta(x,t) = a(t) X(x) \cos(\omega_\theta t + \phi(t)),
\]

У (5) амплітуда крутильних коливань \( a(t) \) та її фаза \( \psi = \omega_\theta t + \phi(t) \) визначаються системою (4).

Вказані розв’язок буде першим наближенням поставленої задачі. Щоб описати стрибкоподібний характер зміни основних параметрів крутильних коливань шнеку, необхідно знайти його перше покращене наближення. Для його знаходження припускаємо, що розв’язком диференційних рівнянь (4) є функції \( a = a(t) \) і \( \psi = \psi(t) \). Тоді перше “покращене” наближення параметрів \( a \) і \( \psi \) представляється у вигляді
where \( \sigma(t, t_1) \) – periodic function, which is the sum of \( \sum_j \sin \left( j \omega (t - t_1) \right) / j \) 

The above mentioned shows, that in non-resonance case, the pulse pattern of loading becomes apparent in the jump change of the amplitude \( a_{\text{swz}} \) and phase \( \psi_{\text{swz}} \) at the moment of pulse forces action. The value of the jumps is low because the intensity of pulse forces is low. Despite of this, during the use of screw machinery their action is increasing and in some time it can lead to major amplitudes of torsorial vibrations.

Resonance torsorial vibrations of a screw conveyor under the influence of pulse forces should be considered. Much more important case of torsorial vibrations is the one, where the frequency of natural oscillations is connected with the frequency of pulse disturbance by the correlation \( \omega_0 \approx q / p \), \( (p, q - \text{reciprocals}) \); here \( \omega = \frac{2\pi}{\tau} \).

The above mentioned substantiates the following differential equation for pulse forces action

\[
\frac{d^2 T}{dt^2} + \left( \frac{q}{p} \right)^2 T = \mu F \left( T, \frac{dT}{dt}, \omega T \right) - \Delta T + \sum_{j=1}^{n-1} \left( \frac{q}{p} \right)^2 \delta \left( t - (t_j + j\tau) \right) \tag{7}
\]

where \( \mu \Delta \) – dregulation of frequencies \( T(t) = a \cos \psi \). In this case, the usual differential equations relative to variables \( a(t) \) and \( \varphi(t) \) acquire the form of

\[
\frac{da}{dt} = -\sin \psi \frac{p}{q} \mu F \left( a \cos \psi, -av \frac{q}{r} \sin \psi \right) - \Delta a \frac{q}{p} \cos \psi + \sum_{j=1}^{n-1} \left( \frac{q}{p} \right)^2 \delta \left( t - (t_j + j\tau) \right) \tag{9}
\]

\[
\frac{d\varphi}{dt} = -\cos \psi \frac{p}{q} \mu F \left( a \cos \psi, -av \frac{q}{r} \sin \psi \right) - \Delta a \frac{q}{p} \cos \psi + \sum_{j=1}^{n-1} \left( \frac{q}{p} \right)^2 \delta \left( t - (t_j + j\tau) \right) \tag{9}
\]

Taking into consideration the assumption, that \( Q(... \) and \( Q_j (... \) - multinominals, the functions \( F \left( a \cos \psi, -av \frac{q}{r} \sin \psi \right) \) and \( F_j \left( a \cos \psi, -av \frac{q}{r} \sin \psi \right) \) are represented in the form of Fourier series. Using the information above and the properties of \( \delta \) of Dirac function (2), (3), the system of the differential equations (9) after the approximation acquires the form of

\[
\frac{d a}{d t} = -\frac{\mu p}{2\pi q} \sum_{j=1}^{n} \left( F_0^m \left( a \right) + \sum_{n} \left( F_m^m \left( a \right) \cos n \left( p \varphi + q \psi \right) + F_m^n \left( a \right) \sin n \left( p \varphi + q \psi \right) \right) \right) \tag{9}
\]

Thus, in resonance case, in contrast to non-resonance, in the approximated equations the additional terms have appeared. But similarly to non-resonance case, the values \( a_{\text{swz}} \) and \( \psi_{\text{swz}} \) at the

where \( \sigma(t, t_1) \) – periodична функція, яка є сумою ряду

\[
\sum_j \sin \left( j \omega (t - t_1) \right) / j
\]
The torsorial vibrations of a screw conveyer should be considered in case, when the moment of sustaining power is proportional to the relative angular velocity of a screw conveyer \( \frac{\partial \theta(x,t)}{\partial t} \), and the moment of pulse forces is approximated by the function \( \lambda \theta(x,t) + \gamma \theta^3(x,t) \). The differential equation of the torsorial vibrations of a screw conveyer is as follows

\[
\frac{\partial^2 \theta}{\partial t^2} - GJ_0 \frac{\partial^2 \theta}{\partial x^2} = \mu(\lambda \theta(x,t) + \gamma \theta^3(x,t)) \times \sum_{j=1}^{m} \sum_{i=1}^{n} \delta(t - (t_j + j\tau)) - \beta \frac{\partial \theta}{\partial t}.
\]  

(10)

According to the method by Bubnov-Halorkin, the solution to the equation (10) is shown to be the same as in paper [7] in the form of

\[
\theta(x,t) = X(x)T(t).
\]

After simple transformations, the differential equations are reduced to a simple form of differential equation

\[
\frac{d^2 T(t)}{dt^2} + \left( k \frac{\pi}{t} \right)^2 GJ_0 T(t) = \mu \left( \lambda T + \gamma T^3 \right) \times \sum_{j=1}^{m} \sum_{i=1}^{n} \delta(t - (t_i + j\tau)) - \beta \frac{dT}{dt}.
\]  

(11)

For non-resonance vibrations of a screw conveyer, the amplitude and the frequency of the vibrations according to the results given in paper [3] ( \( t_1 = 0 \), \( t_2 = \frac{\pi}{2\omega} \)) are described with the help of the differential equations

\[
\frac{da}{dt} = -\mu \beta \frac{a}{2} ,
\]

\[
\frac{d\psi}{dt} = \omega_0 - \frac{\mu}{\omega_0 \pi} \left( \frac{\lambda \mu}{8} + \frac{3\gamma a^2}{32} \right).
\]

Having integrated the obtained system of differential equations, the first approximation of the solution to the equation of the torsorial vibrations of a screw conveyer is found

\[
T(t) = a_0 e^{\frac{\beta}{2} \cos(\omega t + \theta_0)} e^{-\left( \frac{\lambda \mu}{8} \omega_0 + \frac{3\gamma a_0^2}{32\pi \omega_0} e^{\frac{\beta}{2}} \right)}.
\]  

(12)

Where

\( a_0 \) and \( \theta_0 \) are determined to be starting conditions.

Thus, the influence of pulse forces becomes apparent only in change of the frequency of the vibrations of a screw conveyer.

Resonance vibrations should be considered. Let’s assume, that the frequency of natural oscillations of a screw conveyer is connected with the frequency of the pulse disturbance by the following correlation

\[
\omega \approx \frac{q}{2}.
\]  

(13)

In this case, a first approximation of the solution of the differential equation (12) has the following form

\[
d_{mOP} \text{ and } \psi_{mOP} \text{ in moment dії імпульсних сил змінюються стрибківкою.}
\]

Розглянемо крутильні коливання шнека за умови, що момент сил опору пропорційні відносній кутовій швидкості руху шнеку \( \frac{\partial \theta(x,t)}{\partial t} \), а момент імпульсних сил прихрестується функцією \( \lambda \theta(x,t) + \gamma \theta^3(x,t) \). Диференціальне рівняння крутильних коливань шнека в такому разі матиме вигляд

\[
\frac{d^2 T(t)}{dt^2} + \left( k \frac{\pi}{t} \right)^2 GJ_0 T(t) = \mu \left( \lambda T + \gamma T^3 \right) \times \sum_{j=1}^{m} \sum_{i=1}^{n} \delta(t - (t_i + j\tau)) - \beta \frac{dT}{dt}.
\]  

Відповідно до методу Бубнова-Гальоркіна розв’язок рівняння (10) представимо як і в роботі [7] у вигляді \( \theta(x,t) = X(x)T(t) \). Після нескладних перетворень диференціальних рівнянь зводяться до звичайного диференціального рівняння вигляду

\[
\frac{d^2 T(t)}{dt^2} + \left( k \frac{\pi}{t} \right)^2 GJ_0 T(t) = \mu \left( \lambda T + \gamma T^3 \right) \times \sum_{j=1}^{m} \sum_{i=1}^{n} \delta(t - (t_i + j\tau)) - \beta \frac{dT}{dt}.
\]  

(11)

Для нерезонансних коливань шнеку амплітуда та частота коливань шнеку відповідно до результатів роботи [3] ( \( t_1 = 0 \), \( t_2 = \frac{\pi}{2\omega} \)) описуються диференціальними рівняннями

\[
\frac{da}{dt} = -\mu \beta \frac{a}{2} ,
\]

\[
\frac{d\psi}{dt} = \omega_0 - \frac{\mu}{\omega_0 \pi} \left( \frac{\lambda \mu}{8} + \frac{3\gamma a^2}{32} \right).
\]

Зінтегрувавши отриману систему диференціальних рівнянь, знаходимо перше наближення розв’язку рівняння крутильних коливань шнека у вигляді

\[
T(t) = a_0 e^{\frac{\beta}{2} \cos(\omega t + \theta_0)} e^{-\left( \frac{\lambda \mu}{8} \omega_0 + \frac{3\gamma a_0^2}{32\pi \omega_0} e^{\frac{\beta}{2}} \right)}.
\]  

(12)

de

\( a_0 \) и \( \theta_0 \) визначаються початковими умовами.

Таким чином, вплив імпульсних сил проявляється в зміні лише частоти коливань шнека.

Розглянемо резонансні коливання. Нехай частота власних коливань шнека зв’язана із частотою імпульсного збурення співвідношенням

\[
\omega \approx \frac{q}{2}.
\]  

(13)

В такому разі перше наближення розв’язку диференціального рівняння (12) матиме вигляд
Figure 1 shows the amplitudes of the torsional vibrations of a screw conveyor when there is a transition through the resonance at different parameter values \( \omega_0 = \frac{k \pi}{l} \sqrt{\frac{GJ_0}{I_0}} \) at \( l = 10 \text{m} \); \( G = 80 \text{MPa} \); \( I_0 = 3,4675 \times 10^{-6} \text{m}^4 \).

\[ T(t) = a(t) \cos \left( \frac{\omega_0}{2} qt + \varphi(t) \right), \]

where functions \( a(t) \) and \( \varphi(t) \) are determined from the system of differential equations.
correlations, which describe the resonance mode of the vibrations of a screw conveyor, to zero. We get a system of algebraic equations

$$\frac{\beta a}{2} + \frac{a \left(2\lambda + \gamma a^2\right)}{4\pi q} \left(\sin 2\varphi + \sin \left(2\varphi + q \frac{\pi}{2}\right)\right) - \frac{\gamma a^3}{8\pi q} \left(1 + (-1)^q\right) \sin 4\varphi = 0,$$  \hspace{1cm} (15)

$$\frac{\omega_0^2 - \left(\frac{q \omega}{2}\right)^2}{\omega_0^2} = \mu\left(\frac{4\lambda + 3\gamma a^2}{4\pi q} + \frac{\lambda + \gamma a^2}{2\pi q}\right) \left(\cos 2\varphi + \cos \left(2\varphi + q \frac{\pi}{2}\right)\right) + \frac{\gamma a^2}{8\pi q} \left(1 + (-1)^q\right) \cos 4\varphi = 0.$$  \hspace{1cm} (16)

This relation shows, that the amplitude of permanent vibrations of a screw conveyor (16) is actual, if the conditions are met

$$\begin{align*}
\varphi &< 4\omega_0 - \frac{8\lambda}{\pi} - 2\sqrt{17} |\beta|, \\
\varphi &> 4\omega_0 - \frac{8\lambda}{\pi} + 2\sqrt{17} |\beta|.
\end{align*}$$  \hspace{1cm} (17)

If we put $\beta = 0$ in these relations, in case of resonance $\omega_0 = \frac{\upsilon}{2}$ the invariant of motion can be found for a first approximation. To order to find it, we will limit to the values of first order of smallness.

Thus, at $q = 1$ we get the correlation

$$\left(2\omega_0 - \upsilon\right) \frac{1}{2} a^2 - \frac{2}{\pi} a^2 - \frac{3\gamma a^4}{8\pi} = \frac{2\lambda a^2 + \gamma a^4}{2\sqrt{2}\pi} \cos \left(20 + \frac{\pi}{4}\right) = c,$$  \hspace{1cm} (18)

where $c$ is a constant, which is determined by starting conditions.

With the help of this correlation we can evaluate the value of the amplitude of resonance vibrations. For this reason, we transform the relation (18) to the form of

$$\cos \left(20 + \frac{\pi}{4}\right) = \left(2\omega_0 - \upsilon\right) \frac{1}{2} a^2 - \frac{2}{\pi} a^2 - \frac{3\gamma a^4}{8\pi} - c \frac{2\sqrt{2}\pi}{2\lambda a^2 + \gamma a^4}.$$  \hspace{1cm} (19)

Having marked $\Phi\left(a^2\right)$ in the right part, we develop graphical relations $\Phi\left(a^2\right)$ as the functions from $a$ at different fixed values $c$. These graphical relations under the condition $-1 \leq \Phi\left(a^2\right) \leq 1$ determine the domain of the stability of resonance vibrations. Figure 2-3 shows these domains.
The analysis of the graphical relations shows, that at different resonances under different conditions $\gamma$ and $\nu$, the amplitudes of the torsorial vibrations of a screw conveyer are limited. This limitedness of the amplitude of the vibrations in a system, which is described by the equation (10) in cases of the considered resonances, is the result of non-linearity of the system. This matches the known results concerning non-linear vibrations of a system. It is worth mentioning, that the action of pulse loading on a linear vibration system in resonance case leads to unlimited increase in the amplitude of vibrations.

Figure 4 shows graphical dependancies of the function $\Phi(a^2)$ on the square of the amplitude at different values of deregulation of frequencies.

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Figure 4 shows graphical dependancies of the function $\Phi(a^2)$ on the square of the amplitude at different values of deregulation of frequencies.
The above mentioned dependacies in Figure 4 show, that the increase in the value of deregulation of frequencies shifts the domain of stable values of the amplitude of the vibrations of the flexible component of a drive to the right. In other words, the closer to the resonance, the less are the values of the amplitude of vibration, at which the dynamic process is stable. With an increase in the value of deregulation of frequencies from 0.01 \( \text{c}^{-1} \) to 0.08 \( \text{c}^{-1} \), resonance values of the amplitude of vibrations, at which the dynamic process is stable, increase up to 5%.

Figure 5 shows graphical dependancies of the influence of the value of non-linear restoring force (coefficient \( \gamma \)) on the domain of stable values for resonance amplitudes of the vibrations of a screw conveyer.

\[
\begin{array}{c|c|c|c|c|c}
\alpha^2 & 0.01 & 0.03 & 0.04 & \gamma \\
\hline
0 & 10 & 20 & 30 & 40 \\
\end{array}
\]

These dependancies show, that with an increase of the non-linearity of the system (for larger values of the coefficient \( \gamma \)), the domain of the values of the amplitude of the torsional vibrations of a screw conveyer, at which the dynamic process is stable, narrows. At \( \gamma = 80 \), the domain of the values of the amplitude of the vibrations of a flexible component, at which the dynamic process is stable, is less from the domain of the values of the amplitude at \( \gamma = 40 \) for 42%.

**CONCLUSION**

The represented graphical dependencies and their comparison with the resonance curves in case of flexural vibrations [4] make possible to state, that resonance value of the amplitude of the vibrations of a screw conveyer takes a smaller value at larger frequencies. The obtained results give the possibility to avoid resonance torsional vibrations of a screw conveyer in case of its exploitation under the influence of pulse forces due to the change of material transportation conditions. Based on the taken out equations, it is possible to develop the automated systems of management for the processes of material transportation using screw machinery.

**REFERENCES**


Fig. 5 — Область стійких значень амплітуди крутильних коливань шнека за різних значень коефіцієнта \( \gamma \) при \( e_0 = 90 \text{ c}^{-1} \)

\[ c = -0.005 \]

Из наведених залежностей випливає, що із зростанням нелінійності системи (для більших значень коефіцієнта \( \gamma \)) область значень амплітуди крутильних коливань шнека для яких динамічний процес буде стійким звужується. При \( \gamma = 80 \) область значень амплітуди коливань гнучкого елемента, за яких динамічний процес буде стійким є меншою на 42% від області значень амплітуди при \( \gamma = 40 \).

**ВИСНОВОК**

Представлені графічні залежності та їх інтерпретація дозволють стверджувати, що результати досліджень надають можливість уникнути резонансних крутильних коливань шнека у випадку його експлуатації при дії імпульсних сил за рахунок зміни режимів транспортування матеріалів. На основі виконаних досліджень можливе створення автоматизованих систем управління процесами транспортування матеріалів шнековими машинами.

**БІБЛІОГРАФІЯ**


MODELLING OF THE VERTICAL SCREW CONVEYER LOADING

INTRODUCTION

Nowadays screw conveyers are the major means of continuous transportation of agricultural bulk-cargo materials. A great number of screw carriers are used now for transporting of grain beside the screws, which are parts of complex agricultural machines [2,4,5,9]. They are of extremely simple design and are characterized by their small size and reliability in operation. But their disadvantage is that of decrease of efficiency under high frequency of the screw rotation caused by the increase of the centrifugal forces in the loading area, which results in the increase of the transporting process power-consumption by these devices.

Despite of great number of papers dealing with the studying of transporting materials by the screw mechanisms, there are only experimental investigations of different ways of loading, basing on which the recommendations on the choice of the loading devices are presented [1,6,7].

The objective of the work is to develop the mathematical model of the vertical screw conveyer loading, which can be used to obtain the picture of the stresses and speeds distribution in the screw channel and, consequently, the dependence of the screw conveyer efficiency on its geometric parameters, rate of angular motion, as well as physical-mechanical properties of the bulk-cargo.

MATERIAL AND METHOD

Screw conveyer, which is in the tank loaded with bulk-cargo, with given physical-mechanical properties is presented in Fig. 1.

To investigate the movement of bulk-cargo in the screw channel generally, the screw coordinates system, which is connected with the screw rigidly, is used.

But, to obtain even approximate solution of the movement equation in this system is difficult enough. That is why in order to simplify the given task, cylinder coordinates system is used instead of the screw one.
As we are analyzing high-speed vertical screw conveyer, the cross-section of the screw channel can be presented as in Fig.2, that is, bulk-cargo under the action of centrifugal forces moves in the channel of width $H = R_1 - R_0$ [8].

Here $R_1$ – screw radius, $r_s$ – screw shaft radius.

In this case the coefficient of loading will equal:

$$K_z = \frac{R_1^2 - R_0^2}{R_0^2}$$

Hence $R_0 = \sqrt{R_1^2 - K_z (R_1^2 - r_s^2)}$.

If we assume, that coefficient of loading is $K_z = 0.8$, $r_s = 0.3R_0$, we will obtain $R_0 \approx 0.5R_1$.

Thus, further we will analyze the movement of the bulk-cargo in the “conventional” screw channel, the shaft radius of which equals $R_0$.

Here friction force between the bulk-cargo and screw shaft is usually not available, as well as the shaft pressure on the screw surface.

As $H/B << 1$, $H = R_1 - R_0$, $B = 2R_1$, we can study the plane model of the bulk-cargo medium movement in the screw channel (Fig.3). In this case taking into account the fact, that bulk-cargo movement is of the layer-type, let us assume that $V_z = 0$, $\partial V_0/\partial z = 0$.

The equation of movement will look like:

$$\rho \left( V_r \frac{\partial V_r}{\partial r} + V_0 \frac{\partial V_0}{\partial r} - \frac{V_z^2}{r} \right) = \frac{\partial \sigma_r}{\partial r} + \frac{1}{r} \frac{\partial \tau_{r\theta}}{\partial \theta} + \frac{\sigma_r - \sigma_\theta}{r} + \rho F_r,$$

$$\rho \left( V_r \frac{\partial V_\theta}{\partial r} + V_0 \frac{\partial V_\theta}{\partial r} - \frac{V_z V_\theta}{r} \right) = \frac{\partial \tau_{r\theta}}{\partial \theta} + \frac{1}{r} \frac{\partial \sigma_\theta}{\partial \theta} + \frac{2\tau_{r\theta}}{r} + \rho F_\theta,$$

$$\frac{\partial V_0}{\partial r} + \frac{1}{r} \frac{\partial V_0}{\partial \theta} = 0.$$
where \( V_r, V_{\phi} \) – particle speed vector projection relatively on the radius-vector direction and on the perpendicular to it direction; \( F_r, F_{\phi} \) – mass force projections on the same directions; \( \sigma_r, \sigma_{\phi}, \tau_{r\phi} \) – components of the tensor stresses in the polar coordinates.

Equations 2, 3 are the equations of the total medium movement written as Eulerian variables, and equation 4 – continuity equation in the polar coordinates. Unlike the elastic medium, let us assume the rule of signs for stresses, according to which in the area the outside normal of which coincides with the positive direction of the coordinate axis, positive stress components have directions opposite to those of corresponding coordinate axes.

According to the investigations [6], the speed \( V^n \) with which the bulk-cargo moves into the screw channel of the intake area of the screw, decreases from the maximum value to zero according to the linear law:

\[
V^n = 2V_c \left( 1 - \frac{R}{L_0} \phi \right) = 2V_c \left( 1 - \frac{\phi}{\phi_0} \right)
\]

(5)

where \( V_c \) – average speed, with which the bulk-cargo moves from the tank to the screw channel.

\[
V_c = \frac{Q}{L_0 R}.
\]

(6)

where \( Q \) – volumetric efficiency of the screw conveyer \( \frac{M^3}{C} \). \( B \) – screw channel width \( B = S \cdot \cos \alpha \); \( S \) – screw helix; \( \alpha \) – screw line angle of elevation; \( L_0 \) – screw channel length in the intake area \( \phi_0 = L_0/R \).

As in our case the channel height is greater enough than its length, we can assume, that radial speed decreases from the maximum value \( V_c^0 \) to zero along the radius according to the linear law:

\[
\frac{\partial V_r}{\partial r} = C,
\]

(7)
where \( C = C(\varphi) \) – some function dependent on the coordinate \( \varphi \) (Fig. 3).

Let us write the boundary conditions:

\[
V_{r} = C(\varphi)r + C_{0}
\]  

(8)

where \( C = C(\varphi) \) – деяка функція, яка залежить від координати \( \varphi \) (рис. 3).

Запишемо граничні умови:

\[
\frac{\partial V_{r}}{\partial r} = 0, \quad \frac{\partial V_{\varphi}}{\partial r} = -V_{r}^{0}.
\]

(9)

Then from the equation (8), taking into account (9), we will obtain:

\[
C(\varphi) = \frac{V_{r}^{0}}{R_{2} - R_{1}},
\]

(10)

\[
C_{0}(\varphi) = \frac{V_{r}^{0} \cdot R_{1}}{R_{2} - R_{1}},
\]

(11)

\[
V_{r} = \frac{V_{r}^{0}(r - R_{1})}{R_{2} - R_{1}} = \frac{2V_{r}^{0}(r - R_{1})}{R_{2} - R_{1}} \left( 1 - \frac{\varphi}{\varphi}_{1} \right).
\]

(12)

From the continuity equation (4) we will obtain:

\[
C(\varphi) + \frac{V_{r}^{0}}{r} + \frac{1}{2} \frac{\partial V_{r}}{\partial \varphi} = 0
\]

(13)

or

\[
\frac{\partial V_{r}}{\partial \varphi} = V_{r} + C(\varphi) = \frac{2V_{r}^{0}(r - R_{1})}{R_{2} - R_{1}} \left( 1 - \frac{\varphi}{\varphi}_{1} \right) + r2V_{r}^{0} \left( 1 - \frac{\varphi}{\varphi}_{1} \right) = 2V_{r}^{0} \left( 1 - \frac{\varphi}{\varphi}_{1} \right) \left( r - R_{2} + \frac{R_{2} - R_{1}}{R_{2} - R_{1}} \right)
\]

(14)

Having integrated this equation we will have

\[
V_{r} = \frac{2V_{r}^{0}}{R_{2} - R_{1}} \left( \varphi - \frac{\varphi^{2}}{2\varphi_{1}} \right) + \psi(r)
\]

(15)

where \( \psi(r) \) – some function from \( r \).

Then to find \( \psi(r) \) let us assume, that relative rates of angular motion of the part of the bulk-cargo in the screw channel of the transporting area of the screw are distributed according to the law [3].

\[
\omega = \omega_{0} - \frac{CR_{1}}{r^{2}},
\]

(16)

where \( \omega_{0} \) – screw rate of angular motion, \( C \) – some constant, which depends on the physical-mechanical properties of the bulk-cargo and the screw parameters.

Then the volumetric efficiency of the screw conveyor will equal:

\[
Q = B \times \int_{\frac{R_{1}}{\cos \alpha}}^{R_{2}/\cos \alpha} \frac{C}{\cos \alpha} dr = \frac{B}{\cos \alpha} \left[ 0.5\omega_{0}(R_{2}^{2} - R_{1}^{2}) - CR_{1} \ln \frac{R_{1}}{R_{2}} \right]
\]

(17)

where \( B = S \cos \alpha \); taking into account that:

\[
\omega = \omega_{0} - \frac{CR_{1}}{r^{2}},
\]

де \( \omega_{0} \) – кутова швидкість гвинта; \( C \) – деяка константа, яка залежить від фізико-механічних властивостей матеріалу, та параметрів гвинта.

Тоді об’ємна продуктивність гвинтового конвеєра буде рівна:

\[
Q = B \times \int_{\frac{R_{1}}{\cos \alpha}}^{R_{2}/\cos \alpha} \frac{C}{\cos \alpha} dr = \frac{B}{\cos \alpha} \left[ 0.5\omega_{0}(R_{2}^{2} - R_{1}^{2}) - CR_{1} \ln \frac{R_{1}}{R_{2}} \right]
\]

(17)

where \( B = S \cos \alpha \); враховуючи, що:

\[
\omega = \omega_{0} - \frac{CR_{1}}{r^{2}},
\]

де \( B = S \cos \alpha \); враховуючи, що:
\[
Q = \frac{\pi [D_1^2 - D_2^2]}{4} n \cdot S \cdot K_n = \pi (R_1' - R_0') B \times n \cdot S \cdot K_n ,
\]

where \( n = \omega / 2\pi \) – frequency of revolving (rev/sec); \( K_n \) – screw conveyer efficiency coefficient.

de \( n = \omega / 2\pi \) – частота обертання об/с; \( K_n \) – коефіцієнт продуктивності гвинтового конвеєра.

\[
C = \frac{\omega_0 (R_1'^2 - R_0'^2)}{2 R_1 \ln \frac{R_1}{R_0}} (1 - K_n)
\]

Taking into account that at \( \varphi = \varphi_1 \)
\[
V_o = \left( \omega_0 - CR_0 / r^2 \right) r, \text{ let us find function } \psi = \psi(r) :
\]

\[
V_o = 2V \left( \frac{2r - R_0}{R_0 - R_1} \right) \left( \frac{\varphi_1 - \varphi_0}{2\varphi_1} \right) + V(r) = 2V \left( \frac{2r - R_0}{R_0 - R_1} \right) \left( \frac{2\varphi_1 - \varphi_0}{2\varphi_1} \right) + V(r) = 2V \left( \frac{2r - R_0}{R_0 - R_1} \right) \frac{\varphi_1}{2} + V(r),
\]

\[
\psi_r = \left( \omega_0 - \frac{CR_0}{r^2} \right) r - V \left( \frac{2r - R_0}{R_0 - R_1} \right) \frac{\varphi_1}{2},
\]

\[
V_o = 2V \left( \frac{2r - R_0}{R_0 - R_1} \right) \left( \frac{\varphi_1 - \varphi_0}{2\varphi_1} \right) - V \left( \frac{2r - R_0}{R_0 - R_1} \right) \varphi_1 + \left( \omega_0 - \frac{CR_0}{r^2} \right) r - V \left( \frac{2r - R_0}{R_0 - R_1} \right) \left( \varphi_1 - \varphi_0 \right)^2 .
\]

As we are analyzing non-ramming screw, in the end of the intake area we can assume: at \( \varphi_1 = \varphi \) \( \frac{\partial \tau_m}{\partial \varphi} = 0 \)
\[
V_o = \left( \frac{\omega_0 - CR_0}{r^2} \right) r \ V_o = 0 . \text{ Besides let us assume that } \sigma_0 = k \sigma_r , \text{ where } k \text{ – lateral pressure coefficient.}
\]

From the equation (12) we will obtain:

\[
\frac{\partial V_o}{\partial \varphi} = \frac{2V_o (R_0 - r)}{(R_0 - R_1) \varphi_1},
\]

or

\[
\frac{1}{r} \frac{\partial V_o}{\partial \varphi} = \left( \frac{\omega_0 - CR_0}{r^2} \right) \frac{2V_o (R_0 - r)}{(R_0 - R_1) \varphi_1}.
\]

Then the equation (2) will look like:

\[
\frac{\partial \sigma}{\partial r} + \frac{\sigma}{r} = \rho \left( \frac{\omega_0 - CR_0}{r^2} \right)^2 r - \rho \left( \frac{\omega_0 - CR_0}{r^2} \right) \frac{2V_o (R_0 - r)}{(R_0 - R_1) \varphi_1},
\]

where \( \sigma = \sigma_r - \sigma_0 \).

Let us find general solution of the equation (25) without the right part:

\[
\frac{d \sigma}{d r} + \frac{\sigma}{r} = 0 ,
\]

\[
\frac{d \sigma}{\sigma} = - \frac{d r}{r} ,
\]

\[
\ln \sigma = - \ln r + \ln C , \quad \ln \sigma = \ln \frac{C}{r} , \quad \sigma = \frac{C}{r} .
\]
Let us change the integration constant $C$ by the unknown function $u = u(r)$ and we will obtain

$$\sigma = \frac{u}{r},$$

(30)

then

$$\frac{d\sigma}{dr} = \frac{d}{dr}\left(\frac{u}{r}\right) = \frac{d}{dr}u(r^{-1} + u(r^{-2}) = \frac{1}{r} \frac{du}{dr} - \frac{u}{r^2},$$

(31)

Let us substitute (29) in (25).

(32)

where $B = CR_0$, $A = \frac{2V}{(R_1 - R_0)\rho}$.

Let us divide variables and integrate

$$\int du = \rho\int \left(\frac{u - B}{r^2} + \frac{2B}{r}\right)^2 r dr - A\int \left(\frac{u - B}{r^2} - A(r - R_0)\right) dr.$$

(34)

Finally we will obtain:

$$\sigma = \frac{B}{r}\left[\left(\frac{u^3 - A^3}{3}\right) + \frac{AR_0 R_1^2}{2} + BR_0 (A - 2\omega_0) + \frac{B^2}{r} - AR_0 B 1n R_0\right],$$

(37)

Integration constant $C_1$ can be found from the condition: $\sigma_{r=R_0} = 0$

$$C_1 = \rho\left[\left(\frac{u^3 - A^3}{3}\right) + \frac{AR_0 R_1^2}{2} + BR_0 (A - 2\omega_0) + \frac{B^2}{r} - AR_0 B 1n R_0\right].$$

(38)

RESULTS

In Fig. 4 (a and b) diagrams of speeds distribution of the bulk-cargo parts in the transporting area of the screw channel with the following parameters are presented: screw diameter $D=0.1$ m, screw shaft diameter $d=0.05$m at different efficiency coefficients $K_{\mu} = 0.7$ (Fig.4a) $K_{\mu} = 0.8$ (Fig.4b).
На різноманітними механізми міцності гвинта \( \sigma \), в кінці забірної частини гвинтового каналу від кутової швидкості гвинта для різних значень коефіцієнта продуктивності \( K_p \). Очевидно, що необхідна величина \( \sigma \), дорівнює боковому тиску сипкого матеріалу в бункері, який можна визначити аналітичним шляхом [10]. З наведених графіків видно, що для стабільної роботи вертикального гвинтового конвеєра необхідно створити значний тиск, який можна досягти збільшенням розмірів бункера, або застосовуючи примусову подачу сипкого матеріалу в забірну частину. Залежність коефіцієнту продуктивності \( K_p \) від кутової швидкості гвинта \( \omega \) наведена на фіг. 6 при \( \sigma = 2000 \text{ Pa} \), що відповідає гравітаційному завантаженню шнекового транспортера. Оскільки продуктивність швидкісного гвинтового конвеєра зменшується із збільшенням частоти обертання гвинта, то для забезпечення необхідної продуктивності цього транспортного засобу необхідно використовувати специальні забірні пристрої.

На фіг. 5, наведені залежності напруження \( \sigma \), в кінці забірної частини гвинтового каналу від кутової швидкості гвинта для різних значень коефіцієнта продуктивності \( K_p \). Очевидно, що необхідна величина \( \sigma \), дорівнює боковому тиску сипкого матеріалу в бункері, який можна визначити аналітичним шляхом [10]. З наведених графіків видно, що для стабільної роботи вертикального гвинтового конвеєра необхідно створити значний тиск, який можна досягти збільшенням розмірів бункера, або застосовуючи примусову подачу сипкого матеріалу в забірну частину. Залежність коефіцієнту продуктивності \( K_p \) від кутової швидкості гвинта \( \omega \) наведена на фіг. 6 при \( \sigma = 2000 \text{ Pa} \), що відповідає гравітаційному завантаженню шнекового транспортера. Оскільки продуктивність швидкісного гвинтового конвеєра зменшується із збільшенням частоти обертання гвинта, то для забезпечення необхідної продуктивності цього транспортного засобу необхідно використовувати спеціальні забірні пристрої.

In Fig. 5 dependences of stresses \( \sigma \), in the end of the intake area of screw channel on the rate of the angular motion of the screw for different values of the efficiency coefficient \( K_p \) are presented. The necessary value \( \sigma \), is likely to be equal to the lateral pressure of the bulk-cargo in the tank, which can be found analytically [10]. From the presented diagrams it is clear that in order to provide stable operation of the vertical screw conveyor it is necessary to provide sufficient pressure, which can be provided by increasing the tank sizes or using the forced feeding of the bulk-cargo in the intake area. Dependence of the efficiency coefficient \( k \), on the screw rate of angular motion \( K_p \) is presented in Fig.6 at \( \sigma = 2000 \text{ Pa} \), which corresponds to the gravitation loading of the screw conveyor. As the efficiency of the high-speed screw conveyor is decreased with the increase of the screw rotation frequency, to provide the desired efficiency of this transporting means it is necessary to take advantage of special intake devices.

![Fig. 4 - Diagrams of the speeds distribution of bulk-cargo parts in the transporting area of the screw channel at](image)

\[ \text{a) } K_p = 0.7; \text{ b) } K_p = 0.8 \]

![Fig. 5 - Dependence of stresses \( \sigma \), in the end of intake area of the screw channel on the screw rate of angular motion](image)

\[ \omega, \text{c}^{-1} \]

\[ \sigma, \text{Pa} \]

![Fig. 6 - Dependence of efficiency coefficient of the screw conveyor \( K_p \), on the screw rate of angular motion](image)

\[ \omega, \text{c}^{-1} \]
CONCLUSIONS
Taking advantage of the obtained solution algorithm of differential equations, which describe the movement of bulk-cargo medium under certain boundary conditions, the picture of distribution speeds and stresses in the screw channel can be obtained. Achieving the proposed model makes possible to develop new designs of intake devices of screw conveyers and to interpret their efficient parameters.

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ВИСНОВОК
Використовуючи отриманий алгоритм розв’язку диференціальних рівнянь, які описують рух сипкого середовища, при відповідних граничних умовах можна отримати картину розподілу швидкостей та напружень у гвинтовому каналі шнека. Реалізація запропонованої моделі дає можливість розробляти нові конструкції забірних пристрій гвинтових конвеєрів з обґрунтуванням їх раціональних параметрів

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FRUIT VOLUMETRIC DETERMINATION BASED ON MOIRÉ TECHNIQUES / RECONSTITUIÇÃO TOPOGRAFICA E VOLUMÉTRICA DE FRUTOS UTILIZANDO TÉCNICAS OPTICAS DE MOIRÉ


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INTRODUCTION

The Moiré optical techniques are of very broad application in agricultural fields, especially in agricultural engineering, as well as in the overall engineering fields. These applications include micro relief survey of the soil for tillage quality control, of fruit and vegetables, plant-machine mechanical relations, and mechanical behavior of vegetative materials. It worth emphasize the application of Moiré methods as photo-elastic technique, similarly as the classic photo-elasticity, as hologram, as speckle and others. The opportunity of generating scientific knowledge associated to the Moiré methods applied to agricultural engineering subjects has motivated this research work, attempting to the possibilities of generating Digital Elevation Models (DEM) of regular as well as irregular surfaces, generating the volume and the three-dimensional views of the body under study [5].

This research work emphasizes the optical grid frequency influence on the resulting DEM, discussing on the advantages and disadvantages of each tested grid frequency.

Phase shifting Moiré technique is considered a quite simple method, needing not moving equipment and being of low cost [10]. It also exhibits high precision and adaptable to objects of different sizes by just varying the

Resumo: A medição de sólidos tridimensionais tem recebido uma grande atenção da comunidade científica, devido à sua ampla gama de aplicações. Porém existem diversos métodos e técnicas para se obter tais medições, este trabalho demonstra a técnica de moiré que é uma técnica sem contato e não destrutiva, com um rápido processo de digitalização cujos fenômenos de Franjas de Moiré são o resultado da subtração da projeção de grades sobre um certo objeto com relação as grades projetadas em um plano referencial. Possui medição precisa comparável com a de outros sistemas. Demonstram também a exatidão das técnicas de moiré, sendo dado maior enfoque na técnica de moiré de projeção com deslocamento de fase, e pela utilização de dois tipos de grades a de Ronchi e senoidal, onde são observados os possíveis erros. Neste trabalho foi comprovado o melhor desempenho dos tipos e variação da frequência de grades incluindo vários exemplos práticos da sua aplicação em sólidos irregulares (frutos), determinação volumétrica de sólidos irregulares. Emprego de “softwares” gratuitos o qual também foi uma preocupação para disseminação da técnica, tais como ImageJ, RisingSun Moiré, SCILAB/SIP e rotinas.

Palavras-chave: técnicas perfilométricas ópticas, técnicas de moiré com deslocamento de fase, determinação de volume em sólidos e reconstituição tridimensional de sólidos

INTRODUÇÃO

A utilização das técnicas de moiré é de grande importância para diversos segmentos, como na Engenharia Agrícola, envolvendo vários problemas associados ao estudo da topografia de superfícies, o comportamento mecânico de materiais biológicos, controle da qualidade na operação de preparo do solo baseado na determinação do micro relevo, relações mecânicas máquina–planta, etc. Em função da oportunidade de gerar conhecimento da aplicabilidade das técnicas de moiré em atividades ligadas a Engenharia Agrícola, motivou-se o desenvolvimento desta pesquisa, demonstrando assim, que a técnica de moiré pode ser aplicada com resultados satisfatórios na geração de Modelos Digitais de Elevação de superfícies regulares e irregulares, gerando a reconstituição de sólidos ou superfícies em três dimensões [5], juntamente, com a obtenção de medição volumétrica.

A pesquisa aborda as variações nos tipos e frequências das grades, demonstrando comparações nos resultados obtidos, bem como as vantagens e desvantagens de cada uma, comprovando que a sensibilidade depende principalmente do período do retículo da grade.

Em pesquisas anteriores não foi constatada nenhuma evidência de que o tipo de grade influenciava na reconstituição tridimensional e na medição volumétrica. A Técnica de moiré com Deslocamento de Fase (Phase shifting) é uma técnica muito simples, não possui peças móveis e é de baixo custo [10]. Além disso, tem alta
grid period [1]. A variation of that method was developed, by projecting onto the body surface a sinusoidal grid pattern with codified RGB colors, obtaining, that way, the DEM by phase shifting, requiring not more of one image.

The results can be influenced by color of the object being tested, indicating that the method is recommended for bodies of neutral colors [1, 14, 15]. [3] reports the application of the RisingSun Moiré program to calculate the phases, generating the wrapped phase image, as well as to obtain the unwrapped image to generate the DEM of a pear fruit model. [8] and [9] developed algorithms for the MATLAB program to calculate the phases and the unwrapping procedures, eliminating the steps by adding or subtracting π values and by comparing a pixel with its neighboring one the differences with that value, positive or negative, respectively are found.

[11] described the Phase Shifting Method applied to Shadow Moiré, emphasizing the need of 04 images of Moiré fringes. At each image, the object is approximated or distanced from the reference grid (Rg), displacing the Moiré fringes by 1/2π, π and 3/2π of phase. However, when 04 images are employed and displaced by π/2, the light intensity at each one of these images is described by the following equation.

\[
I_1(x,y) = a(x,y) - b(x,y) \cos \phi(x,y) \\
I_2(x,y) = a(x,y) - b(x,y) \cos[\pi/2 + \phi(x,y)] \\
I_3(x,y) = a(x,y) - b(x,y) \cos[\pi + \phi(x,y)] \\
I_4(x,y) = a(x,y) - b(x,y) \cos[3\pi/2 + \phi(x,y)]
\]

Where \(a(x,y)\) stands for light intensity of the background at each image point, \(b(x,y)\) stands for modulation intensity at image point and \(\phi\) stands for the phase to be determined. [13] demonstrated that phase term, \(\cos \phi\), for each point of the image comes from the simultaneous solution of these 4 equations.

\[
\phi(x,y) = \arctan \left( \frac{I_4(x,y) - I_2(x,y)}{I_2(x,y) - I_4(x,y)} \right)
\]

For each 3 images displaced by \(\pi/3\), the phase term can be obtained through the Equation 6.

\[
\phi(x,y) = \arctan \left( \frac{I_4(x,y) - I_2(x,y)}{I_2(x,y) - I_4(x,y)} \right)
\]

For the 5 images displaced by \(\pi/5\) the phase term can be obtained through the Equation 7.

\[
\phi(x,y) = \arctan \left( \frac{2I_4(x,y) - I_2(x,y)}{2I_2(x,y) - 2I_4(x,y)} \right)
\]

[2, 8, 9, 11] reported the application of phase shift method to the shadow Moiré with 4 images. At each image, the object is approximated or distanced from the reference grid (Rg), displacing the Moiré fringes by 1/2π, π and 3/2π of phase. At each image, the object is approximated or distanced from the reference grid (Rg), displacing the Moiré fringes by 1/2π, π and 3/2π of phase. When 04 images are employed and displaced by π/2, the light intensity at each one of these images is described by the following equation.

\[
I_1(x,y) = a(x,y) - b(x,y) \cos \phi(x,y) \\
I_2(x,y) = a(x,y) - b(x,y) \cos[\pi/2 + \phi(x,y)] \\
I_3(x,y) = a(x,y) - b(x,y) \cos[\pi + \phi(x,y)] \\
I_4(x,y) = a(x,y) - b(x,y) \cos[3\pi/2 + \phi(x,y)]
\]

\[
Onde a(x,y) é a intensidade luminosa do fundo em cada ponto da imagem, b(x,y) é a intensidade de modulação em cada ponto da imagem, \(\phi\) é a fase a ser determinada. [13], demonstra que resolvendo as 4 equações simultaneamente, pode se obter o termo fase (\(\cos \phi\)) para cada ponto da imagem:

\[
\phi(x,y) = \arctan \left( \frac{I_4(x,y) - I_2(x,y)}{I_2(x,y) - I_4(x,y)} \right)
\]

Para 3 imagens deslocadas de \(\pi/3\), o termo fase pode ser obtido pela equação 6.

\[
\phi(x,y) = \arctan \left( \frac{I_4(x,y) - I_2(x,y)}{I_2(x,y) - I_4(x,y)} \right)
\]

E Para 5 imagens deslocadas de \(\pi/5\), o termo fase pode ser obtido pela equação 7.

\[
\phi(x,y) = \arctan \left( \frac{2I_4(x,y) - I_2(x,y)}{2I_2(x,y) - 2I_4(x,y)} \right)
\]
1π and 3/2π of phase.

[13] emphasizes some advantages of these techniques when compared to the techniques supported by this one: high precision, quickness, good results even with low contrast.

MATERIAL AND METHODS

Volume measurement through the Moiré technique included a PC, a LCD projector, a CCD camera coupled to a Data Translation model DT313 data capturing board and the Global Lab Image2 of the Data Translation for image capturing. Six rubber cylinders and resin made fruit models for volume tests. Two types of grids, Ronchi and sinusoidal with 100 and 200 lines per millimeter, projected a distance of 1 meter. Four images were captured displaced of 90°. Four images of Moiré fringes were captured, referred as I1, I2, I3 and I4, displacing the grid in the Z direction from the reference grid which generated displacement from the fringes of 0, 1/4π, 1/2 π and 3/4π. From these images, the “RISING-SUN MOIRÉ” software generated the wrapped phase. The phase unwrapping produced the digital model of the fruit. The obtained image is qualified as a “raster” which color varies from zero to 255, i.e. 256 color levels corresponding to Z values. The measure by immersion is based on the volume of liquid displaced by the testing body as shown on Figure 1. Two types of optical grids were applied, the sinusoidal grid and the Ronchi grid.

RESULTS AND DISCUSSIONS

Figure 2, (a), (b), and (c) shows the projected grid onto a the surface of an apple fruit model, the topographic view expressed in gray scale and digital elevation model, respectively. Table 01 shows the volume values as generated by the immersion technique. Table 02 shows the fruit volumes as obtained by the phase displacement Moiré method and processed by the Scilab. These volume values include the mean error obtained by means of calibrating object of regular geometry. The fluid displacement technique also generated the error calculation. Errors were applied to correct the sample dimensions.

resultados e discussão

Foi utilizado o método de deslocamento de fluido, onde foram obtidos os seguintes valores volumétricos encontrados na Tabela 1. Utilizando o software Scilab através de rotinas foram calculados os volumes do fruto conforme mostrados na Tabela 02 e comparados com os medidos através do deslocamento de fluido. Sendo que os valores obtidos no item TM são valores diretos obtidos Através da técnica de moiré por deslocamento de fase e tratados no scilab obtendo o volume da amostra, o valor do erro médio utilizado é obtido através de um objeto que foi utilizado como calibrador, cujas dimensões são conhecidas e que posteriormente foram utilizadas para calcular a variação sendo similar ocorrido com a medição de volume por deslocamento de fluido onde o valor do erro médio utilizado é também o do objeto calibrador que posteriormente foi utilizado para calcular a variação e corrigindo os valores das amostras.

a) b) c)
Fig. 3 - Result of subtraction of the grid plan with the sample

Fig. 4 - Result of subtraction of the grid plan with filtered sample image

Table 1

<table>
<thead>
<tr>
<th>Replication 1 (ml)</th>
<th>Replication 2 (ml)</th>
<th>Replication 3 (ml)</th>
<th>Replication 4 (ml)</th>
<th>Replication 5 (ml)</th>
<th>Mean (ml)</th>
<th>Mean (mm³)</th>
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<td>400</td>
<td>380</td>
<td>400</td>
<td>390</td>
<td>390</td>
<td>392</td>
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</table>

Table 2

<table>
<thead>
<tr>
<th>Fruit Model</th>
<th>100lines/mm Ronchi (mm³)</th>
<th>100lines/mm Sinoidal (mm³)</th>
<th>200lines/mm Ronchi (mm³)</th>
<th>200lines/mm Sinoidal (mm³)</th>
<th>Mean (mm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TM</td>
<td>392201.520</td>
<td>389125.730</td>
<td>388780.070</td>
<td>386896.520</td>
<td>389250.960</td>
</tr>
<tr>
<td>Mean error (%)</td>
<td>3.91</td>
<td>2.21</td>
<td>1.86</td>
<td>0.61</td>
<td>1.340</td>
</tr>
<tr>
<td>Variation</td>
<td>15335.079</td>
<td>8599.679</td>
<td>7231.309</td>
<td>2360.069</td>
<td>5215.963</td>
</tr>
<tr>
<td>Corrected value</td>
<td>37866.441</td>
<td>380526.051</td>
<td>381548.761</td>
<td>38536.451</td>
<td>384034.997</td>
</tr>
<tr>
<td>Displaced fluid volume</td>
<td>392000,000</td>
<td>392000,000</td>
<td>392000,000</td>
<td>392000,000</td>
<td>392000,000</td>
</tr>
<tr>
<td>Mean error (%)</td>
<td>1.9</td>
<td>1.9</td>
<td>1.9</td>
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<tr>
<td>Corrected value</td>
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<td>384552,000</td>
<td>384552,000</td>
<td>384552,000</td>
<td>384552,000</td>
</tr>
</tbody>
</table>

The adjustment of variation between methods led to a value of 0.13 in percentage. Figures 5, 6 and 7 refer to the three-dimensional reconstitution of the apple fruit model as obtained by grid variation.

Foi aferida a variação entre os métodos obtendo-se um índice de 0.13 pontos percentuais médio entre as técnicas. Logo a seguir tem-se a reconstituição tridimensional da maçã utilizando as quatro variações sendo-as de tipos de grade e espessura.
Referring to three-dimensional reconstruction the obtained results were shown to be satisfactory and useful to determine fruit volume. The application of different grids indicated the sinusoidal grid to generate better results.

CONCLUSIONS
Based on what it has been exposed before it can be concluded that Moiré method yields satisfactory results in determining fruit topography. These techniques allowed the determination of surface digital models; however they require specific computer programs. Sinusoidal grid with greater line density yielded better three-dimensional reconstruction. The Moiré method with phase displacement was noted to be of quick execution, causing no bruising on the testing material, mainly the results generated by the sinusoidal grid of higher density.

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Os resultados da reconstrução tridimensional obtidos mostraram ser satisfatórios e úteis na determinação do volume de frutas. Quanto a aplicação de diferentes tipos de grades ópticas, a grade senoidal gerou melhores resultados.

CONCLUSÕES
Baseado no que foi acima exposto, as seguintes conclusões podem ser emitidas. A introdução das TM de deslocamento de fase determinou satisfatoriamente a topografia de um fruto. Estas técnicas permitiram a geração de modelos digitais da superfície das amostras utilizadas. A TM com deslocamento de fase é bastante rápida, reconhece automaticamente picos e vales, mas necessita do uso de programas computacionais específicos. Foi possível reconstruir as amostras tridimensionalmente sem qualquer dano ao material amostrado com detalhamento de pontos, sendo esses mais perceptíveis utilizando grade senoidal com maior número de linhas/mm.

REFERÊNCIAS


FREE SURFACE EQUATION OF BEER WORT IN A ROTAPOOL

ECUAŢIA SUPRAFEŢEI LIBERE A MUSTULUI DE BERE ÎN ROTAPAPOOL

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Abstract: In this paper is presented a mathematical model that allows an analytical description of the free surface of the beer wort in a rotapool. The free surface of the beer wort in the rotapool has the equation of a rotation paraboloid. The developed mathematical model has allowed, using the Microsoft Excel program, plotting variation graphs after radial direction of the liquid height, for different supply conditions of beer wort and different typo-dimensionai vessels.

Keywords: mathematical model, rotapool, free surface, beer wort, hydrodynamic process

INTRODUCTION

Beer wort boiled with hops contains hops draff in suspension and precipitates formed during wort boiling, which is called “hot trub”, with particles of 30-80 µm, containing a quantity of 40-80 g d.s./hl of wort [11, 13].

The study of the wort, yeast and beer fermentation, its manufacturing technology, have been studied in numerous papers [1, 2, 3, 5, 6, 8, 9] in order to determine if the new equipment can influence the flavor of beer [4], if the baker’s yeast influence the formation of fungi [7] or if the wort fermentation by increased gravity has an influence on the metabolism [10, 12].

Hot trub can be separated by sedimentation, centrifugation, filtration or, more commonly, by a process of complex hydrodynamic separation in a vessel called rotapool (Fig. 1), cylindrical-shaped and closed, into which the hot wort is introduced tangentially at velocities of up to 5 m/s through a connection (nozzle) 1, located in the lower third of the vessel. The vessel body and bottom are isolated, in order to maintain a high temperature 6 of the wort in the process of trub separation, through isolation 2.

Rezumat: În cadrul acestei lucrări, este prezentat un model matematic care permite descrierea analitică a suprafeţei libere a mustului de bere în rotapool. Suprafaţa liberă a mustului de bere în rotapool are ecuaţia unui paraboloid de rotaţie. Modelul matematic elaborat a permis, folosind programul Microsoft Excel, trasarea graficelor de variaţie după direcţia radială a înălţimii lichidului, pentru diverse condiţii de alimentare cu must de bere şi diverse tipo-dimensiuni de vase.

Cuvinte cheie: model matematic, rotapool, suprafaţa liberă, must de bere, proces hidrodinamic

INTRODUCERE

Mustul de bere fiert cu hamei conţine în suspensie borhotul de hamei şi precipitate formate în timpul fierberii mustului, care poartă denumirea de “trub la cald”, având particule de 30-80 µm, fiind în cantitate de 40-80 g s.u. / hl must [11, 13].

Studiul mustului, drojdiei şi fermentarea berii, tehnologia de fabricare a acesteia, au fost studiate în numeroase lucrări [1, 2, 3, 5, 6, 8, 9] pentru a se determina dacă echipamentele noi pot influenţa aroma berii [4], dacă drojdia din brutării influenţează formarea ciupercilor [7] sau ce influenţa asupra metabolismului o are fermentarea mustului prin gravitaţie ridicată [10, 12].

Trubul la cald se poate separa prin sedimentare, centrifugare, filtrare sau, cel mai adesea, printr-un procedeu de separare hidrodinamică complexă, într-un vas numit rotapool (Fig. 1), care este de formă cilindrică, închis, în care mustul fierbinte este introdus tangenţial cu viteze de până la 5 m/s printr-un racord (duză) 1, situată în treimea inferioară a vasului. Corpul şi fundul vasului sunt izolate, pentru a menţine temperatura ridicată a mustului 6 în procesul de separare a trubului, prin intermediul unei izolaţii 2.
After 20-40 minutes, as long as it takes the separation process [11, 13], the wort is discharged through the connection 3, while trub 5 accumulated at the bottom of the vessel is discharged through the connection 4, mixed with the washing water introduced into the vessel through the connection 9. The vessel is also fitted with a basket 8 for secondary steam evacuation and a sight 7.

Due to the complex hydrodynamic process taking place in the rotapool, the free surface of beer wort is not plane, having the shape of a rotation paraboloid.

The isolation of the vessel walls must cover entirely the contact surface between wort and walls, in order to reduce heat exchange with the outside environment and to maintain a high temperature of the wort in the vessel. But, during the working process, the height of the liquid on the lateral walls increases, so, due to that fact, at present, isolation width remains constant up to the top of the vessel.

Deducting the free surface equation of the liquid in the rotapool, the maximum height of the liquid in the vessel walls can be inferred, from which the above no longer requires an isolation of the same consistency.

MATERIALS AND METHOD

The equation defining the shape of the free surface of beer wort in the rotapool can be deduced based on the following assumptions:
- the effect of beer wort viscosity is neglected;
- the velocity of beer wort is maximum near the wall, being directly proportional with the horizontal component of liquid input velocity in the vessel;
- the study refers to the final stage of trub separation process, when the volume of liquid in the vessel reaches the nominal value.

The wort is placed in the lower third of the vessel, tangential to its body, with velocity \( v_l = 2\text{-}5 \text{ m/s} \) and an angle \( \alpha = 15^\circ \), supply that prints a rotation movement of the liquid in the vessel, forming upward currents in the central area of the vessel bottom (Fig. 2).


Datorită procesului hidrodinamic complex care se desfăşoară în rotapool, suprafaţa liberă a mustului de bere nu este plană, ci este de forma unui paraboloid de revoluție.

Izolaţia peretilor vasului trebuie să acopere întreaga suprafaţă de contact dintre must şi pereţi, pentru a reduce schimbul de căldură cu mediul înconjurător şi pentru a menţine temperatura ridicată a mustului în vas. Dar, în procesul de lucru, înălţimea lichidului pe pereţii laterali creşte şi de aceea, în prezent, vasele au izolaţii cu aceeaşi grosime până la partea superioară a vasului.

Deducându-se ecuaţia suprafeţei liberă a lichidului în rotapool se va putea deduce care este înălţimea maximă a lichidului pe pereţii vasului, de la care în sus nu se mai impune o izolaţie de aceeaşi consistenţă.

MATERIALE ŞI METODĂ

Ecuaţia care defineşte forma suprafeţei liberă a mustului de bere în rotapool se deduce pe baza următoarelor ipoteze:
- se neglijază efectul vâscozităţii mustului de bere;
- viteză mustului de bere în zona peretelui este maximă, fiind direct proporţională cu componenta orizontală a vitezei de introducere a mustului în vas;
- studiul se referă la etapa finală a procesului de separare a trubului, când volumul de lichid din vas ajunge la valoarea nominală.

Mustul este introdus în vas în treimea inferioară, tangenţial la corpul acestuia, cu viteză \( v_l = 2\text{-}5 \text{ m/s} \) şi sub un unghi \( \alpha = 15^\circ \), alimentare care imprima o mişcare de rotaţie a lichidului în vas, luând naştere curentilor ascensionali la partea centrală a vasului şi coboătorii la periferie, care transportă şi depun particulele de trub în partea centrală a fundului vasului (Fig. 2).

Theoretical tangential velocity of the liquid in the vessel, on its periphery, is calculated from velocity \( v_l \), angle \( \alpha \) and a decrease coefficient of the velocity in the vessel \( k = 0\text{-}3\text{-}0\text{-}5 \), with the equation:

\[
v = k \cdot v_l \cdot \cos \alpha = R \cdot \omega
\]

from which it results the angular velocity of the liquid in}

\[
\omega = \frac{v}{R} = \frac{k \cdot v_l \cdot \cos \alpha}{R}
\]

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\[
\omega = R \cdot k \cdot v_l \cdot \cos \alpha
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the vessel:

\[ \omega = \frac{k \cdot v_j \cdot \cos \alpha}{R} \]  

(2)

On the free surface of the beer wort (Fig. 3) are acting the centrifugal force \( F_c \) and weight \( G \):

\[ F_c = m \cdot r \cdot \omega^2 \]  

(3)

\[ G = m \cdot g \]  

(4)

with the resultant \( N \) normal to the surface (Fig. 3).

care au rezultanta \( N \) normală la suprafață (Fig. 3).

\[ \text{Fig. 3} \quad \text{– Force components} \]

From figures 3 and 4, equation (5) can be written:

\[ \tan \theta = \frac{F_c}{G} = \frac{m \cdot r \cdot \omega^2}{m \cdot g} = \frac{r \cdot \omega^2}{g} = \frac{dz}{dr} \]  

(5)

Considering that the velocity distribution is linear:

\[ v = r \cdot \omega \]  

(6)

It results:

\[ dz = \frac{r \cdot \omega^2}{g} \cdot dr \]  

(7)

By integrating relation (7) it results:

\[ \int dz = \int \frac{r \cdot \omega^2}{g} \cdot dr = \frac{\omega^2}{g} \int r \cdot dr \]  

(8)

respectively:

\[ \text{respectiv:} \]
so the free surface equation of the beer wort in the rotapool has the following form:

\[ z = z_0 + \frac{\omega^2}{2g}r^2 \]  \hspace{1cm} (10)

equivalent to the equation:

\[ z = z_0 + \frac{\omega^2}{2g}(x^2 + y^2) \]  \hspace{1cm} (11)

\( z_0 \) can be deduced from the following conditions:

\[ r = R \Rightarrow z = H + h_1 = z_0 + \frac{\omega^2}{2g}R^2 \]  \hspace{1cm} (12)

\[ r = 0 \Rightarrow z = z_0 = H - h_2 \]  \hspace{1cm} (13)

\[ h_1 = h_2 \]  \hspace{1cm} (14)

it results:

\[ z_0 = H - \frac{\omega^2}{4g}R^2 \]  \hspace{1cm} (15)

Given the relation (15), equations (10) and (11) will have the final form:

\[ z = H - \frac{\omega^2}{4g}R^2 \left( 1 - \frac{r^2}{R^2} \right) \]  \hspace{1cm} (16)

\[ z = H - \frac{\omega^2}{4g}R^2 \left( 1 - \frac{x^2 + y^2}{R^2} \right) \]  \hspace{1cm} (17)

RESULTS

The mathematical model developed in this paper has allowed obtaining data which were processed in Microsoft Excel and plotting variation graphs after radial direction of the height of the points on the free surface of beer wort, for various supply conditions of beer wort and various typo-dimensional vessels.

Three different vessels were studied, with diameters of 3 m, 2 m and 1 m, for which, in all cases, the liquid height \( H \) was 1 m. The liquid input velocity in the vessel was 3 m/s, 4 m/s and 5 m/s.

Variations in liquid height after radial direction in the three vessels, for three different input velocities of beer wort in the rotapool, are shown in figures 5 and 6.

REZULTATE

Modelul matematic elaborat în cadrul prezentei lucrări a permis obţinerea unor date care au fost prelucrate în Microsoft Excel și au permis trăsarea graficelor de variație după direcția radială a înălțimii punctelor de pe suprafața liberă a mustului de bere, pentru diverse condiții de alimentare cu must de bere și diverse typo-dimensiuni de vase.

Au fost studiate trei vase diferite, având diametru de 3 m, 2 m și 1 m, la care, în toate cazurile, înălțimea \( H \) a lichidului a fost de 1 m. Viteza de introducere a lichidului în vas a fost de 3 m/s, 4 m/s și 5 m/s.

Variația înălțimii lichidului după direcția radială în cele trei vase studiate, pentru cele trei vitezve diferite de introducere a mustului de bere în rotapool, este prezentată în figurele 5 și 6.
Fig. 5 – Variation in liquid height after radial direction in vessels of radius R=1.5 m, R=1 m, R=0.5 m, for three velocities $v_l$.

Fig. 6 – Variation in liquid height after radial direction, after entering the vessel with velocities $v_l=3$ m/s, $v_l=4$ m/s, $v_l=5$ m/s, for three radius R.
CONCLUSIONS

The free surface equation of beer wort in the rotapool, deduced in this paper, has the expressions (16), respectively (17), representing a rotation paraboloid.

Figures 5 and 6 show that regardless of the vessel diameter, for the same liquid height H and the same liquid input velocity in the vessel vl, the maximum beer wort height in the rotapool is the same.

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RESEARCHES ON HORTICULTURAL PRODUCTS DECONTAMINATION DESIGNED TO FRESH CONSUMPTION, USING NON-IONIZING UV-C ULTRAVIOLET RADIATION

CERCETARI PRIVIND DECONTAMINAREA PRODUSELOR HORTICOLE DESTINATE CONSUMULUI IN STARE PROASPATA, UTILIZAND RADIATIA NEIONIZANTA ULTRAVIOLETA UV-C


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Abstract: Consumed in fresh-state, horticultural products can be carriers of some optional pathogenic microorganisms: bacteria, yeasts, molds. These microorganisms can cause either loss of horticultural products in the storage process, due to the post harvest decay process or food-borne diseases with direct effects on consumer human health. In this context, the paper presents experimental researches on the possibility of using non-ionizing ultraviolet radiation UV-C within the conditioning technologies of horticultural products, by investigating the capability of an experimental model of installation for the decontamination of external surfaces of horticultural products, to apply the minimum dosage recommended for the destruction of the most representative pathogens.

Keywords: post harvest treatment., UV-C radiation, fruits and vegetable, shelf-life

INTRODUCTION

Fruits and vegetables play an important role in the human nutrition. The nutritive value of horticultural products consumed in fresh-state, is given especially by large quantities of vitamins which they synthesize. Vitamins are biocatalysts of life processes, essential for life, their absence from the human metabolism causing serious functional disorders. The failure of keeping the vitamins into the body, implies the need for a permanent intake in daily food components. For the continuous supply of fresh fruits and vegetables, it is necessary to extend the shelf-life of these products, to eliminate the seasonality of consumption, to get closer the production areas to the consumption ones, to reduce as much as possible the loss due to the degradation of perishable food products.

Consumed in fresh-state, horticultural products can be carriers of some optional pathogenic microorganisms: bacteria, yeasts, molds. These microorganisms can cause either loss of horticultural products in the storage process, due to the post harvest decay process or food-borne diseases with direct effects on consumer human health. Losses of horticultural products, due to the post-harvest decay process, are at the level of 10-50% depending on the degree of development of the area and the facilities for temporary storage. In order to limit these losses, there have been used synthetic fungicide substances. Residues of these substances, which remain on the surface of horticultural products, after treatment, are considered a potential threat to consumer health and especially children [9].

Rezumat: Consumate în stare proaspătă, produsele horticol pot fi purtătoare ale unor microorganisme facultativ patogene: bacterii, drojii, mucegaiuri. Aceste microorganisme pot provoca fie pierderi de produse horticole la pastrare, datorate procesului de descompunere postrecoltare, fie îmbolnăviri sau toxinfecții alimentare cu efecte directe asupra sănătății consumatorului uman. În acest context, lucrarea prezintă cercetări experimentale privind posibilitatea de utilizare a radiatiai ultraviolete neionizante UV-C în cadrul tehnologiilor de conditionare a produselor horticole, prin investigarea capabilității unui model experimental de instalatie pentru decontaminarea suprafetelor exterioare ale produselor horticole, de a aplica dozele minime de radiatie recomandate pentru distrugerea celor mai reprezentativi agenti patogeni.

Cuvinte cheie: tratament post recoltare, radiatie UV-C, fructe si legume, perioada de valabilitate

INTRODUCERE

Fructele si legumele joacă un rol important în alimentația umana. Valoarea nutritivă a produselor horticole consumate în stare proaspătă este dată în special de cantitățile importante de vitamine pe care le sintetizează. Vitaminele sunt biocatalizatoarei aici proceselor vitale, indispensabile vieții, absența lor din metabolismul uman producând grave tulburări funcționale. Imposibilitatea de păstrare în organism a vitaminelor, implică necesitatea unui aport permanent în componentele alimentare zilnice. Pentru aprovizionarea continuă cu fructe și legume proaspate, este necesar să se prelungească durata de păstrare a acestor produse, să se elimine cât mai mult caracterul sezonier al consumului, să se apropie zonele producătoare de cele consumatoare și să se reducă într-o măsură cât mai mare pierderile prin degradarea produselor alimentare perisabile.

Consumate în stare proaspătă, produsele horticole pot fi purtătoare ale unor microorganisme facultativ patogene: bacterii, drojii, mucegaiuri. Aceste microorganisme pot provoca fie pierderi de produse horticole la pastrare, datorate procesului de descompunere postrecoltare, fie îmbolnăviri sau toxinfecţii alimentare cu efecte directe asupra sănătăţii consumatorului uman. Pierderile de produse horticole, datorate procesului de descompunere postrecoltare, se situează la nivelul a 10-50% în funcție de gradul de dezvoltare al zonei respective și facilitățile de pastrare temporară. În vederea limitării acestor pierderi, s-au utilizat substanțe fungicide sintetice. Reziduurile acestor substanțe, care raman pe suprafața produselor horticole...
Alternative methods to fungicide treatments have been studied in order to prevent horticultural products losses in the post harvest phase. Within these methods the applications of biological control agents, plant bioactive compounds and physico-chemical methods showed interesting results but still far from a practical application in Europe. Despite the substantial progress obtained with biological control agents, the use of them is limited due to their insufficient and inconsistent performance. The use of plant bioactive compounds has shown that the treatment conditions (concentration, form of application, time of treatment, etc.) can deeply influence their efficacy. A barrier to use the plant bioactive compounds may not be the efficacy, but rather the off-odours caused in horticultural products and/or the phytotoxicity. Physico-chemical methods include heat, ionising radiation, ultraviolet UV-C radiation and food additives which induce the resistance to pathogens [13].

Conventional thermal methods of food sterilization are unsuitable for fruits and vegetable destined for fresh consumption because of the heat which causes inevitable changes of color, smell, flavor and a loss of nutritional value [12].

Recent research has identified a number of energy-based alternative technologies to improve the safety of fresh and fresh-cut fruits and vegetables: ultraviolet radiation, electron-beam irradiation, technology with pulsed visible light and technology with cold plasma. In some cases, such as UV light, these technologies have a substantial database of information regarding the use in other domains, and can be adapted to use with fresh produce. In other cases, such as with electron-beam irradiation, advances in technology need new researches. Other technologies, such as pulsed visible light and cold plasma, are newer areas of research that hold promise as antimicrobial processes which can reduce the viability of bacterial pathogens on fresh products.

Within the methods earlier mentioned, a special potential has the use of non-ionizing ultraviolet radiation UV-C. The wavelength range that varies between 200 and 280 nm, which is considered lethal to most types of microorganisms, affects the DNA replication of these microorganisms [3], [4]. Non-ionizing UV radiation can cause breaks of molecular chemical bonds and can induce photochemical reactions. The biological effects of UV radiation depend on the wavelength and the exposure time. UV-C ultraviolet radiation is already successfully used in various fields such as medicine (decontamination of air and medical instruments), environment (wastewater treatment), packaging industry (decontamination of packaging for various food products) etc. Worldwide, there are initiatives in using this method for decontaminating the outer surfaces of food products. As a postharvest treatment on fresh produce, UV-C irradiation has been proven beneficial to reduce respiration rates, control rot development, and delay senescence and ripening in different whole or fresh-cut fruits and vegetables, such as apples, citrus, peaches, dupa tratare, sunt considerate o amenintare potențială la adresa sanatății consumatorilor și în mod special a copiilor [9].

Au fost studiate, de asemenea, metode alternative la tratamentele cu fungicide, in vederea prevenirii pierderilor de produse hortice in perioada postrecoltare. In cadrul acestor metode, utilizarea agentilor de control biologic, compusilor bioactivi obtinuti din plante si metodelor fizico-chimice au obtinut rezultate interesante dar inca departe de o aplicare practica in Europa. In ciuda progresului substantial obtinut in privinta agentilor de control biologic, utilizarea acestora este limitata datorita performantelor insuficiente si inconsistent echinat. Utilizarea compusilor bioactivi obtinuti din plante a aratat faptul ca eficienta lor poate fi influenta de conditiile de tratament (concentratie, forma de aplicare, timp de tratament etc.). Un obstacol in calea aplicarii nu este reprezentat de eficienta metodei ci de mirourile nespecifice si/sau fitotoxicitatea induse materialului horticol. Categoriile metodelor fizico-chimice includ utilizarea calorilor, radiatiei ionizante, radiatiei ultraviolele UV-C si adivitilor alimentari ce induc rezistența la agentii patogeni [13].

Metodele termice convenționale de decontaminare sunt improprieti utilizarii pentru fructe si legume destinates consumului in stare proaspata datorita caldurii care produce modificari permanente ale culorii, mirosului, aromelor si pierderi ale valorii nutritionale [12].

Cercetările recente au identificat o serie de tehnologii alternative bazate pe energie pentru a îmbunătăți siguranța fructelor și legumelor proaspete și proaspat tăiate: radiatia ultravioleta, iradierea cu fascicul de electroni, tehnologia cu impulsuri de radiatie luminoasa vizibilă și tehnologia cu plasmat rece. In unele cazuri, cum ar fi radiatia ultravioleta, aceste tehnologii au o baza de date substanțială de informații privind utilizarea in alte domenii, iar pot fi adaptate pentru a fi utilizate pentru produsele proaspete. In alte cazuri, cum ar fi iradierea cu fascicul de electroni, progresele tecenologice necesită cercetări noi. Alte tehnologii, cum ar fi tehnologia cu impulsuri de radiație luminoasă vizibilă și cu plasmat rece, sunt domenii noi de cercetare care promit a fi utilizate în procese antimicrobiene cu potențial de reducere viabilității agenților patogeni bacterieni în cazul produselor proaspete.

În cadrul metodelor enumerate anterior, un potential deosebit il are utilizarea radiatiei neionizante ultraviolele UV-C. Lungimea de unda cuprinsa intre 200 si 280 nm, care este considerata letala pentru majoritatea tipurilor de microorganisme, afecteaza reactiva replicarii microorganismelor patogene [3], [4]. Radiatiile UV neionizante pot produce ruperi de legături chimice moleculare și pot induce reacții fotochimice. Efectele biologice ale iradierii cu ultraviolete depind de lungimea de undă și de timpul de expunere. Radiatia ultravioletea UV-C este deja utilizata cu succes in diverse domenii precum medicina (decontaminarea aerului si a instrumentului medical), ecologie (epurarea apelor uzate), industria ambalajelor (decontaminarea ambalajelor pentru diverse produse alimentare) etc. Pe plan mondial exista preocupari in domeniul utilizarii acestui procedeu pentru decontaminarea suprafetelor exterioare ale produselor alimentare. Ca si tratament postrecoltare al produselor hortice, iradierea cu radiație ultravioleta UV-C s-a dovedit benefica in diminuarea ratei...
watermelon, grape berries, tomatoes, lettuce, baby spinach and mushrooms [5], [10], [1], [2], [6], [8], [7], [11].

The researches undertaken and presented in this paper, focus on the following approaches:

- performing experimental researches on the possibility of using non-ionizing ultraviolet radiation UV-C within the conditioning technologies of horticultural products;
- investigating the capability of an experimental model of installation for the decontamination of external surfaces of horticultural products, to apply the minimum dosage recommended for the destruction of the most representative pathogens.

MATERIAL AND METHOD

The most common microorganisms that can contaminate horticultural products, with adversely affect on storage or human health, are shown in table 1. For the destruction of these potentially pathogenic microorganisms, it is recommended to apply certain doses of UV-C radiation.

Considering the data presented above, the experimental researches on the possibility of using non-ionizing ultraviolet radiation UV-C within the conditioning technologies of horticultural products, have focused on investigating the capability of applying the minimum dosage recommended for the most representative pathogens. In this respect, it was experimented a new technical equipment (fig. 1) - installation for the decontamination of external surfaces of horticultural products, IDPH. The main technical characteristics of the decontamination installation are presented in table 2.

The installation is proposed to be used for the decontamination of external surfaces of horticultural products, as preliminary stage for the temporary storage phase itself. The main characteristic of the transport system is that it performs not only the transportation of the product along the installation but also the rotation of it around an axis perpendicular to the direction of advance. This characteristic assures a homogenous distribution of the UV-C radiation upon the exterior surfaces of the products.

de respiratie, controlul deprecierii produselor si in intarzierea proceselor de maturare si coacere la diferite fructe si legume, intregi sau maruntite, precum mere, citrice, piersici, pepene, boabe de struguri, rosii, salata verde, spanac si ciuperci [5], [10], [1], [2], [6], [8], [7], [11].

Cercetarile intreprinse si prezentate in aceasta lucrare, se focalizeaza pe urmatoarele abordari:

- realizarea de cercetari experimentale privind posibilitatea de utilizare a radiaiei ultraviolete neionizante UV-C in cadrul tehnologiilor de conditionare a produselor horticole;

- investigarea capabilitatii unui model experimental de instalatie pentru decontaminarea suprafețelor exterioare ale produselor horticole, de a aplica dozele minime de radiație recomandate pentru distrugerea celor mai reprezentativi agenti patogeni.

MATERIAL ŞI METODĂ

Cele mai frecvente microorganisme care pot contamina produsele horticole, cu efecte directe asupra pastrarii sau sanatatii consumatorului uman, sunt prezentate in tabelul 1. Pentru distrugerea acestor microorganisme potential patogene, se recomanda aplicarea anumitor doze de radiație UV-C.

### Table 1

<table>
<thead>
<tr>
<th>Microorganism</th>
<th>UV-C radiation dose (mWs/cm²) necessary for the destruction of</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BACTERIA</strong></td>
<td></td>
</tr>
<tr>
<td>Bacillus anthracis</td>
<td>4.52</td>
</tr>
<tr>
<td>Clostridium tetani</td>
<td>6.00</td>
</tr>
<tr>
<td>Escherichia coli</td>
<td>6.00</td>
</tr>
<tr>
<td>Mycobacterium tuberculosis</td>
<td>6.00</td>
</tr>
<tr>
<td>Salmonella enteritidis</td>
<td>6.00</td>
</tr>
<tr>
<td>Shigella dysenteriae</td>
<td>6.00</td>
</tr>
<tr>
<td>Staphylococcus aureus</td>
<td>6.00</td>
</tr>
<tr>
<td><strong>MOLDS</strong></td>
<td></td>
</tr>
<tr>
<td>Aspergillus flavus</td>
<td>6.00</td>
</tr>
<tr>
<td>Penicillium expansum</td>
<td>12.00</td>
</tr>
<tr>
<td>Rhizopus nigricans</td>
<td>22.00</td>
</tr>
<tr>
<td><strong>YEASTS</strong></td>
<td></td>
</tr>
<tr>
<td>Saccharomyces spores</td>
<td>8.00</td>
</tr>
</tbody>
</table>

Avand in vedere datele prezentate mai sus, cercetarile experimentale privind posibilitatea de utilizare a radiației ultraviolete neionizante UV-C in cadrul tehnologiilor de conditionare a produselor horticole, s-au focalizat pe investigarea capabilitatii de a aplica dozele minime de radiație recomandate pentru distrugerea celor mai reprezentativi agenti patogeni. In acest sens, a fost experimentat un echipament tehnic nou (fig. 1) – Instalatie pentru decontaminarea suprafețelor exterioare ale produselor horticole, IDPH. Principalele caracteristici tehnice ale instalatiei de decontaminare sunt prezentate in tabelul 2.

Instalatia este propusa a fi utilizata pentru decontaminarea suprafețelor exterioare ale produselor horticole, ca etapa preliminara pentru faza de pastrare temporara propriu-zisa. Principală caracteristica a sistemului de transport este aceea că realizează nu numai transportul produsului de-a lungul instalatiei dar și rotirea acestuia în jurul unei axe perpendiculare pe directia de deplasare. Aceasta caracteristica permite o distributie omogena a radiației UV-C asupra suprafețelor exterioare ale produselor.
The experimentation was aimed to determine the energetic indices and qualitative working indices of the decontamination installation. For this purpose, there were taken into account the following parameters:

- The minimum and maximum rotational speed of the driving system of the conveyor - these were determined by varying the frequency of the supply current of the gearmotor, through the frequency converter currently existing within the automation installation;
- The minimum and maximum transport time - these were determined by measuring the time needed for a product subjected to decontamination, to pass a length of the transport system, in terms of maximum and minimum rotational speed of the driving system.

In order to determine the intensity of non-ionizing ultraviolet radiation UV-C, there were performed measurements using a set of tools, sglux brand, Germany, comprising of the following elements: an intensity sensor for ultraviolet radiation, calibrated for the UV-C spectrum (UV Sensor “UV-Water-D”), a communication interface between the sensor and the laptop (“DIGIBOX” - CAN-to-USB converter) and a data acquisition software for the radiation intensity and air temperature, based on LabView programming environment (“DigiLog”).

<table>
<thead>
<tr>
<th>Table 2</th>
<th>The main technical characteristics of the decontamination installation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensions (LxWxH)</td>
<td>3420x1215x1340 mm</td>
</tr>
<tr>
<td>Length of the transport system</td>
<td>1500 mm</td>
</tr>
<tr>
<td>UV Generator type</td>
<td>discharge lamps at low pressure mercury vapor</td>
</tr>
<tr>
<td>The wavelength of the emitted radiation</td>
<td>253.7 nm (UV-C)</td>
</tr>
<tr>
<td>Power of the UV-C lamps</td>
<td>55 W / pcs.</td>
</tr>
<tr>
<td>Number of UV-C lamps</td>
<td>5 pcs.</td>
</tr>
</tbody>
</table>

Experimentarea a avut ca obiectiv determinarea indicilor energetici si indicilor calitativi de lucru ai instalatiei de decontaminare. In acest scop, s-au luat in considerare urmatoarele parametri:

- Turatia minima si maxima a sistemului de actionare a transportorului - s-au determinat prin varierea frecventei curentului de alimentare a motoreductorului, prin intermediul convertizorului de frecventa existent in cadrul instalatiei de automatizare a echipamentului tehnic;
- Timpul minim si maxim de transport - s-au determinat prin masurarea duratei in care un produs supus decontaminarii, parcurge o lungime a sistemului de transport, in conditii de turatie maxima si minima a sistemului de actionare;

In vederea determinarii intensitatii radiatiei neionizante ultraviolete UV-C, s-au realizat masurari utilizand un pachet de instrumente de masura (fig. 2) marca sglux, Germania, avand in componenta urmatoarele echipamente: un senzor de intensitate a radiatiei ultraviolete, calibrat pentru spectrul UV-C (UV Sensor „UV-Water-D”), o interfata de comunicatie intre senzor si laptop („DIGIBOX” – CAN-to-USB converter) si un software pentru achizitia datelor privind intensitatea radiatiei si temperatura aerului, bazat pe mediul de programare LabView („DigiLog”).

Fig. 1 - Installation for the decontamination of external surfaces of horticultural products, IDPH

Fig. 2 - Measuring instruments for UV-C radiation intensity
There were performed determinations at different distances from the source of radiation (50 mm, 75 mm, 100 mm and 125 mm), under a lamp and also in the space between two adjacent UV-C lamps. The first objective of the research was to investigate if the radiation intensity is homogenous, as well under the lamps, as between the two adjacent lamps, with or without the aluminium deflector for the lamps (a semicylindrical aluminium sheet). The second objective was to highlight the influence of the distance on the intensity of emitted UV-C radiation. Also, there were calculated the UV-C radiation doses, according to the measured radiation intensity and its duration of application, using the equation (1). The durations of application for the UV-C radiation were considered to be the minimum and maximum time that a product needs to pass through the transport system of the installation.

\[ D = I \cdot t , \quad [\text{mWs/cm}^2] \]  

**RESULTS**

After carrying out experimental researches on the installation for decontamination, there were achieved a series of results regarding the energetic indices and qualitative indices of the decontamination installation (tables 3, 4 and 5).

**Table 3**

<table>
<thead>
<tr>
<th>No.</th>
<th>Parameter</th>
<th>Measure unit</th>
<th>Parameter values determined from tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>The length of the transport system</td>
<td>mm</td>
<td>1620</td>
</tr>
<tr>
<td>2.</td>
<td>The minimum rotational speed of the driving system of the conveyor</td>
<td>rpm</td>
<td>5.5</td>
</tr>
<tr>
<td>3.</td>
<td>The maximum transport time</td>
<td>s</td>
<td>45</td>
</tr>
<tr>
<td>4.</td>
<td>The minimum transport speed</td>
<td>m/s</td>
<td>0.036</td>
</tr>
<tr>
<td>5.</td>
<td>The energy consumption of the whole installation at minimum transport speed</td>
<td>kWh</td>
<td>0.335</td>
</tr>
<tr>
<td>6.</td>
<td>The maximum rotational speed of the driving system of the conveyor</td>
<td>rpm</td>
<td>72</td>
</tr>
<tr>
<td>7.</td>
<td>The minimum transport time</td>
<td>s</td>
<td>2.93</td>
</tr>
<tr>
<td>8.</td>
<td>The maximum transport speed</td>
<td>m/s</td>
<td>0.55</td>
</tr>
<tr>
<td>9.</td>
<td>The energy consumption of the whole installation at maximum transport speed</td>
<td>kWh</td>
<td>0.643</td>
</tr>
</tbody>
</table>

**Table 4**

<table>
<thead>
<tr>
<th>No.</th>
<th>Distance from the source of radiation [mm]</th>
<th>The intensity of UV-C radiation [W/m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Under the lamp</td>
<td>With deflector</td>
</tr>
<tr>
<td>1.</td>
<td>50</td>
<td>37.66</td>
</tr>
<tr>
<td>2.</td>
<td>75</td>
<td>31.42</td>
</tr>
<tr>
<td>3.</td>
<td>100</td>
<td>27.16</td>
</tr>
<tr>
<td>4.</td>
<td>125</td>
<td>25.32</td>
</tr>
</tbody>
</table>

**Table 5**

<table>
<thead>
<tr>
<th>No.</th>
<th>Parameter</th>
<th>Measure unit</th>
<th>Parameter values determined from tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>The distances from the source of radiation</td>
<td>mm</td>
<td>125 100 75 50</td>
</tr>
<tr>
<td>2.</td>
<td>The intensity of UV-C radiation</td>
<td>W/m²</td>
<td>52.87 55.53 57.41 64.03</td>
</tr>
<tr>
<td>3.</td>
<td>The minimum UV-C radiation dose, according to the minimum transport time</td>
<td>mWs/cm²</td>
<td>15.45 16.26 16.82 18.75</td>
</tr>
<tr>
<td>4.</td>
<td>The maximum UV-C radiation dose, according to the maximum transport time</td>
<td>mWs/cm²</td>
<td>238.05 249.75 258.30 288.00</td>
</tr>
</tbody>
</table>
The radiation intensity values from table 5 represent the average of the values obtained with deflector, under the lamp and between the lamps. The minimum and maximum doses at various distances from the source of UV-C radiation were calculated based on relation (1), considering the minimum and maximum time that a product needs to pass through a length of the transport system.

Figures 3, 4 and 5 show the influence of the aluminium deflector on the intensity of UV-C radiation, under the lamp and between lamps.

Figure 6 shows the variation of the radiation intensity with the distance from the source.

Fig. 3 - Influence of the deflector on the intensity of UV-C radiation under the lamp

Fig. 4 - Influence of the deflector on the intensity of UV-C radiation between lamps
Influence of the aluminium deflector on the intensity of UV-C radiation

\[ y = -7 \times 10^{-5}x^3 + 0.0192x^2 - 1.8502x + 117.1 \]
\[ R^2 = 1 \]

Variation of the radiation intensity with the distance from the source

\[ y = -6 \times 10^{-5}x^3 + 0.017x^2 - 1.6956x + 113.57 \]
\[ R^2 = 1 \]

Linear regression performed using Excel, allowed the identification of a third degree polynomial function, which estimates the variation of the radiation intensity depending on the distance from the source, with a maximum coefficient of determination.

Figure 7 shows the variation of minimum and maximum dose of UV-C radiation with the distance from the source of radiation.
Also, using linear regression was identified a third degree polynomial function, which estimates the variation of UV-C radiation dose depending on the distance from the source, with a maximum coefficient of determination.

Some aspects during the determination of the energy indices and qualitative indices of the decontamination installation, are shown in figures 8 and 9.

De asemenea, cu ajutorul regresiei liniare s-a identificat o functie polinomiala de gradul 3 care sa estimeze varitia dozei de radiatie UV-C in functie de distanta fata de sursa, cu un coeficient de determinare maxim.

Cateva aspecte din timpul determinarii indicilor energetici si indicilor calitativi ai instalatiei de decontaminare, sunt prezentate in figurile 8 si 9.
CONCLUSIONS

Analyzing the data obtained, regarding the use of aluminium deflector for the UV-C lamps, it is found that its use increases the radiation intensity by 70 % - 105 % under the lamp and by 8 % - 103 % between lamps. Also it conducts to the obtaining of a homogenous distribution of UV-C radiation on the working width of the installation, with a variation index of the intensity between 0.01 % and 2.45 %.

Following the analysis of the obtained experimental data and the data contained in table 1, regarding the UV-C radiation doses recommended for the destruction of the most common potentially pathogenic microorganisms existing on the exterior surfaces of the horticultural products, it is found that the experimented decontamination installation has the capability to achieve quality indices superior to the recommendations in table 1. However, although the installation is able to provide radiation doses higher than those shown in table 1, the product subjected to decontamination receives only half the dose, relative to its entire surface. This statement was set forth taking into account the simplifying assumption that, at a certain moment in time, only the upper half of the product will be exposed to UV-C radiation, the other half being shadowed. Considering this hypothesis, the installation still achieves a destruction rate of 90% of the most resistant pathogens presented in table 1, in a single pass, adjusted at 125 mm distance from the radiation source, without having to repeat the exposure to UV-C radiation. For a destruction rate of 99 %, the installation is able to provide the necessary radiation doses for almost all the pathogens in the table 1, except for *Rhizopus nigricans* which needs a higher dose. The next phase of the research will be directed towards the measurement of the microbial count existing on the exterior surfaces of horticultural products.

Given the results obtained, the use of UV-C ultraviolet non ionizing radiation may be a viable solution as post harvest treatment method, in order to decrease the microbiological load from the exterior surfaces of horticultural products.

CONCLUZII

Analizand datele obtinute, in ceea ce priveste utilizarea deflectorului de aluminiu pentru lampile UV-C, s-a constatat faptul ca utilizarea acestuia creste intensitatea radiaiei cu 70 % - 105 % sub lampa si cu 8 % - 103 % intre lampi. De asemenea, conduce la obtinerea unei distributii omogene a radiaiei UV-C pe latimea de lucru a instalatiei, cu un indice de variatie a intensitatii cuprins intre 0,01% si 2,45%.

In urma analizei datelor experimentale obtinute si a datelor continue in tabelul 1, in ceea ce priveste dozele de radiaie UV-C recomandate pentru distrugerea celor mai frecvente microorganisme potential patogene existente pe suprafetele exterioare ale produselor horticole, s-a constatat ca instalatia de decontaminare experimentata are capabilitatea de a atinge indici de calitate superioare recomandarilor din tabelul 1. Totusi, desi instalatia poate furniza doze de radiaie mai mari decat cele prezentate in tabelul 1, produsul supus decontaminarii receptioneaza numai jumatate de doza, raportat la intreaga sa suprafata. Aceasta afirmatie a fost enuntata luand in considerare ipoteza simplificativa conform careia la un anumit moment de timp, numai jumatatea superioara a produsului va fi expusa la radiaia UV-C, cealalta jumatate fiind umbrita. Luand in considerare aceasta ipoteza, instalatia inca poate atinge o rata de distrugere de 90 % a celor mai rezistenti agenți patogeni prezentatii in tabelul 1, chiar dintr-o singura trecere, reglata la o distanta de 125 mm fata de sursa de radiaie, fara a fi nevoie sa se repete expunererea la radiaia UV-C. Pentru o rată de distrugere de 99 %, instalatia poate furniza dozele necesare pentru aproape toți agentii patogeni din tabelul 1, cu excepția *Rhizopus nigricans* care necesita doze mai ridicate. Următoarea etapa a cercetării va fi direcționată către determinarea numărului de microorganisme existente pe suprafetele exterioare ale produselor horticole.

Avand în vedere rezultatele obtinute, utilizarea radiației ultraviolete neionizante UV-C poate fi o soluție viabilă ca și metoda de tratare post recoltare, în scopul micșorării incarcării microbiene de pe suprafetele exterioare ale produselor horticole.
REFERENCES


BIBLIOGRAFIE

ANALYSIS OF INFLUENCE OF SPEED VARIATION OF HIGH SPEED BALL BEARINGS ON CAGE DYNAMIC PERFORMANCE /

高速球轴承转速变化对保持架动态性能影响分析


1) School of Engineering, Zunyi Normal College, Zunyi / China; 2) School of Mechatronics Engineering, Harbin Institute of Technology, Harbin / China; 3) Nano-Tribology of Discrete Track Recording Media, University of California, San Diego, La Jolla / United States

Abstract: With the aim of increasing the stability of high-speed ball bearings in the transmission system of agricultural machinery, taking a type 7004 high speed angular contact ball bearings as the research material, a dynamic model of high speed ball bearings was built based on the geometry and force relationship of bearing elements. The integration method used by Runge-Kutta and Newmark-Raphson is proposed to efficiently solve the nonlinear equations. The accuracy of the dynamic model constructed in this paper was verified by the testing and computation results studied by Gupta. A computation program is developed and the cage stability at different bearing rotation speeds is studied. The results shown that the increase of bearing rotation speed has improved both the cage stability and cage sliding ratio. In addition, the impact between the cage pocket and the ball has a serious effect on cage stability when the bearing is in the starting process. This study provides support for the design of working conditions and failure analysis of ball bearings, as well as a theoretical basis for analysis of the system stability of transmission systems in agricultural machinery.

Keywords: High speed ball bearings; Dynamic; Cage stability; Static condition; Transitional condition

INTRODUCTION

With developments in modern agricultural machinery moving toward lightweight and intelligent designs, the reliability and stability of agricultural machinery transmission systems has gradually become an area of focus [13,14,16]. Over the years, many researchers have studied the rolling bearings in the transmission systems of agricultural machinery in terms of two aspects: a detection technique for bearing faults [4,11,22] and predictions and simulations which focus on the influence of bearing structure on performance [1,2,5,21]. However, those simulation analyses only consider the static properties of the bearing and rarely involve the dynamic stability of the bearings.

The dynamic performance of high-speed rolling bearings in these transmission systems not only affect their own life and stability, but also relates to the vibration and reliability of the rotor system. In order to understand the dynamic performance of the bearings during operation, a fully dynamic analysis of the bearings is needed. Over the years, much research has been done on the dynamic characteristics of high-speed ball bearings. In particular, with regard to the force and motion analysis of cage, Gupta developed the influence of cage clearance on bearing stability [7], while Weinzapfel et al. [17] also analyzed and compared the effects of rigid and flexible cage on bearing stability. In addition, Bai [3] and Liu [19] also studied the dynamic characteristics of the bearings in terms of the waviness and cage clearance ratio of angular contact bearings. However, previous studies on high-speed rolling bearings in these transmission systems are limited to the

Abstract: 针对农机传动系统中高速球轴承的稳定性问题，根据高速球轴承内部的几何位置关系以及相互作用力关系，以 7004 型高速角接触球轴承作为研究对象，建立了高速球轴承的动力学模型。采用 Runge-Kutta 法和 Newton-Raphson 法求解非线性方程组进行了高效求解。采用 Gupta 的实验和仿真结果验证了本文模型和方法的可靠性。从轴承稳态和瞬态过渡两种工况角度研究了轴承转速变化对保持架动态性能的影响规律。结果表明轴承转速增加有利于保持架的稳定性,但同时也增大了保持架的滑动率;变速过程中,保持架在启动阶段产生的兜孔和滚动体频繁冲击对其稳定性影响较大。研究结果为高速球轴承在设计计算以及失效分析等方面提供有力的支持,并为传动系统的系统稳定性分析提供了理论基础。

关键词: 高速球轴承; 动力学; 保持架振动; 稳态工况; 瞬态过渡工况

引言

随着现代农业机械朝着轻量化和智能化方向的发展,农机传动系统的可靠性和稳定性逐渐成为农机设计和使用的重点内容[13,14,16]。多年来,许多学者对农机传动系统中的滚动轴承进行了研究,一方面是集中在针对轴承故障进行检测技术的研究[4,11,22],另一方面集中在轴承结构对性能影响的仿真预测分析[1,2,5,21],但是仿真分析多考虑到轴承承载性能而很少涉及到轴承动动态稳定性。

农机传动系统中高速滚动轴承的动性能不仅影响其自身的寿命和稳定性,还关系到转子系统的振动和可靠性。为了清楚的研究轴承在工作过程中的动性能必须对轴承进行完全动力学分析。多年来,国内外的众多学者在高速球轴承的动性能方面做了大量的研究工作,特别是针对保持架受力动力分析 Gupta 专门讨论了保持架间隙对动态稳定性的影响[7], Nick Weinzapfel 等[17]还分析对比了保持架刚性和柔性对轴承稳定性的影响。国内的白长青[3]、刘秀海[19]等也针对角接触球轴承的接触精度、保持架间隙的影响研究了轴承的动性能特性。但是通过分析可以发现,对于农机传动系统高速滚动轴承的研究基本都局限在不同稳态工况下的动性能分析,对于农机传动系统在
basic dynamic performance analysis of different steady state conditions and have rarely ever investigated the dynamic properties of the bearing in the variable transition process. Frequent impact of the cage and the rolling elements during transmission operation directly affects the dynamic stability of the cage and ultimately influences the stability and reliability of transmission systems in agricultural machinery.

In this paper, through the establishment of a dynamic analysis model and development of an efficient dynamics program, the effect of velocity changes of high-speed ball bearings on the dynamic performance of the cage was analyzed and discussed. The results support the improvement of the design computation and failure analysis of high-speed rolling bearings in agricultural machinery transmission systems.

MATERIAL AND METHOD

Research materials

7004 angular contact ball bearings are used in this paper as the research material, their material and geometry parameters being shown in Table 1 and Table 2. The lubrication oil type MIL-L-7808 is used. The axial load \( F_x \) and radial load \( F_z \) on the bearings are 2000 N and 400 N, respectively.

<table>
<thead>
<tr>
<th>Elements</th>
<th>Density [kg/m³]</th>
<th>Elastic modulus [GPa]</th>
<th>Poisson's ratio [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ball</td>
<td>3200</td>
<td>310</td>
<td>0.260</td>
</tr>
<tr>
<td>Rings</td>
<td>7750</td>
<td>200</td>
<td>0.250</td>
</tr>
<tr>
<td>Cage</td>
<td>1500</td>
<td>1.73</td>
<td>0.300</td>
</tr>
</tbody>
</table>

Table 1

<table>
<thead>
<tr>
<th>Geometry parameter</th>
<th>u.m.</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pitch diameter</td>
<td>[mm]</td>
<td>31</td>
</tr>
<tr>
<td>Ball diameter</td>
<td>[mm]</td>
<td>8</td>
</tr>
<tr>
<td>No. of balls</td>
<td>[-]</td>
<td>6</td>
</tr>
<tr>
<td>Contact angle</td>
<td>[°]</td>
<td>24</td>
</tr>
<tr>
<td>Inner curvature factor</td>
<td>[-]</td>
<td>0.56</td>
</tr>
<tr>
<td>Outer curvature factor</td>
<td>[-]</td>
<td>0.52</td>
</tr>
<tr>
<td>Cage inner diameter</td>
<td>[mm]</td>
<td>30</td>
</tr>
<tr>
<td>Cage outer diameter</td>
<td>[mm]</td>
<td>35</td>
</tr>
<tr>
<td>Cage pocket clearance</td>
<td>[mm]</td>
<td>0.1</td>
</tr>
<tr>
<td>Cage guiding clearance</td>
<td>[mm]</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Table 2

Analysis Method

The contact load \( Q \) between the raceways and the balls are calculated by the Hertz contact theory [10], so the contact load between the \( j \)th rolling element and the raceways is expressed as:

\[
Q_j = K \delta_j^{3/2}
\]  

where the stiffness \( K \) is calculated according to the study by Johnson [10], and the contact deformation \( \delta \) is determined by the positional relationship between the rolling element and the raceway as shown in Fig. 1. Thus, the contact deformation \( \delta_j \) between the \( j \)th rolling element and the raceway is expressed by the vector \( \mathbf{O}_j \mathbf{O}_{pj} \) which means that the center of the raceway to the center of the ball, the groove curvature coefficient \( f \) of the ring, and the diameter of the ball \( D_w \) are expressed as:

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\]  

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The traction force $F_{\mu}$ of the contact area is equal to the traction coefficient $\mu$ multiplied by the contact load $Q$. The traction coefficient formula [20] is:

$$\mu = (A + B s) e^{-C s} + D$$

where $s$ is the slip-roll ratio which could be obtained from the kinematic analysis. Coefficients $A$, $B$, $C$, and $D$ are calculated according to the formula in the study by Wang [20].

Fig. 2 shows the relative position relationship between the rolling element and the cage pocket. According to the vector $O_{pj}O_{bj}$ between the cage pocket and the center of the ball bearing and the initial clearance between the cage pocket and the ball bearing $\Delta_{bp}$, the minimum clearance $\delta_{bp}$ can be expressed as follows:

$$\delta_{bp} = \Delta_{bp} - |O_{pj}O_{bj}|$$

According to the amplitude of the clearance between the cage pocket and the ball bearing $\delta_{bp}$, taking into consideration both the roughness of the ball bearing $\varepsilon_{b}$ and the cage $\varepsilon_{p}$, two interaction models are used:

$$d_{bp} \leq \sqrt{\varepsilon_{b}^{2} + \varepsilon_{p}^{2}} \quad \text{(5a)}$$

$$d_{bp} > \sqrt{\varepsilon_{b}^{2} + \varepsilon_{p}^{2}} \quad \text{(5b)}$$
If the inequality (5a) is true, the interaction is assumed to be Hertz contact. The normal load between the cage pocket and ball bearing is calculated by Hertz point contact theory [10], and the tangential load between cage pocket and the ball bearing equals the normal load multiplied by the friction coefficient.

Otherwise, if the inequality (5b) is true, the interaction is assumed to be hydrodynamic lubrication. Reynolds equations [9] are used to calculate the interaction force. The interactions in two directions, shown as Fig. 3, are assumed to be independent of each other.

Fig. 3- Hydrodynamic effect between ball bearing and cage pocket

Fig. 4 shows the interaction between the cage and the guiding ring, and the force between the two can be approximated as the fluid dynamic pressure of the journal bearing. As the contact surface of the ring flange and cylinder surface of the cage is relatively small, the short journal bearings model [18] is adopted.

Fig. 4- The interaction between cage and guiding ring

Where:

- $W_m$, $W_\Theta$, and $W_\rho$ are the normal force, tangential force, and moment between the cage and the guiding ring.
- $\eta$ is the viscosity of the oil.
- $R_g$ and $B_g$ are the radius and the width of the guiding surface.
- $C_g$ is initial clearance of the bearings.
- $\varepsilon$ is the eccentricity ratio of the cage center.
- $\omega$ is the rotational speed of the element.
- Subscripts 1, 2, and c represent the outer ring, inner ring, and cage, respectively.

According to the interaction angle between the cage and the ring $\phi_d$, the interaction force could be expressed as equation (7) through a coordination transformation.

$$W_m = \pm \frac{\pi \eta R_g B_g^2}{4C_g^2 \varepsilon} \frac{\varepsilon^2}{(1-\varepsilon^2)} (\omega_1 + \omega_2)$$

$$W_\Theta = \frac{\pi \eta R_g B_g^2}{4C_g^2 \varepsilon} \frac{\varepsilon^2}{(1-\varepsilon^2)^2} (\omega_1 + \omega_2)$$

$$W_\rho = \frac{2\pi \eta R_g B_g^2}{C_g} \frac{1}{\sqrt{1-\varepsilon^2}} (\omega_1 - \omega_2)$$

(6)

式中，$W_m$, $W_\Theta$ and $W_\rho$分别代表保持架和套圈引导面之间的法向力、切向力以及转矩。$\eta$为润滑油粘度。$R_g$和$B_g$代表引导面直径及宽度。$C_g$为轴承初始游隙。$\varepsilon$为保持架的偏心率。$\omega$为轴承元件的转速。下标 1, 2 和 c 分别代表外圈、内圈和保持架。若保持架由外圈引导，计算式前取负号，否则取正号。

根据保持架和套圈引导面之间的作用角 $\phi_d$，通过坐标变换将二者之间的作用力变换为固定坐标系下的表达形式，如式（7）所示。

图 4 所示为保持架和引导套圈之间的作用，套圈挡边与保持架引导面间的作用力可以近似为滑动轴承计算中的流体动压力，由于挡边与保持架柱面间的作用面比较小，故通常采用短滑动轴承模型[18]。
Solution method

In addition to the interaction force, the bearing lubricant retarding force $F_D$ and retarding moments $M_D$, which can be calculated by Schlichting’s fluid theory [15], should also be taken into consideration. Forces of the loaded rolling element are shown in Figure 5. In the figures, $M_{yp}$ and $M_{yp}$ are the traction moment between the raceway and the rolling element and friction moment between the cage and the rolling element, respectively. The motion equation of the $j^{th}$ rolling element centroid and of its revolving around the centroid is determined by its resultant force and the moment as shown in equation (8).

$$
egin{align*}
F_{nx} &= F_{nx} + F_{nxx} = m_b \omega_1^2 \chi_j \\
M_{nxx} &= -M_{nxx} + M_{nyy} = I_b \dot{\theta}_j \\
M_{nyy} &= -M_{nyy} + M_{nzz} = I_b \dot{\theta}_j \\
M_{nzz} &= -M_{nzz} + M_{nym} = I_b \dot{\theta}_j
\end{align*}
$$

where, $m_b$ and $l_b$ are the mass and rotary inertia of ball. $r_b$ is the revolution radius of ball. $\theta$ is the azimuth angle of ball and $\omega$ is the rotation speed of ball. Subscript $j$ represents the parameter of $j^{th}$ ball. Subscripts $x$, $y$, and $z$ represent the components in each of the three directions.

To eliminate high-frequency vibrations generated by contact between a ball bearing and rings, a balance constraint is adopted for the contact between the ball and the ring. First, nonlinear equilibrium equations with the quasi-dynamic method are established, and the Newton-Raphson method is used to solve the equations [12].

Similarly, based on the force condition, the differential equations of the cage can be listed as equation (9). Where, $n$ is the ball number. $m_c$ and $l_c$ are mass and rotary inertia of cage. $x_c$, $y_c$, and $z_c$ are displacement of cage mass center on direction $x$, $y$, and $z$. $\theta_c$ is the relative rotation angle between cage mass center and bearing center.

$$
\begin{align*}
\sum_{j=1}^{n} (-F_{nxx}) &= m_c \ddot{x}_c \\
F_{nx} + \sum_{j=1}^{n} (-F_{nxx} \cos \theta_j - F_{nxx} \sin \theta_j) &= m_c \ddot{y}_c \\
F_{nz} + \sum_{j=1}^{n} (-F_{nzz} \sin \theta_j - F_{nzz} \cos \theta_j) &= m_c \ddot{z}_c \\
\sum_{j=1}^{n} (-F_{nym} \frac{D}{2}) + M_i &= I \dot{\theta}_i
\end{align*}
$$

求解方法

轴心套圈、保持架以及滚动体除了相互作用力，还需要考虑轴承中润滑油的阻滞力 $F_D$ 和阻滞力矩 $M_D$，根据 Schlichting 的流体理论进行计算 [15]。考虑所有载荷的滚动体受力情况如图 5 所示，其中 $M_y$ 和 $M_{zy}$ 分别为滚道/滚动体之间拖动力矩及保持架/滚动体之间摩擦力矩。第 $j$ 个滚动体的运动方程和绕质心的运动方程分别根据第 $j$ 个滚动体所受的合力和合力矩确定，式 (8) 所示：

$$
\begin{align*}
F_{nx} &= F_{nx} + F_{nxx} = m_b \omega_1^2 \chi_j \\
M_{nxx} &= -M_{nxx} + M_{nyy} = I_b \dot{\theta}_j \\
M_{nyy} &= -M_{nyy} + M_{nzz} = I_b \dot{\theta}_j \\
M_{nzz} &= -M_{nzz} + M_{nym} = I_b \dot{\theta}_j
\end{align*}
$$

式中 $m_b$, $l_b$ 分别表示球的重量和转动惯量，$r_b$ 表示球的公转半径，$\theta$ 表示球的方位角。$\omega$ 表示球的转速。下标 $j$ 表示第 $j$ 个滚动体；下标 $x$, $y$, $z$ 表示 $x$, $y$, $z$ 三个坐标方向的分量。

图 5 - 行星和作用在球上的力和力矩。

为消除球和套圈接触产生的高频振动，球和套圈之间接触采用平衡约束，通过拟动力学的分析方法建立非线性平衡方程组并采用 Newton—Raphson 方法求解 [12]。

同理，对于保持架可以根据其受力情况列出其运动微分方程如式 (9) 所示，其中 $n$ 表示球数，$m_c$ 和 $l_c$ 表示保持架质量和转动惯量，$x_c$, $y_c$ 和 $z_c$ 表示保持架质心在 $x$, $y$, $z$ 方向的位移，$\theta_c$ 表示保持架质心相对轴承中心的转角。
Based on simultaneous motion differential equations of the ball bearing and cage, one should use non-dimensional quantities to the parameters of the equation in formula (10), and resolve the non-dimensional differential equations with the adaptive step size fourth-order Runge-Kutta method. A stationary solution is obtained by the quasi-dynamic method as the initial values of whole solution process. The calculation procedure is shown in Fig. 6.

\[
\begin{aligned}
F &= \frac{F}{F_s} \\
m &= \frac{m}{m_b} \\
r &= \frac{r}{D_v/2} \\
t &= \frac{t}{\sqrt{m_b \cdot D_v / (2F_s)}}
\end{aligned}
\] (10)

Fig. 6 - Calculation flow chart of dynamic equations

**Model validation method**

Taking a certain type of angular contact ball bearings as used in Gupta’s experiment, the reliability verification on the bearing dynamic model is carried out. The axial load of the bearing is 4448 N, the working velocity is 20000rot/min, and other specific parameters are those used in the reference [8].

Fig. 7 shows the results of the cage mass center orbit simulated by Gupta’s experimental and theoretical work. Fig. 8 shows the results of the cage mass center orbit and the ratio of the cage epicycle speed and bearing speed simulated in this study.

Fig. 7- Cage mass center orbit determined by Gupta [8]
It can be seen that there is good agreement between the shape of the experimental orbit and the theoretical prediction. In addition, according to the ratio of cage epicycle speed and bearing speed simulated in this study, the range of the cage speed ratio is 0.4-0.65 when the cage whirl tends to be stable. Also, the range of the cage speed ratio determined by Gupta's experiment and theory is 0.37-0.50 and 0.31-0.35, respectively [10]. It can be seen that errors exist between the experimental work and theoretical work on the ratio of the cage epicycle speed and bearing speed, but the errors are in the acceptable range.

RESULTS AND DISCUSSIONS
Effect of bearing velocity on the dynamic performance of the cage
Fig. 9 shows the cage whirl track when the velocity of the bearing is 30000 r/min, 60000 rot /min, 80000 r/min, and 120000 r/min. In the figure, axes indicate dimensionless displacement, which is defined as the ratio of actual displacement of the cage mass to the guiding clearance of the cage. As shown in the figure, with the increase in the revolving velocity of the inner ring, the whirl track of the cage becomes regular.

From the whirl track, it can be seen that the model simulation results are consistent with Gupta's experimental results. The variation range of the ratio of cage center whirl speed to bearing speed obtained from this study is 0.4-0.65, while Gupta obtained a variation range of 0.37-0.50 and 0.31-0.35, respectively [10]. It can be seen that there are errors between the simulation and experimental results, but they are within the acceptable range.

从涡动轨迹上看，本文模型仿真结果与 Gupta 实验及仿真获得的结果较为一致。从本文仿真得到的保持架质心涡动速度比可以看出，保持架涡动趋于稳定时的速度比变化范围在 0.4~0.65 之间，而 Gupta 通过实验以及仿真获得的保持架质心涡动速度比变化范围分别为 0.37~0.50 以及 0.31~0.35[10]。比较可知，仿真结果和实验结果之间存在误差，但是在可接受的范围内。

Fig. 9 - Cage whirl motion at different bearing operation speeds
According to the criteria of Ghaisas et al. [6], cage instability can be determined by the calculation of the deviation ratio $\sigma$ of the whirl velocity which is defined as the ratio between the standard deviation value and average value of the velocity vector as shown in eq. (11).

$$
\sigma = \frac{\sqrt{\frac{\sum (v_i - v_m)^2}{N}}}{v_m}
$$

(11)

Where, $N$ is the number of sampling. $v_m$ is the average speed of cage mass center.

Figure 10 shows the deviation ratio of cage whirl velocity at four different velocities. A comparison shows that with the increase of the rotational velocity of the bearings, the deviation ratio of cage whirl velocity reduces, indicating the gradual stability of the cage. The main reason for this stability is that the increase in velocity causes the cage to be pushed against the guide surface of the ring quickly under the force of the rolling element, during which the cage reaches a new balance. Meanwhile, the increase in velocity also helps to enhance the centrifugal force, which gradually increases the guiding force of the ring to the cage. Therefore, the cage whirl track tends to be stabilized.

Figure 10 - Stability of cage at different bearing operation speeds

The vibration spectrum of cage mass center at four different bearing velocities is shown in Figure 11. A comparison of the vibration frequency and the characteristic frequency of the cage mass center shows that whirl frequency of the cage mass center is always near to its revolving frequency. Also, with the increase in the bearing velocity, the whirl frequency of the cage mass center is higher than its revolving frequency at first and then gradually decreases. Therefore, to avoid having the contact between the cage and the guiding ring restricted in only one place or several places which would cause rapid wear of the cage, the relationship between the vibration frequency of cage mass center and the main frequency, the sub-frequency, and the multi-frequency of the cage revolution must be known.

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根据 Ghaisas 等人的判断标准[6]，保持架质心涡动的不稳定性可以通过计算保持架的涡动速度偏差比 $\sigma$ 来进行量化判定，速度偏差比定义为速度向量的标准偏差值与其平均值之比：

$$
\sigma = \frac{\sqrt{\frac{\sum (v_i - v_m)^2}{N}}}{v_m}
$$

式中，$N$ 表示采样的点数，$v_m$ 表示保持架质心运动的平均速度。

图 10 所示为四种不同转速下的保持架涡动速度偏差比。比较可知，随着轴承转速的提高，保持架的涡动速度偏差比逐渐减小，说明保持架的稳定性逐渐增强。其主要原因在于转速的上升促使保持架在滚动体的作用下被迅速推向套圈引导面而获得新的平衡，另外随转速增加带来的离心力升高促使套圈引导面对保持架的引导作用也逐渐增强，这两方面同时促使保持架质心涡动趋于稳定。

在四种不同轴承转速下的保持架质心振动频谱如图 11 所示。将保持架质心振动频率和保持架特征频率进行对比可知，保持架质心振动频率始终处于保持架转动频率附近，且随着转速的升高保持架质心振动频率逐渐从大于保持架转动频率变为小于保持架转动频率。因此，为了避免保持架和引导套圈的接触发生在同一点或少数几点而导致保持架快速磨损，随着轴承工作转速的提升，必须关注保持架质心振动频率和保持架转动主频、分频及倍频的关系。
Effect of changing bearing velocity on the dynamic performance of cage

According to the analysis results of the impact of different velocities on dynamic performance of the cage in the last section, it is clear that for different initial velocity, the changing processes of the bearing starting and the velocity increasing should be treated differently in terms of their impact on the dynamic performance of the cage.

Figure 12 shows the speeds of bearing elements during the starting process. It is indicated that the range of the speed of the rolling elements during the starting process follows the same trend of the speed ranges of the inner ring which shows a linear acceleration. However, there is stagnation and fluctuation of the cage speed within 6 ms while the bearing is started. This phenomenon can be ascribed by the fact that the cage speed relies entirely on the promotion of the rolling elements during the short period in which the bearing is started, and the relatively long interaction cycle between the cage and the rolling elements under the low velocity determines some delay of the cage starting. Meanwhile, the difference of speed between the rolling elements and the cage on the sudden start-up condition causes reciprocating collision between the cage pocket and the rolling element, leading to momentary velocity fluctuations of the cage during start-up.

Figure 13 shows the time response of the cage during the bearing starting process. According to Figure 13a, the impact of the cage pocket and the rolling element appears mainly in the short period when the cage is
starting-up, and the driving force of the rolling element to the cage weakens gradually with time, with the cage eventually reaching a stable stage. Meanwhile, it can be seen from Figure 13b that the impact of the guiding surface of the ring on the cage increases gradually, indicating that under the force of the rolling element, the cage is getting close to the guiding surface of the ring to achieve a new balance.

Fig. 13 - Load vibration of cage in the bearing starting process

Fig. 14 shows the speed of bearing elements when the speed of inner ring ranges from 80000 - 85000 rot/min. As the figure shows, when the velocity of the bearing is accelerated under high-speed operation, the velocity of the rolling elements and the cage shows a fluctuating rising state, which is different from that of the bearing starting process. The main reasons that are the frequent collision of the rolling element and the cage pocket under a high velocity as well as the centrifugal force generated at a high velocity have an influence on the internal load distribution of the bearings which causes a difference among the traction force of the rolling elements at different azimuths.

Fig. 14 - Speed of bearing element in bearing acceleration process

Fig. 15 shows the spectra of the interaction between the cage and the rolling element as well as the interaction between the cage and the guiding ring during the bearing acceleration process.

Fig. 15 - Load spectra of cage in bearing acceleration process
As shown in Fig. 15, despite the spectral peaks appearing in the force spectrum of the interaction between the cage and the rolling element, broadband noise still exists. Therefore, there is a random impact process in the interaction between the cage and the rolling element in the bearing acceleration conditions with high speed. Meanwhile, multi-cycle vibration characteristics occur in the interaction between the cage and the guiding ring, indicating that the guiding effect of the ring to the cage is obvious when the bearing is accelerated.

CONCLUSIONS
In this paper, a dynamics analysis model of high-speed ball bearings is established, the reliability of which is verified by using the experimental examples of Gupta. The model can be used for the steady and transitional dynamic analysis for bearings under different working conditions, which provides a theoretical tool for the design of working conditions and failure analysis of high-speed ball bearings in the transmission systems of agricultural machinery. Though analysis of the effects of velocity changes on the stability of the dynamic performance of high-speed ball bearings, there are some conclusions that have been reached:

(1) As the velocity increases, the vibrational frequency of the cage mass center changes from being higher than the cage rotation frequency to be lower than it. Thus, in order to avoid the contact between the cage and the guiding ring being restricted in only one place or several places which would cause rapid wear of the cage, the relationship between the cage whirl frequency and the main frequency, the sub-frequency, the multi-frequency of the cage must be analyzed during actual operation.

(2) The cage suffers from periodic impact of the rolling elements during the startup phase of the bearing, which causes the cage to be in an unstable state. However, when the bearing is moving high-speed, bearing acceleration has no significant effect on the stability of the cage.

ACKNOWLEDGEMENT
The work has received support from the National Natural Science Foundation of China (51375108), Science and Technology Foundation of GuiZhou Province of China (Qian Ke He J Zi[2014]2172) and Natural Science Research Project of Education Department of GuiZhou Province of China (Qian Jiao He KY Zi[2014]294).

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FROM FIG. 15 can be seen that the support of the cage periphery and rolling bodies is still effective. High-speed ball bearings have a random impulse process in the interaction between the cage and the rolling element in the high-speed operation conditions. Meanwhile, multi-cycle characteristic vibration occurs in the interaction between the cage and the guiding ring, indicating that the guiding effect of the ring to the cage is obvious when the bearing is accelerated.

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MULTI-SYSTEM COUPLING VIBRATION OF A DISTRIBUTED ELECTRIC-DRIVE AGRICULTURAL VEHICLE

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Abstract: To ensure riding comfort, vibration generated by engine, drive system and ground need to be considered in designing an agricultural vehicle. This study examines multi-body dynamics model of an agricultural vehicle, and focuses on the distributed electric-drive agricultural vehicle. To simulate the response of an electric-drive agricultural vehicle to vibrations excited by the drive motors, engine and road roughness, this study proposes a vibration model of a distributed electric-drive agricultural vehicle that has 11 degrees of freedom and coupled excitation sources. The model was derived from vehicle dynamics equations and solved numerically employing fast Fourier transform. The model was validated in experiments on a real distributed electric-drive agricultural vehicle. Simulations and experiments showed that the amplitude of low-frequency vibration of the cab was increased by simultaneous excitations, which could not be ignored. This result is useful for the design of the suspension component and overall design of agricultural machinery.

Keywords: Electric drive; Agricultural vehicle; Riding comfort; Vibrations; Multiple systems

INTRODUCTION
An electric-drive agricultural vehicle is energetically efficient, environmentally friendly and convenient. It is increasingly being used for transportation work in farm lands. However, because of road roughness, simultaneous shocks generated by farming land and vehicle systems have a significant effect on the health of the driver and the reliability of the vehicle. A distributed electric-drive agricultural vehicle is powered by hybrid of diesel engine and battery. Compared with the traditional mechanical transmission, the vehicle is specially designed for farming lands with in-motor wheel, and deleting the gearbox, driveshaft, final drive, differential, so the vehicle has advantages of simple structure, small space requirement, easy high torque performing, convenient feedback control and continuous speed change. Thus, the wheel electric drive has great application potential for agricultural vehicles. However, an electric-drive agricultural vehicle has a significant unsprung load. Additionally, the connection of the hydro-pneumatic spring and wheel rim drive unit generates interacting vibrations from the engine and drive motor and reduces the ride comfort. Thus, the relationship between ride comfort and the structure of the distributed electric-drive agricultural vehicle should be examined.

Present studies on the effects of drive motor vibration on vehicle power and riding comfort usually focus on passenger cars, and the drive motor is typically designed as a sprung load [1,5,7,14,17]. Researchers have analyzed the vibration of a switched reluctance motor proposes a vibration model of a vehicle simplified model探讨非簧载质量增加对平顺性影响较大而不能忽略。通过分析实测数据验证了耦合激励模型在实车中的有效性,耦合激励模型对农用汽车悬架及整车平顺性设计具有指导意义。

关键词: 电驱动; 汽车; 平顺性; 振动; 多系统

引言
电驱动农用汽车具有节能、环保、便捷等优势，目前，耕地属于非公路，其路面不平度产生的冲击和车辆本身的振动对驾驶员的健康及车辆的可靠性有很大影响。分布式电传动农用汽车动力系统采用柴油机与蓄电池混合动力。其传动方式不同于传统的机械传动，牵引电动机直接驱动车轮，省去了变速箱、传动轴、主减速器、差速器等传动部件，能实现高力大、结构简单、可靠性高，同时便于实现反馈控制和无级变速平稳运行，具有良好的应用前景。但是，该传动方式以车轮驱动单元作为驱动桥，非簧载质量大，悬架下端与车轮驱动单元相连接，牵引电动机与发动机共同作为激励源引起车辆平顺性恶化。因此，对分布式电传动结构形式带来的整车平顺性问题的研究是十分必要的。

牵引电动机振动对车辆动力性及平顺性能的影响，目前研究多集中于乘用车[1,5,7,14,17]。有学者以开关磁阻驱动电动机的振动为例分析，表明电机激振力对悬架系统的响应较大而不能忽略[9]；谭迪以1/4车辆简化模型探讨非簧载质量增加对平顺性影响[12]；李朝峰等针对四轮乘用车
motor and pointed out that the effect of motor excitation on the suspension cannot be ignored [9]. Tan [12] built a ¼ vehicle model and discussed the effect of increasing the unsprung load on the riding comfort. Li, using road excitation as the main source of motivation, established a nonlinear model of riding comfort with 11 degrees of freedom (DOFs) for a passenger car [6]. The analysis of riding comfort by Wellman and Wang showed that the powertrain and road excitation cannot be ignored [15, 16]. However, few studies on riding comfort have investigated the coupled excitation effects of the in-wheel motor, engine and road for a distributed electric-drive agricultural vehicle. This paper initiates modeling and discussion on this topic.

Taking the distributed electric-drive agricultural vehicle as the study object, this paper proposes a method of describing the coupled vibration generated by multiple systems of the vehicle and builds a vibration model with 11 DOFs. Moreover, the riding comfort of the vehicle travelling on random surfaces is simulated by employing white-noise filtering. The model and simulation are validated in experiments on a real vehicle undergoing coupled vibration.

MATERIALS AND METHODS
Vibration subsystem analysis of the electric-drive agricultural vehicle

An engine vibration system has a variety of vibration forms. The dominant vibration is the oscillation of the whole machinery, which is much stronger than the vibration of an axle or local vibration [2]. As mentioned, the road roughness, engine vibration and in-wheel electric motor vibration are excitation sources of vibration. The vibration subsystem includes the engine vibration system and in-wheel electric motor vibration system. The electric-drive agricultural vehicle studied in this paper has a Cummings engine. The vibration of the engine is mainly due to the unbalanced forces and torques produced in operating the engine. According to the characteristics of the engine, the excitation frequency is [4]:

\[ f = \frac{n\lambda Z}{60r} \]

Where, \( r \) — the stroke number, \( n \) — the engine speed (r/min), \( Z \) — the cylinder number, and \( \lambda \) — the incentive order.

The engine exciting force is mainly generated by the imbalance torque and moment produced by the running of the engine. According to the working characteristics of the four-cylinder engine, a cycle of crank shaft rotation has two instances of torque fluctuation. Based on the traditional dynamic analysis formula, two reciprocating inertia force expressions are [18]:

\[ P_j = -4\lambda m_rw^2 \cos(2\alpha) = -4\lambda m_rw^2 \cos(wt + \varphi) \]

\[ m_j = m_{nc} + m_A \]

Where, \( P_j \) — twice the reciprocating inertia force, \( \lambda \) — the link ratio, \( r \) — the radius of the crank, \( m_{nc} \) — the quality of the piston assembly, and \( m_A \) — the quality of the small end of the link.

In the experiment conducted in this study, the engine speed measured using a controller area network was 1500 rpm when the vehicle speed reached 30 km/h.

建立了11自由度非线性车辆平顺性模型, 模型主要取路面激励为主要的激励来源[6]。Wellman Thomas和王登峰针对动力总成振动对整车行驶平顺性展开分析，表明动力总成和路面激励在平顺性分析中不可忽略[15, 16]。分析常见车辆平顺性研究, 以分布式电驱动车辆为研究对象的论文较少, 激励源往往没有同时考虑驱动电机激励、发动机激振、路面不平度的影响, 本文正是基于以上问题展开建模和讨论。

本文以分布式电驱动农用汽车为研究对象, 提出了考虑电驱动、发动机振动和路面不平度来描述整车多系统耦合振动的方法, 建立整车十一自由度的振动模型。采用白噪声滤波法模拟时域内的随机路面进行平顺性仿真。通过联立动力方程分析振动特性并进行了实车现场测试, 探究在耦合激励下整车平顺性的影响。

材料与方法
分布式电驱动农业机械振动子系统分析

发动机系统运转时, 机体内存在各种激振力, 产生的整机振动主要指机体跳动, 这类振动对机体的结构影响较大, 而轴系振动、局部振动影响较小[2]。如前所述, 系统振动的激励源包括: 路面不平度, 发动机振动以及轮边电机振动激励。整机振动子系统包括发动机振动系统和轮边电机振动系统。本文所研究的分布式电驱动汽车采用康明斯发动机, 发动机振动主要来自于发动机运转过程中产生的不平衡力和力矩, 根据发动机自身的特性可知, 发动机的激励频率为 [4]:

\[ f = \frac{n\lambda Z}{60r} \]

式中: \( r \) — 冲程数, \( n \) — 发动机转速 (r/min), \( Z \) — 气缸数, \( \lambda \) — 激振阶数。

发动机激励力主要来自于发动机运转过程中产生的不平衡力和力矩。根据发动机自身的特性可知, 在四缸发动机中曲轴每转一周就会产生两次转矩波动。按照传统的动力学分析公式二次往复惯性力表达式为 [18]:

\[ P_j = -4\lambda m_rw^2 \cos(2\alpha) = -4\lambda m_rw^2 \cos(wt + \varphi) \]

\[ m_j = m_{nc} + m_A \]

式中: \( P_j \) — 二次往复惯性力, \( \lambda \) — 连杆比; \( r \) — 曲柄半径; \( m_{nc} \) — 活塞组件的质量, \( m_A \) — 一质量系统代换得到的连杆小头的质量。

后续试验过程中车速为 30km/h 时, CAN 数据采得发动机
Using equation (1), we calculated the first-order excitation frequency of the engine as 37.5 Hz and the force as 25.3 kN. These results are consistent with data provided by the engine manufacturer.

The drive motor vibration comprises electromagnetic vibration, mechanical vibration and pneumatic vibration [3]. The electromagnetic vibration is generated by the interaction of the magnetic field in the air gap, and varies with time and space. It is also a major vibration source [8]. The main frequency of the drive motor is twice the power frequency. For a synchronous motor, the relation between the revolving speed and power frequency is [11]:

$$n' = \frac{60f'}{p}$$  (4)

Where, $f'$—the power frequency, $p$—the number of drive motor pole pairs, $n'$—the drive motor speed (r/min).

The Maxwell stress tensor is used to calculate the electromagnetic exciting force acting on the stator. Here, the magnetic field strength on the surface of the stator object is $H$, the object is surrounded by air and the electromagnetic force acting on the object is[10]:

$$F = \int \mu_0 \mu_n H^2 n + \mu_0 (n \cdot H)H \, ds$$  (5)

The force can be decomposed into $x$ (vertical) and $y$ (horizontal) directions:

$$F_x = \int \mu_0 H_x H_y \, ds$$  (6)

$$F_y = \int \mu_0 \left( H_y^2 - H_x^2 \right) \, ds$$  (7)

Establishment of a three-dimensional vibration model

To control the torque of the in-wheel drive motor and monitor the revolving speed of the wheel, a dynamic model of a distributed electric-drive agricultural vehicle that can be used to analyze the force between the vehicle and ground surface was constructed. Three DOFs in the vertical, horizontal and transverse directions were adopted for the whole vehicle.

The following preconditions were proposed to be taken into consideration for the dynamic model [13]:

1. The vehicle speed is less than 30 km/h; thus, the unbalanced excitations of tires and transmission shaft can be ignored.

2. The excitation frequency of the engine as 37.5 Hz, driving force as 25.3 kN.

3. The drive motor speed (r/min) and excitation frequency of the engine as 37.5 Hz and the excitation frequency is approximately 120 Hz. The frequency in other segments can be similarly estimated.

In the experiment, the revolving speed of the electric motor in stable operation was 1200 r/min. The excitation force of the electric motor was calculated as 15.6 kN by employing the FEM software ANSOFT. The equation shows that the excitation frequency is approximately 120 Hz. The frequency in other segments can be similarly estimated.

For a synchronous motor, the relation between the revolving speed and power frequency is

$$n' = \frac{60f'}{p}$$  (4)

式中: $f'$—供电频率; $p$—电动机极对数; $n'$—电动机转速 (r/min)。

电枢上受到的电磁激振力可用麦克斯韦应力张量法计算, 假设受力物体表面 $S$ 上的磁场强度为 $H$, 并且这个物体外部被空气所包围, 则这个物体受到的电磁力$[10]$ 为:

$$F = \int \mu_0 \mu_n H^2 n + \mu_0 (n \cdot H)H \, ds$$  (5)

将力分解在 $x$ (垂直) 和 $y$ (水平) 方向, 则:

$$F_x = \int \mu_0 H_x H_y \, ds$$  (6)

$$F_y = \int \mu_0 \left( H_y^2 - H_x^2 \right) \, ds$$  (7)

式中: $\mu_0$ ——空气中的磁导率, $n$ ——沿表面 $S$ 法方向上的单位矢量, $H_x$ 和 $H_y$ 分别为受力物体表面 $S$ 上 $x$ 和 $y$ 方向上的磁场强度。电动机各处磁场分布可以通过有限元方法求得。将得到的电磁力与路面激励带入整个系统微分方程组求解系统响应。

所研究的分布式电驱动农用汽车试验电机稳定段运行转速为 1200 r/min。电动机激振力可通过有限元软件 Ansoft 分析得出，激振力大小为 15.6 kN，带入公式(3) 可知激振频率约为 120 Hz。不同段频率可依此估计。

三维整机振动模型建立

建立整车动力学模型来分析车辆与地面的作用力关系，达到控制轮边牵引电机转矩和监测电机转速的目的。选取纵向、侧向和横摆三个自由度，建立整车动力学模型。

从研究问题的需要出发，针对所研究的分布式电驱动农用汽车的特点提出以下前提[13]:

机转速 $n$ 为 1500 r/min，代入式(1) 可得理论的发动机一阶激励频率为 37.5 Hz，激振大小为 25.3 kN。这与发动机厂家提供数据一致。

对于电动机系统振动分别由电磁振动、机械振动、气体振动三部分组成[3]。电磁振动是由气隙中磁场的相互作用而产生，且随时间和空间变化，电磁振动为主要振动源 [8]。电动机激动力主波频率为二倍电源频率。对于同步电机，转速与供电电源频率关系如下[11]:
(1) 在低速情况下工作，故忽略轮胎和传动轴不平衡的激励；
(2) 机身和车架刚度很大，忽略车身弹性引起的振动；
(3) 铰接体对机身的垂直振动没有影响，不考虑铰接体转向自由度；
(4) 非悬挂质量简化为单自由度质量系统，只考虑对整机振动影响较大垂向振动自由度；
(5) 在发动机、轮边电机以及路面激励作用下，整车在平衡位置附近作微幅振动，车身质量在水平面内的振动忽略不计，机身绕Z轴的角振动忽略不计。

本文将车辆简化为11自由度三维整机模型（如图1），图中，前悬架为油气悬架，后悬架为平衡梁结构。

影响乘坐舒适性的唯一因素是由发动机振动和电机振动引起的垂向振动。模型考虑了路面不平度激励，发动机振动和轮边驱动电机振动。发动机前后悬置的刚度和阻尼由发动机的垂向、侧倾以及俯仰三个自由度来描述。

模型11个自由度分别为：
\[ Z_s \] ——整车簧载质量质心垂向位移；
\[ A \] ——整车簧载质量绕质心的俯仰角位移；
\[ \theta_1, \theta_2 \] ——前后车体分别绕前后车体质心的侧倾角位移；
\[ Z_6 \] ——发动机垂直方向位移；
\[ \alpha_0 \] ——发动机绕其质心的俯仰角位移；
\[ \theta_0 \] ——发动机绕其质心的侧倾角位移；
\[ Z_7, Z_8 \] ——前轮垂直方向位移；
\[ \beta_1, \beta_2 \] ——两平衡梁绕铰接处的角位移。

模型中其他参数如下：
\[ Z_{11} \] ——路面对六轮的输入力；
\[ F_{d1} \text{至} F_{d6} \] ——发动机驱动的输入力；
\[ F_{de} \] ——发动机驱动的输入力；
\[ Z_7, Z_8 \] ——油气弹簧与簧载质量连接点处的垂直位移；
\[ Z_{2r}, Z_{2f} \] ——中后桥轮胎角位移；
\[ K_1, K_2 \] ——油气弹簧的刚度系数；
\[ K_{r1}, K_{r2} \] ——轮胎的刚度系数；
\[ C_1, C_2 \] ——油气弹簧的阻尼系数；
\[ C_{r1}, C_{r2} \] ——轮胎的阻尼系数；
\[ L_1 \] ——前轮距整机质心的水平距离；
\[ L_2 \] ——中后桥轮胎中心点处的垂直位移；
\[ L_3 \] ——油箱的中后轴；
\[ L_4, L_5 \] ——中后轴的水平距离；
\[ L_6 \] ——前轮距整机质心的水平距离；
\[ L_7, L_8 \] ——中后轮间的水平距离；
\[ L_9 \] ——前轮距；
\[ L_{10} \] ——后轮距；
\[ L_11 \] ——驾驶室质心距整机质心的水平距离；
\[ L_{17} \] ——发动机前
engine, \( L_f \)—the distance between front suspensions, \( L_r \)—the distance between rear suspensions, \( M_0 \)—the sprung mass of the vehicle, \( M_{01} \) and \( M_{02} \)—the sprung masses of front and rear frames respectively, \( M_1 \sim M_6 \)—the unsprung masses of the six wheels, \( M_e \)—the engine mass, and \( I_1 \)—the longitudinal moment of inertia of the sprung mass that turns around the vehicle centre of mass. \( I_2 \)—the horizontal inertia moment of the sprung load of the front frame, \( I_3 \)—the horizontal inertia moment of the sprung load of the rear frame, \( I_{e1} \)—the inertia moment produced by the rotation of the engine around its longitudinal axis, and \( I_{e2} \)—inertia moment produced by the rotation of the engine around its horizontal axis.

\[
M_{ij} \ddot{z}_i = C_{ij} (\ddot{z}_j - \dot{z}_j) + K_{ij} (z_j - z_i) + C_{ij} (\dot{z}_i) + K_{ij} (\dot{z}_i - \dot{z}_j) + F_i - C_{ij} (\dot{z}_j - \dot{z}_i) - K_{ij} (z_j - z_i) - F_i
\]

The equations that govern the micro-vibration of the machinery are:

\[
M_{ij} \ddot{z}_i = C_{ij} (\ddot{z}_j - \dot{z}_j) + K_{ij} (z_j - z_i) + C_{ij} (\dot{z}_i) + K_{ij} (\dot{z}_i - \dot{z}_j) + F_i - C_{ij} (\dot{z}_j - \dot{z}_i) - K_{ij} (z_j - z_i) - F_i
\]

\[
I_{ij} \ddot{\theta}_i = (L_f + L_r / 2) [C_{ij} (\ddot{z}_j - \dot{z}_j) + K_{ij} (z_j - z_i) + C_{ij} (\dot{z}_i) + K_{ij} (\dot{z}_i - \dot{z}_j) + F_i - C_{ij} (\dot{z}_j - \dot{z}_i) - K_{ij} (z_j - z_i) - F_i]
\]

Fig.1- Model of an agricultural vehicle with 11 DOFs

整机微分振动的动力学方程如下：
\[ M\ddot{Z} + C\dot{Z} + KY = K_1Q + C_1\dot{Q} + A_dF_d + A_eF_e \]  

where, \( M \) is an 11 \times 11 mass matrix, \( C \) is an 11 \times 11 damping matrix, \( K \) is an 11 \times 11 stiffness matrix of the tires, \( K_t \) is an 11 \times 6 stiffness matrix of the tires, \( A_d \) is the drive motor excitation coefficient matrix, \( A_e \) is the excitation coefficient matrix of the engine, \( Q \) is the excitation matrix of the ground surface, \( F_d \) is the excitation matrix of the drive motor, and \( F_e \) is the excitation matrix of the engine. These matrices are expressed as:

\[ M = \begin{bmatrix} M_5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & M_1 & 0 \\ 0 & I_1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & I_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & I_3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & I_4 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & M_5 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & M_1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & M_1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & M_1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & M_1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & M_1 \end{bmatrix} \]

\[ C = \begin{bmatrix} C_9 & C_{10} & C_{11} & C_{12} \\ 0 & C_9(L_2 + L_7) & C_{10}(L_2 + L_7) & C_{11}(L_2 + L_7) & C_{12}(L_2 + L_7) \\ 0 & 0 & C_9L_3 & -C_{10}L_3 & C_{11}L_3 & -C_{12}L_3 \\ 0 & 0 & 0 & C_9L_7 & -C_{10}L_7 & C_{11}L_7 & 0 \\ 0 & 0 & 0 & 0 & C_9L_9 & -C_{10}L_9 & C_{11}L_9 & 0 \\ 0 & 0 & 0 & 0 & 0 & C_9L_9 & -C_{10}L_9 & C_{11}L_9 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & C_9L_9 & -C_{10}L_9 & C_{11}L_9 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & C_9L_9 & -C_{10}L_9 & C_{11}L_9 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & C_9L_9 & -C_{10}L_9 & C_{11}L_9 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & C_9L_9 & -C_{10}L_9 & C_{11}L_9 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & C_9L_9 & -C_{10}L_9 & C_{11}L_9 & 0 \end{bmatrix} \]

The analytic solution can be obtained by putting the experimental parameters into the above equations. Given that road roughness is an important excitation for

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根据路面不平度系数 $G_d(n_0)$ 的大小，将路面分为 8 级。试验路面情况一般，应选用较为平整但碎石较多的 D 级路面模型建模。本文用谐波叠加法编写了速度为 30 km/h D 级标准路面得到车辆实际行驶过程中左右车辙的路面不平度激励如图 2 所示。

在随机路面的基础上加入两个高度分别为 $b_1, b_2$ 的木块，其宽度分别为 $b_1, b_2$，间距为 $S_1$。仿真时车辆以速度 $v$ 匀速驶过木块。图 3 为速度为 10 km/h，B 级标准路面上得到车辆实际行驶过程中左右车辙的路面不平度激励。
respectively. For comparison, the results obtained when ignoring the excitations of the engine and drive motor are also shown.

The simulation started from a static state. Figure 4 reveals that the maximum acceleration is 2.5 m/s² when the excitations of the engine and drive motor are included. After 1 s, a state of stable vibration is reached regardless of whether the excitations of the engine and drive motor are included or not. The maximum acceleration is 0.5 m/s² when the excitations of the engine and drive motor vibration are included, whereas it is only 0.4 m/s² when the excitations are excluded. The trend is seen more clearly when the result is converted to the frequency domain by Fourier transformation as shown in Fig 5.

![Image](a) Including the vibration of the engine and drive motor (b) Excluding the vibration of the engine and drive motor

**Fig.4 - Vertical acceleration of the cab vibration**

![Image](a) Including the vibration of the engine and drive motor (b) Excluding the vibration of the engine and drive motor

**Fig.5 - Vertical acceleration PSD of the cab vibration**

The comparison of Fig. 5 (a) and (b) shows that the power at low frequency is affected by the engine and drive motor. The maximum power increases from 0.6 m²/s³ to 0.85 m²/s³ after the inclusion of the excitations from the engine and drive motor. Additionally, obvious spikes in the power spectrum appear at the frequency of the engine (37.5 Hz) and at the frequency of the drive motor (120 Hz). Significant power increases in the frequency domain analysis cannot be ignored.

**Experimental validation**

To validate the coupled vibration model, an experiment was conducted using an agricultural vehicle. The machinery was controlled by six-wheel-drive motors independently. Acceleration sensors were placed on fixed surfaces of the cab, the rear frame, the left suspension, the right suspension and a drive motor as shown in Fig. 6. The signals of vibration acceleration were measured using a data capture card. The signals through the INMATEH-Agricultural Engineering

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**Experimental validation**

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of the engine and drive motor speeds were collected using a controller area network (CAN) bus device. Acceleration signals of motor vibration at low frequency were filtered to remove the vibration excitation of the road. The sampling frequency of each sensor was 2560 Hz, which was appropriate for signal analysis.

The experiment was conducted on a fine-gravel road corresponding to ISO level D. The vehicle was driven at an even speed of 30 km/h with relative error less than ±5%. The mean value was calculated for three repetitions of the experiment. The vertical vibration acceleration of the cab at the stage of stable running is shown in Fig. 7. Figure 8 presents the vertical vibration PSD after fast Fourier transformation. Fig 9 clearly shows the PSD of the drive motor at high frequency by focusing on the data range of 0–0.2 m²/s³.

设备的实验在相当于 ISO D 级的细砂石路面上进行，以 30km/h 速度匀速行驶，车速变化不大于±5%，且同一工况条件下的试验重复三次，结果取其平均值。平稳运行阶段实测驾驶室垂向振动加速度如图 7。经 FFT 变换后为图 8，即驾驶室垂向振动加速度功率谱密度，为了清晰展示高频段的电动机功率谱可截取 0–0.2 m²/s³ 段功率谱进行分析，得到图 9。
Comparison of the acceleration time-domain curves and PSD curves of the cab obtained in the experiment with the simulation results reveals that the coupled vibration model and experimental results are basically consistent. The power spectrum obtained in the experiment mainly ranged from 1 Hz to 20 Hz and had a peak value of 0.85 m$^2$/s$^3$ at 2 Hz. Additional peaks at the excitation position of the engine and drive motor were found in both simulation and experiment. Figure 9 shows that the PSD had a second peak of 0.06 m$^2$/s$^3$ near the excitation frequency of the drive motor, 120 Hz. Another obvious peak value of 0.09 m$^2$/s$^3$ was recorded at a frequency of approximately 37 Hz. The result obtained excluding the vibrations of the engine and drive motors showed a peak value of only 0.6 m$^2$/s$^3$, which was obviously lower than the value when these two vibrations were included. The good match of simulation and experimental results shows that the multisystem coupled vibration model including the excitations of the engine and drive motors can be used to simulate the vibrations and riding comfort of the cab.

We next consider the vehicle running at a speed of 10 km/h over two blocks with heights of 0.06 m and 0.09 m and spaced 10 m. Table 1 provides the root mean square of the vibration acceleration in both simulation and experiment.

### Table 1

<table>
<thead>
<tr>
<th>Measuring point</th>
<th>Test value</th>
<th>Simulation value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cab</td>
<td>0.2801</td>
<td>0.2967</td>
</tr>
<tr>
<td>Upper fulcrum of the left suspension</td>
<td>0.3124</td>
<td>0.3019</td>
</tr>
<tr>
<td>Rear frame</td>
<td>0.4933</td>
<td>0.5123</td>
</tr>
<tr>
<td>Upper fulcrum of the left motor</td>
<td>0.7123</td>
<td>0.7506</td>
</tr>
</tbody>
</table>

The acceleration results obtained under the impulse excitation are similar to those obtained for the random road. The experimental acceleration (Fig. 11) differs from the simulation acceleration (Fig. 10) by only less than 10%, and the trends of the acceleration are consistent between simulation and experiment.

In pulse excitation, the results obtained under impulse excitation are similar to those obtained for the random road. The experimental acceleration (Fig. 11) differs from the simulation acceleration (Fig. 10) by only less than 10%, and the trends of the acceleration are consistent between simulation and experiment.

![Fig.10 - Vibration acceleration in simulation](image)

![Fig.11 - Vibration acceleration in experiment](image)

Fig 10 and Fig 11 reveal obvious fluctuations in acceleration near 4.5 s. The instantaneous acceleration reached 0.93 m/s$^2$ and 1.29 m/s$^2$ in the experiment and simulation, respectively. Then, under the effect of suspension damping, the acceleration began to attenuate. At 12 s, a second obvious fluctuation occurred, with the instantaneous acceleration reaching 1.41 m/s$^2$ in the experiment and 2.06 m/s$^2$ in the simulation. The acceleration then gradually decayed.

In pulse excitation, the results obtained under impulse excitation are similar to those obtained for the random road. The experimental acceleration (Fig. 11) differs from the simulation acceleration (Fig. 10) by only less than 10%, and the trends of the acceleration are consistent between simulation and experiment.

![Fig.10 - Vibration acceleration in simulation](image)

![Fig.11 - Vibration acceleration in experiment](image)

By Fig. 10 and Fig. 11, it can be seen that the acceleration results obtained under impulse excitation are similar to those obtained for the random road. The experimental acceleration (Fig. 11) differs from the simulation acceleration (Fig. 10) by only less than 10%, and the trends of the acceleration are consistent between simulation and experiment.

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CONCLUSION

A model was constructed to analyze the vibration response of a distributed electric-drive agricultural vehicle considering coupled excitations of the road roughness, engine and drive motors. The conclusions are shown as follows:

1. The experiment result shows that the 11-DOF vibration model built in consideration of the coupled excitations of the road can accurately describe the vibration characteristics of the distributed electric-drive agricultural vehicle.

2. The excitation forces of the engine and drive motors increased the PSD of the vehicle acceleration, and obvious PSD peaks registered at the excitation frequency. Therefore, the excitation forces of the road roughness, drive motors and engine must all be considered to ensure the riding comfort and reliability of the distributed electric-drive agricultural vehicle.

Compared with the research on a passenger vehicle, that on the riding comfort of agricultural vehicle has obvious differences. Air suspension with variable stiffness can improve riding comfort and has a good application prospect in the field of agricultural vehicle.

ACKNOWLEDGEMENT

This study was supported by the National High Technology Research Program (2011AA060404).

REFERENCES


图 12 表示仿真和实验所得驾驶室振动加速度的功率谱密度。仿真加速度功率谱密度在 1.75 Hz 处出现最大值 40.26 dB，仿真加速度功率谱密度在 1.98 Hz 处出现最大值 46.1 dB，仿真数据与实验数据基本保持一致。由于所建模型与实验之间的差异，仿真数据要高于实验得到的加速度值，但是其波动时间和趋势基本一致。频域和时域分析得到了相同的结果，进一步验证了车辆单点接触模型的准确性。

结论

论文提出了考虑路面不平度和电机、发动机耦合激振来分析车辆系统振动响应的方法，分析了考虑耦合激振后系统响应的差别，主要结论如下：

1. 所建立电机激振力、发动机激振及路面激励的十一自由度整机三维振动系统模型经实车试验验证结果表明，该模型能够准确的反应分布式农用汽车的振动特性。

2. 电动机和发动机激振力会整体增大整机加速度功率谱，在激振力频率处会出现明显峰值，不可忽略。为提高电动车辆的平顺性及可靠性，需兼顾电机激振力和路面激励，耦合激励模型对农用机械的悬架及整车平顺性设计有指导意义。

农用机械的行驶平顺性研究与乘用车相比具有一定的差距，采用可变刚度的空气弹簧可提高整机的平顺性，是论文下一步研究的方向。

致谢

国家高技术研究发展计划(2011AA060404)。


Abstract: The paper presents the possibility of obtaining some fuels resulted from plastic materials waste recycling, the determination of some physicochemical properties of these fuels and a comparison of the obtained results with those specific to commercial diesel fuels. This concept of recycling is a priority in countries with an important technological breakthrough and having at the same time major concerns related to environment protection. If processing is rigorously controlled by the pyrolysis of plastic polymeric materials [1, 2, 3, 4, 9, 10, 11, 12], following the thermal degradation reaction one can obtain at the final:

- a gaseous blend which contains saturated and unsaturated hydrocarbons;
- a liquid that contains a mixture of saturated and unsaturated hydrocarbons;
- a solid residue that contains mainly carbon;
- the liquid phase having properties close to the diesel fuel, that can be used as fuel for Diesel engines.

Keywords: plastic materials, fuels, properties, viscosity, calorific power, diesel engine.

INTRODUCTION

Low density polyethylene (LDPE) waste is heated at temperatures of about 500°C in a pyrolysis installation [1, 2, 3, 4]. According to specialty literature, thermal degradation of polyethylene takes place in two stages, namely after the first one viscous products are obtained (C₅ C₄₃, ~87% weight percent), while following the second one liquid hydrocarbons are formed (~74% weight percent) [1, 2, 9, 10, 12].

Figure 1 presents the experiments diagram followed in order to obtain the fuel from LDPE, data acquisition regarding those processes and both the analysis of experimental data and of the resulted products, including their characterization [5, 6, 7, 8].

A superior recovery of plastic materials wastes, such as the production of fuels resembling diesel fuel has an important role in natural resources conservation [11].

MATERIAL AND METHOD

The experimental stand and the description of laboratory equipment used for fuel obtaining

A pyrolysis installation has been performed on a laboratory stand using a heating mantle Raypa X-250 with thermosetting stage system, with a maximum temperature heating stage of 450°C (fig. 2).

In order to determine with the best accuracy the conversion yield of solid LDPE in liquid phase, the parts used for installation have been weighted previously with a KERN EMB 200-3 weighting scale with a resolution of 1 mg and an analytical balance Precisa XT-220A with resolution of 0.1 mg. The temperature control during pyrolysis process has been made using a digital thermometer HI-95350 with a resolution of 0.1°C.

Rezumat: Lucrarea prezintă posibilitatea obţinerii unor combustibili rezultanţi din reciclarea deşeurilor de mase plastice, determinarea unor proprietăţi fizico-chemice ale acestora şi compararea rezultatelor obţinute cu cele specifice motorinei comerciale. Acest concept de reciclare este o prioritate în unele ţări cu un ansamblu tehnologic important şi care au în acelaşi timp preocupări majore legate de protecţia mediului. Dacă procesarea prin metoda piroliziei a materialelor plastice polimerice este atent controlată [1, 2, 3, 4, 9, 10, 11, 12], în urma reacţiilor de degradare termică se obţine în final:

- un amestec gazos care conține hidrocarburi saturate și nesaturate;
- un lichid care conține un amestec de hidrocarburi saturate, nesaturate și aromatice;
- un reziduu solid care conține în principal carbon;
- o lichidă fără proprietăți apropriate motorinelor, ea putând fi utilizată ca și combustibil la alimentarea motoarelor Diesel.

Cuvinte cheie: mase plastice, combustibili, proprietăți, viscozitate, putere calorifică, motor diesel.

INTRODUCERE

Deșeurile de polietilenu de joasă densitate (LDPE) sunt încălzite la temperaturi de cca. 500°C într-o instalație de piroliză [1, 2, 3, 4]. Conform literaturii de specialitate, degradarea termică a polietilenei are loc în două etape, după prima etapă se obțin producți viscoși (C₅ C₄₃, ~87% procente de masă), iar după a doua rezultă hidrocarburi lichide (~74% procente de masă) [1, 2, 9, 10, 12].

În figura 1 este prezentată diagrama experimentelor desfășurate pentru obținerea combustibilului din LDPE, achiziționarea datelor legate de aceste procese și analiza a datelor experimentale cât și a produsilor rezultați, incluzând aici și caracterizarea acestora [5, 6, 7, 8].

O valorificare superioară a deșeurilor de mase plastice, cum ar fi producerea de combustibil asemănător motorinelor, are un rol important în conservarea resurselor naturale [11].

MATERIAL ȘI METODĂ

Standul experimental și descrierea echipamentelor de laborator utilizeate la obținerea combustibilului

Pe un stand de laborator s-a realizat o instalație de piroliză încălzită electric cu ajutorul unui cuib de încălzire Raypa X-250 cu termostatatic în trepte, cu o temperatură maximă de încălzire de 450°C (fig. 2).

În vederea determinării cât mai corecte a randamentului de conversie din LDPE solidă în fază lichidă, componentele utilizate la alcătuirea instalației au fost cântărite în prealabil cu ajutorul unui cântar KERN EMB 200-3 cu rezoluția de 1 mg și o balanță analitică Precisa XT-220A având o rezoluție de 0,1 mg. Controlul temperaturii în procesul de piroliză s-a făcut utilizând un termometru digital HI-95350 cu o rezoluție de 0,1°C.
For cooling and controlling temperature from condensation area, a recirculation thermostatic bath model DC-1006 with the temperature range between -10°C...95°C and a resolution of 0.05°C, will be used. As cooling agent it was used antifreeze with the recommended concentration for -20°C.

Fig. 1 - Pyrolysis process diagram, its control, data acquisition and data processing

In the first stage the conversion yield of solid LDPE into liquid phase, residues and gases was calculated. The following are the initial values of the masses obtained by weighing the pyrolysis installation components and LDPE granules on which the yield was determined after conversion to the different phases of pyrolysis products [6].

- condenser initial weight \( G_{ic} = 221.8 \) g
- Erlenmeyer glass initial weight \( G_{ie} = 122.6 \) g
- pyrolysis flask initial weight \( G_{if} = 122.8 \) g
- LDPE granules weight \( G_{LDPE} = 100.015 \) g

The weighting made at the final stage of pyrolysis process conducted to the following values:

- condenser final weight \( G_{if} = 222.3 \) g
- Erlenmeyer glass final weight \( G_{if} = 211.9 \) g
- pyrolysis flask final weight \( G_{if} = 127.4 \) g

Making the difference between the final weights and the initial ones and knowing at the same time the weight of LDPE subjected to pyrolysis we will obtain the final conversion yield in liquid phase, by relation (1),

In prima fază s-a calculat randamentul de conversie din fază solidă a granulelor de LDPE în fază lichidă, reziduurii solide și gaz. În continuare sunt prezentate valorile inițiale ale maselor obținute prin cântărirea componentelor instalației de piroliză și a granulelor de LDPE pe baza căror s-a determinat ulterior randamentul de conversie pentru diferitele faze ale producției de piroliză [6].

- masa inițială refrigerent \( G_{ir} = 221.8 \) g
- masa inițială pahar Erlenmeyer \( G_{ie} = 122.6 \) g
- masa inițială balon piroliză \( G_{ib} = 122.8 \) g
- masa granule LDPE \( G_{LDPE} = 100.015 \) g

Cântărirea făcută la finalul procesului de piroliză ne dă următoarele valori:

- masa finală refrigerent \( G_{ir} = 222.3 \) g
- masa finală pahar Erlenmeyer \( G_{ie} = 211.9 \) g
- masa finală balon de piroliză \( G_{ib} = 127.4 \) g

Făcând diferențele dintre masele finale și cele inițiale, cunoscând toată masa de LDPE supusă procesului de piroliză vom obține în final randamentul de conversie în fază lichidă, cu relația (1),
Where:

\[ G_{fr} - G_{frp} = 0.5 \text{ g} \]
\[ G_{fr} - G_{frp} = 89.3 \text{ g} \]
\[ \eta_{\text{liquid}} = \left[ \frac{(G_{fr} - G_{frp}) + (G_{fr} - G_{frp})}{G_{\text{LDPE}}} \right] \times 100 \% \] (1)

it results the yield of conversion in liquid phase:
\[ \eta_{\text{liquid}} = 89.787 \% \]

Applying the mass conservation law, based on the data presented previously taking into account the solid weight the conversion yield in solid residue and gaseous phase has been also determined.

For solid residue we use relation (2):

Where:

\[ G_{fr} - G_{frp} = 4.6 \text{ g} \]
\[ \eta_{\text{res}} = \frac{G_{fr} - G_{frp}}{G_{\text{LDPE}}} \times 100 \% \] (2)

The quantity of gas was determined by relation (3), making the difference between the quantity of LDPE introduced into the pyrolysis installation and the sum of the liquid and solid residue resulted from the process:

\[ \eta_{\text{gas}} = \left[ \left(G_{fr} - G_{frp}\right) + \left(G_{fr} - G_{frp}\right) \right] \times 100 \% \] (3)

\[ \eta_{\text{gas}} = 5.614 \% \]

Based on the measurements and the calculus performed it resulted a superior conversion yield in liquid phase of LDPE, comparing to the one found in the literature [5, 6], the most probable cause being the low temperature maintained into the condensation installation.

RESULTS

The determination of the density and the calculation of the relative density of the obtained fuel

The volume \( V \) occupied by the liquid phase measured with a measuring cylinder at ambient temperature \( t_a = 27.6^\circ \text{C} \) was of 114 ml, and in this case the density of liquid phase has been calculated with relation (4):

\[ \rho = \frac{\left(G_{fr} - G_{frp}\right) + \left(G_{fr} - G_{frp}\right)}{V} \text{ [kg/m}^3\text{]} \] (4)

\[ \rho = 783.33 \text{ [kg/m}^3\text{]} \text{ or else } \rho_{4}^{15} = 0.78333 \text{ [kg/l]} \]

Because the temperature at which the determination has been made is higher than 20°C it has been calculated the relative density of liquid phase obtained from LDPE by pyrolysis with relation (5):

\[ \rho_{4}^{15} = \rho_{4}^{1} + c(t - 15) \] (5)

where:

\( \rho_{4}^{1} \) - represents the relative density at the temperature of the measurement;
\( t \) - is the working temperature;
\( c \) - is the correction coefficient
\[ \rho_{4}^{15} = 0.79333 \]

\[ \rho_{4}^{1} \] - reprezintă densitatea relativă la temperatura la care s-a efectuat determinarea;
\( t \) - este temperatura de lucru;
\( c \) - este coeicientul de corecție a temperaturii
\[ \rho_{4}^{15} = 0.79333 \]
Comparing the density obtained in this way with the density presented in table 1, we were able to estimate that the density of liquid phase obtained from LDPE by pyrolysis is situated between the density of gasoline and diesel fuels.

Comparând densitatea obținută prin metoda de calcul arătată anterior, cu densitățile prezentate în tabelul 1 am putut estima că densitatea fazei lichide obținute din LDPE prin piroliză se încadrează între densitatea benzinelor și a motorinelor.

Table 1

<table>
<thead>
<tr>
<th>Fuel</th>
<th>The relative density [kg/l]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>0.682 – 0.767</td>
</tr>
<tr>
<td>Diesel</td>
<td>0.820 – 0.910</td>
</tr>
</tbody>
</table>

Experimental determination of density and viscosity

For experimental determination of the density and viscosity we used the SVM viscometer, an apparatus that measures the dynamic and kinematic viscosity of fuels and oils respectively, and the results are provided as tables.

The determinations were made in the same conditions for diesel fuel as for the liquid pyrolysis product from LDPE, namely atmosphere pressure of \( P_a = 9.74 \times 10^4 \) [Pa] and environment temperature of \( t_{ma} = 27.6^\circ C \).

The results obtained following the measurements for dynamic and kinematic viscosity for diesel fuel and the fuels from LDPE are presented in figure 3 and 4. The variation of the density of the studied fuels depending on temperature, including the density calculated for 15\(^\circ\)C for the obtained fuel by LDPE pyrolysis is presented in figure 5.

Determinarea experimentală a densității și viscozității

Pentru determinarea experimentală a densității și viscozității s-a folosit viscozimetru SVM 3000, aparatul măsoară viscozitatea dinamică și densitatea combustibililor, respectiv a uleiurilor, iar rezultatele le redă tabelar.

Determinările s-au efectuat în același condiții pentru motorină și faza lichidă a produsului obținut prin piroliză din LDPE, adică presiunea atmosferică de \( P_a = 9.74 \times 10^4 \) [Pa] și temperatura mediului ambiant \( t_{ma} = 27.6^\circ C \).

Rezultatele obținute în urma măsurătorilor pentru viscozitățile dinamice și cinematece ale motorinei și combustibilului din LDPE sunt prezentate în figurele 3 și 4. Variația densității combustibililor studiați în funcție de temperatură, inclusiv a densității calculate la 15\(^\circ\)C pentru combustibilul obținut prin piroliză din LDPE, este redată în figura 5.
Experimental determination of the flash point (Penski-Martens)

For the determination of this parameter it was used Automated Pensky Martens Closed Cup Flash Point Analyzer HFP 339. The determination was made according to ISO 2719A norms. If during the measurements the atmospheric pressure differs from 101.3 kPa (760 mmHg), it is necessary a correction of the determined values with the relation (6):

\[ T_{\text{ref}} = T_{\text{ref max}} + 0.25 \cdot \left( 101.3 - p_{\text{atm}} \right) \]

where:
- \( T_{\text{ref max}} \) is the measured inflammability temperature, in Celsius degrees.
- \( p_{\text{atm}} \) is the atmospheric pressure, expressed in kPa.

After the recalculation of the flash point in this way, the resulted values will be rounded by 0.5 °C.

Table 2 presents the data resulted following the measurements and data correction.

### Table 2

<table>
<thead>
<tr>
<th>Tested fuel</th>
<th>Flash point measured [°C]</th>
<th>Atmospheric pressure [kPa]</th>
<th>Flash point corrected [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel fuel</td>
<td>55</td>
<td>97.3</td>
<td>56.5</td>
</tr>
<tr>
<td>LDPE fuel</td>
<td>44</td>
<td>97.3</td>
<td>45.5</td>
</tr>
</tbody>
</table>

Determinarea experimentală a temperaturii de inflamabilitate (Pensky-Martens)

Pentru determinarea acestei mărimi s-a utilizat analizorul cu creuzet închis HFP 339, aparatul funcționând după metoda Persky-Martens. Determinarea s-a făcut conform normelor ISO 2719A. Dacă pe durata efectuării determinărilor presiunea atmosferică este diferită de 101.3 kPa (760 mmHg), este necesară corectarea valorii determinate cu relația (6):

\[ T_{\text{inf}} = T_{\text{inf max}} + 0.25 \cdot \left( 101.3 - p_{\text{atm}} \right) \]

unde:
- \( T_{\text{inf max}} \) este temperatura de inflamabilitate măsurată, în grade Celsius;
- \( p_{\text{atm}} \) este presiunea atmosferică exprimată în kPa.

După recalcularea în acest mod a temperaturii de inflamabilitate, valorile rezultate se vor rotunji cu o precizie de 0.5 °C.

În tabelul 2 sunt prezentate datele rezultate în urma măsurătorilor și datele corectate.

### Table 2

<table>
<thead>
<tr>
<th>Tested fuel</th>
<th>Flash point measured [°C]</th>
<th>Atmospheric pressure [kPa]</th>
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</tr>
</thead>
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<td>56.5</td>
</tr>
<tr>
<td>LDPE fuel</td>
<td>44</td>
<td>97.3</td>
<td>45.5</td>
</tr>
</tbody>
</table>

Experimental determination of cetane number

Experimental determination was made with the help of the stand for the evaluation of cetane number WAUKESHA CFR-F5, according to norms ASTM D613 and ISO 5165, namely the standards for the determination of cetane number of fuels for Diesel engines. Cetane number (CN) determined for the fuel obtained by LDPE pyrolysis is:

CN=66

The diesel engines function well with diesel fuel with CN varying in the range 40 and 55. A higher cetane number means a faster self-ignition that allows the realization of engines with higher speed rate or, which at the same speed rate, offer longer time for burning completion, resulting smaller noxious emissions.

Determinarea experimentală a cifrei cetanice

Determinarea experimentală s-a făcut cu ajutorul standului pentru evaluarea cifrei cetanice WAUKESHA CFR-F5, în conformitate cu normele ASTM D613 și ISO 5165, acestea fiind standardele de determinare a cifrei cetanice din combustibili pentru motoarele Diesel.

Cifra cetanica (CC) determinată a combustibilului obținut prin piroliza din LDPE este:

CC=66

Motoarele diesel funcționează bine cu motorină cu CC cuprinsă între 40 și 55. O cifră cetanică mai mare înseamnă o autoapriindere mai rapidă, ceea ce permite sau realizarea unor motoare cu turații mai mici, sau, la aceeași turație, oferă mai mult timp pentru completarea ardării, rezultând emisiile de noxe mai mici.
Experimental determination of sulphur content

For the determination of sulphur content from the fuel resulted following the pyrolysis process of LDPE it was used the UV-fluorescence (UVF) Antek 9000 Analyzer.

The used method is based on pyrochemiluminescence. In this case, the apparatus measures the content of sulphur in very small quantities in gasoline, diesel fuel, light oils and other light hydrocarbons, including GPL, according to ASTM D-5453, ASTM D-4629 și SR EN ISO 20846-04. The sulphur quantity determined in the analyzed product was:

\[ S = 2 \, [\text{mg/kg}] \text{ sau } 2 \, [\text{ppm}] \]

Experimental determination of Cold Filter Plugging Point

For this determination it was used the apparatus FPP 5Gs, which provides results according to the testing methods EN 116, 309 IP și ASTM D 6371. The value obtained for cold filter plugging point:

\[ \text{CFPP}_{\text{LDPE}} = +4 \, [^\circ \text{C}] \]

Experimental determination of calorific power

For the determination of calorific power of the analyzed fuel it was used the calorimeter with mantle 5Gs, which provides results according to the testing methods 5Gs, which provides results according to the testing methods EN 116, 309 IP și ASTM D 6371. The value obtained for cold filter plugging point:

\[ \text{CFPP}_{\text{LDPE}} = +4 \, [^\circ \text{C}] \]

Experimental determination of calorific power

For the determination of calorific power of the fuel obtained from LDPE the resulted value was obtained:

\[ Q = 45735,35 \, [\text{kJ/kg}] \]

For diesel fuel, the usual value of calorific power is:

\[ Q_{\text{M}} = 44800 \, [\text{kJ/kg}] \]

Table 3 presents the results for the determinations undertaken for the fuel resulted by the pyrolysis of LDPE comparing to some quality specifications of diesel fuel.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Density @ 15 °C</strong> (kg/m3)</td>
<td>820 ÷ 845</td>
</tr>
<tr>
<td><strong>Cetane number, min.</strong></td>
<td>51,0</td>
</tr>
<tr>
<td><strong>Cetane index, min.</strong></td>
<td>46,0</td>
</tr>
<tr>
<td><strong>Cold Filter Plugging Point</strong> (°C)</td>
<td>Classes (summer) A B C</td>
</tr>
<tr>
<td><strong>Flash point (Penksky-Martens), min.</strong></td>
<td>&gt; 55</td>
</tr>
<tr>
<td><strong>Viscosity @ 40 °C</strong> (mm²/s)</td>
<td>2,00 ÷ 4,50</td>
</tr>
<tr>
<td><strong>Copper strip corrosion</strong> (3 h @ 50 °C)</td>
<td>1</td>
</tr>
</tbody>
</table>

**CONCLUSIONS**

The most used method for obtaining liquid fuels from plastic materials waste, and from LDPE is pyrolysis in the absence of oxygen using or not the catalysts.

Following the experiments there were obtained liquid fuels with properties close to the fuels used in internal combustion engines.

The obtained yield of conversion in liquid phase obtained by the reduction and the control of the temperature from the condensation area is superior comparing to the data from scientific literature.

The calculated and corrected density to the relative density of fuel is fitted between the specific density of gasoline and diesel fuel.

**Determinarea experimentală a conținutului de sulf**

Pentru determinarea conținutului de sulf din combustibilul rezultat în urma procesului de piroliză din LDPE s-a folosit analizorul de sulf prin fluorescență UV ANTKE 9000.

Metoda folosită fiind piro-chemiluminescență, aparatul măsoară conținutul de sulf în concentrația foarte mici în: benzina, motorină, uleiuri ușoare și alte hidrocarburi ușoare, inclusiv în GPL, în concordanță cu ASTM D-5453, ASTM D-4629 și SR EN ISO 20846-04. Cantitatea de sulf determinată în produsul analizat a fost:

\[ S = 2 \, [\text{mg/kg}] \text{ sau } 2 \, [\text{ppm}] \]

**Determinarea experimentală a temperaturii limită de filtrabilitate**

Pentru această determinare s-a folosit aparatul FPP 5Gs, care livrează rezultatele în conformitate cu metodele de testare EN 116, 309 IP și ASTM D 6371. Temperatura limită de filtrabilitate obținută pentru combustibilul LDPE a fost:

\[ \text{TLF}_{\text{LDPE}} = +4 \, [^\circ \text{C}] \]

**Determinarea experimentală a puterii calorifice**

La determinarea puterii calorifice a combustibilului analizat s-a folosit calorimetrul cu mantaua menținută la temperatură constantă PARR CALORIMETER 6200. Fiecare determinare pentru determinarea puterii calorifice a combustibilului obținut din LDPE a rezultat valoarea:

\[ Q_{\text{LDPE}} = 45735,35 \, [\text{kJ/kg}] \]

Pentru motorină valoarea uzuală a puterii calorifice este:

\[ Q_{\text{M}} = 44800 \, [\text{kJ/kg}] \]

În tabelul 3 sunt prezentate rezultatele determinărilor efectuate pentru combustibilul rezultat prin piroliza LDPE comparativ cu unele specificații de calitate ale motorinei.

**CONCLUZII**

Metoda cea mai utilizată pentru obţinerea combustibililor lichizi din deşeuri de mase plastice, implicit și din LDPE, este piroliza în absența oxigenului cu utilizarea sau nu a catalizatorilor.

În urma experimentelor s-au obținut combustibili lichizi cu proprietăți apropiate de ale combustibililor utilizați în motoarele cu ardere internă.

Randamentul de conversie în fază lichidă obținut prin reducerea și controlul temperaturii din zona de condensare este superior datelor întâlnite în literatură de specialitate.

Densitatea calculată și corectată la densitatea relativă a combustibilului obținut se încadrează între densitățile specifice benzinei și motorinei.
The calorific power of the new fuel is higher than the one of diesel fuel by 935.35 kJ/kg, due to the presence in the fuels from LDPE of light hydrocarbons specific to gasoline with higher energetic power and to hydrocarbon with carbon number between C_{24} - C_{36} which increase the concentration of carbon that enters the combustion process.

The determinations and measurements undertaken have put into evidence the fact that this fuel obtained in the laboratory can be used in Diesel engines.

The production of the fuels from plastic material waste saves the stocks of fossil fuels and reduces the emissions of carbon in the case of the utilization of those materials to the obtaining of alternative fuels.

ACKNOWLEDGEMENT
This paper was supported by the Post-Doctoral Programme POSDRU/159/1.5/S/137516, project cofunded from European Social Fund through the Human Resources Sectoral Operational Program 2007-2013.

REFERENCES
[6] Popescu G.L. (2012) - Studies and research on the fuels obtaining from waste plastics and polluting emissions determination when is used to fuelled the compression ignition engines PhD dissertation, Technical University of Cluj-Napoca, Romania;

Puterea calorifică a noului combustibil este mai mare decât cea a motorilor cu 935.35 kJ/kg, cauzele cele mai proabile fiind prezenţa în compoziţia combustibilului din LDPE a hidrocarburilor uşoare specifice benzinelor cu valoare energetică mai mare şi a hidrocarburilor cu număr de carbon cuprins între C_{24} - C_{36} care măresc concentraţia carbonului întrat în procesul arderei.

Determinările și măsurările făcute evidențiază faptul că acest combustibil obținut în laborator poate fi utilizat în motoarele Diesel.

Producția combustibililor din deșeuri de masă plastică conservă stocurile de combustibil fosil și reduc emisii de carbon în cazul utilizării acestora la obținerea de combustibili alternativi.

MULTUMIRI
Această lucrare a beneficiat de suport financiar prin programul Post-Doctoral POSDRU/159/1.5/S/137516, proiect cofinanțat din Fondul Social European prin Programul Operațional Sectorial Dezvoltarea Resurselor Umane.

BIBLIOGRAFIE
MECHANICAL PROPERTIES OF ENERGETIC PLANT STEMS - REVIEW

PROPRIETĂȚILE MECANICE ALE TULPINILOR PLANTELOR ENERGETICE - REVIEW

Abstract: An important component of modern society is represented by renewable energy. This type of energy can be obtained through energetic plant processing, wind energy, solar energy, etc. Taking into consideration the potential of energetic plants regarding ensuring a sustainable future from an energetic point of view, this paper presents a review on the way in which mechanical properties influence the processing stage. Considering that the equipment used for this process is in continuing development, knowing the energetic plant stem mechanical properties is a major component in creating and developing these machines. Energetic plant mechanical properties are important data for mathematical modelling of the processes to which the stems are subjected. Studying shearing resistance, compression/stretching resistance, cutting resistance, as well as the elasticity module, we can see that all the data lead to creating an adequate design for the equipment. The main objective of this paper is to create a synthesis regarding energetic plant mechanical properties.

Keywords: mechanical properties, mathematical modelling, energetic plants

INTRODUCTION

Nowadays, fossil fuels as gas, coal, etc. represent the main source of energy in the world. Studies regarding the quantities of these resources and the use by consumers show that in approximately 40-50 years they will considerable diminish, some will even drain. Also, these energy sources produce annually environment degradation through acid rains, global warming, air pollution, etc. Regarding the lowering of this constant degradation, many countries have analysed the possibility of replacing fossil fuels with renewable energy sources that do not have the same negative impact on the environment. [12]

The varied number of energetic plants nowadays imposes to the researchers extensive studies regarding their characteristics within the use for technological processes. Among these characteristics both biological characteristics influenced by culture conditions [13, 28] as well as physical properties that greatly influence processing stages, were identified.

The study of this paper is focused on presenting energetic plant stem mechanical properties and the influence that they have on these processes.

MATERIAL AND METHOD

Outlining physical properties of energetic plant stems was the focus of many researchers, this current paper showing research papers and studies from speciality sites, ASABE, articles published in journals from international data base (ScienceDirect, Springerlink, etc.) or volumes of some national and international conferences which had as an interest this theme, and are presented as bibliographical sources.

Rezumat: O componentă foarte importantă a societății moderne este reprezentată de energia regenerabilă. Acest tip de energie poate fi obținut prin procesarea plantelor energetice, energie eoliană, energie, solară etc. Luând în considerare potențialul plantelor energetice privind asigurarea unui viitor sustenabil din punct de vedere energetic în această lucrare este prezentat un review privind modul în care proprietățile mecanice ale acestora influențează procesul de prelucrare. Având în vedere faptul că echipamentele utilizeate sunt în continuă dezvoltare, cunoașterea proprietăților mecanice ale tulpinilor plantelor energetice este o componentă importantă în crearea și dezvoltarea acestor utilaje. Proprietățile mecanice ale plantelor energetice constituie date importante în modelarea matematică a proceselor la care sunt supuse tulpinele. Studiind rezistența la forfecare, rezistența la compresiune/întindere, rezistența la tăiere, rezistența la încovoare, rezistența la mărunțire precum și modulul de elasticitate, se constată că toate datele acumulate conduc la crearea unui design adecvat al echipamentelor. Obiectivul principal al acestei lucrări este aceea de a alcătui o sinteză cu privire la proprietățile mecanice ale plantelor energetice.

Cuvinte cheie: proprietăți mecanice, modelare matematică, plante energetice

INTRODUCERE

În prezent, combustibili fosili precum gazele, carbunii etc. reprezintă principală sursa de energie din lume. Studii privind cantitatea acestor resurse și utilizarea lor de către consumatori prezintă faptul că în aproximativ 40 - 50 de ani se vor diminua considerabil, unele chiar vor seca. Totodată, aceste surse de energie utilizate în prezent produc anual degradarea mediului înconjurător prin provocarea de ploi acide, încazire globală, poluarea aeriului etc. În vederea diminuirii acestei degradări constante din ce în ce mai multe țări au analizat posibilitatea de a înlocui combustibilii fosili cu surse de energie regenerabilă care nu au același impact asupra mediului [12].

Numărul variat al plantelor energetice din zilele noastre impune cercetătorilor un studiu amănunțit asupra caracteristicilor acestora pentru utilizarea lor în cadrul diferitelor procese tehnologice. Între aceste caracteristici se identifică atât caracteristicile biologice influențate de condițiile de cultură [13, 28], cât și proprietățile fizice care influențează în mare parte procesele de prelucrare.

Studiul acestei lucrări se concentră pe prezentarea proprietăților mecanice ale tulpinilor plantelor energetice și influența pe care aceastea o are asupra acestor procese.

MATERIALE ŞI METODĂ

Evidențierea proprietăților mecanice ale tulpinilor plantelor energetice a fost studiată de numeroși cercetători, în lucrarea de față fiind prezentate lucrări de cercetare și studii preluate de pe site-uri de specialitate, ASABE, articole publicate în jurnale din baza de date internaționale (ScienceDirect, Springerlink, etc.) sau volume ale unor conferințe naționale si internaționale care au avut ca interes aceasta tematică și utilizate ca surse bibliografice.
RESULTS AND DISCUSSIONS
According to scientific papers [1...28], the processing state of energetic plants and its optimisation can be realised through establishing the mechanical properties of plants used to yield biogas.

Determining mechanical properties of energetic plants is a part of a complex process, mainly because of the composite structure of plants being different from one plant to another [3].

Generally the most used procedure in determining mechanical properties is performed in lab conditions where each component can be analysed individually. Data taken during lab trials can be used as input data inside mathematical models used to determine parameters that affect energy consumption during the processing stage [4]. An example in this purpose can be given by the difference between the energy associated to the obtained product after breaking and the energy associated to the raw material, which is equal with the consumed energy for the breaking process.

The theory of free mincing can be expressed through the relation:

\[ E_p - E_m = \eta \cdot E_c \]  

Where
- \( E_p \) – mincing energy;
- \( E_m \) – raw material energy;
- \( E_c \) – consumed energy by the breaking equipment;
- \( \eta \) - equipment energetic efficiency.

RESULTEȘTE ȘI DISCUTII
Conform lucrărilor științifice [1...28], procesul de prăjire a plantelor energetic precum și optimizarea acestuia pot fi realizate prin stabilirea proprietăților mecanice ale plantelor utilizate în vederea obținerii de biogaz.

Determinarea proprietăților mecanice ale plantelor energetic face parte dintr-un proces complex, mai ales datorită faptului ca structura compozită a plantelor este diferită de o plantă la alta [3].

În general cea mai utilizată procedură de determinare a proprietăților mecanice se realizează în condiții de laborator unde fiecare componentă poate fi analizată individual. Datele preluate din cadrul încercărilor de laborator pot fi utilizate ca date de intrare în cadrul modelelor matematice folosite pentru a determina parametrii care afectează consumul de energie în timpul procesului de prăjire [4]. Un exemplu în acest sens poate fi dat de diferența dintre energia asociată produsului obținut după mărunțire și energia asociată materiei prime, care este egală cu energia consumată pentru procesul de mărunțire. Teoria liberei mărunțiri se poate transpune în relația:

\[ E_p - E_m = \eta \cdot E_c \]  

unde:
- \( E_p \) - energia produsului de mărunțire;
- \( E_m \) - energia materiei prime;
- \( E_c \) – energia consumată de utilajul de mărunțire;
- \( \eta \) - randamentul energetic al utilajului.

Different biomass types mechanical and physical properties

<table>
<thead>
<tr>
<th>Nr. crt.</th>
<th>Plant type</th>
<th>Moisture content, [%wb]</th>
<th>Bulk density, [kg/m³]</th>
<th>True density [kg/m³]</th>
<th>Specific energy, [kN/m]</th>
<th>Ash content, [%]</th>
<th>Paper no.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Wheat straw</td>
<td>8.30</td>
<td>108</td>
<td>1210</td>
<td>15</td>
<td>8.32</td>
<td>[25]</td>
</tr>
<tr>
<td>2</td>
<td>Switchgrass</td>
<td>8</td>
<td>151</td>
<td>1090</td>
<td>86.5</td>
<td>5.49</td>
<td>[26, 27]</td>
</tr>
<tr>
<td>3</td>
<td>Corn stover</td>
<td>11 - 15</td>
<td>148</td>
<td>1280</td>
<td>31.5</td>
<td>7.46</td>
<td>[26, 27]</td>
</tr>
<tr>
<td>4</td>
<td>Barley straw</td>
<td>6.98</td>
<td>98</td>
<td>1100</td>
<td>53k Wh/t</td>
<td>10.72</td>
<td>[25]</td>
</tr>
<tr>
<td>5</td>
<td>Miscanthus</td>
<td>8.5</td>
<td>1170</td>
<td>1080</td>
<td>4.4 kW</td>
<td>2.3</td>
<td>[7]</td>
</tr>
</tbody>
</table>

Resistance at shearing and bending
During outlining plant behavior at different processes in the paper [14], the authors had studied shearing and bending resistance for saffron stems as well as their elasticity module.

Thus, considering the fact that the cutting/grinding process is made out of processes like compression, shearing, bending, stretching and friction [15, 23] the authors have tested saffron stems at different values of humidity content. For determining the shearing resistance the equation was:

\[ \tau_s = \frac{F_s}{2A} \]  

Where:
- \( \tau_s \) – shearing resistance;
- \( F_s \) – shearing force during disposal (N);
- \( A \) – Area of the stem surface subjected to shearing (mm²).

Also, using the same equipment stems have been subjected to bending tests by placing them on a metallic support, than applying force in the center at a load rate of 1mm/min (similar to the shearing test). Calculus formula for bending resistance was:

\[ E_p - E_m = \eta \cdot E_c \]  

Rezistența la forfecare și încovoare
În vederea evidențierii comportamentului plantelor în timpul diferitelor procese în lucrarea [14] autori au studiat rezistența la forfecare și încovoare a tulpinilor de șofran precum și modulul de elasticitate al acestora. Astfel, considerând faptul că procesul de tăiere/tocare este format din procese precum compresiune, forfecare, încovoire, întindere și frecare [15, 23] autori au testat tulpinile de șofran la valori diferite ale conținutului de umiditate. Pentru determinarea rezistenței de forfecare ecuația utilizată a fost:

\[ \tau_s = \frac{F_s}{2A} \]  

unde:
- \( \tau_s \) - rezistența la forfecare;
- \( F_s \) – forța de forfecare în momentul cedării (N);
- \( A \) – aria suprafeței tulpinii supuse forfecării (mm²).

Totodată, folosind aceeași echipament tulpinile au fost supuse testelor de încovoire prin plasarea lor pe un suport metallic, apoi aplicându-se forța în centru probelor la o rată de încărcare de 10 mm/min (similară testului de forfecare). Formula de calcul pentru rezistența la încovoire a fost:
$$\tau_b = \frac{F_b \cdot y \cdot l}{4 \cdot l}$$  (3)

where:

- $\tau_b$ – bending resistance (MPa);
- $F_b$ – bending force (N);
- $y$ – distance from the neutral axis to the most distant point (mm);
- $l$ – distance between the two supports used during experimentation (50mm);

Using statistical data analysis ANOVA the conclusions referring to shearing resistance values have outlined a rise together with a rise in humidity from 4 to 8.46 MPa, results which were also confirmed in the paper [1, 2, 17], when the bending resistance dropped along with a rise in stem humidity content.

The average values of the bending stress, Young’s modulus, shear stress, and shear energy varied from 50.59 to 26.91 MPa, 2.52 to 1.22 GPa, 4.00 to 4.00 MPa, and 231.45 to 730.02 mJ, respectively, as the moisture content increased from 8.61 to 37.16%.

Also a study about shearing resistance is presented in paper [24], where the authors have used as raw material rice stems. Their conclusions showed a rise in shearing resistance together with a rise in stem humidity content.

This effect of stem height on shearing energy was also reported by [2] for alfalfa stem and [18] for barley stem.

Similarly to papers presented earlier, in [21], the authors have subjected Miscanthus Giganteus to shearing tests. These tests had as a basis subjecting stem samples at repeated shearing stresses after which rupture point, bioflow point and the proportionality limit (characteristic of stem elasticity on a transversal section) were determined, from the force-deformation curve. Samples were put on the support frame so that the applied force on the shearing frame will be at the half of the sample. During application the shearing frame goes through an orifice until the moment of rupture point detection. During tests the Hounsfield mechanical trail apparatus was accessorised with metallic shearing plates of 100x70x3 dimensions (fig.1), and the shearing angle (plate opening) was different, of 30, 50, 60 and 75°.

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Cutting resistance and cutting energy

Also, in the paper [19] the authors analysed the cutting resistance of sugarcane stems. During testing the plants were dried in natural conditions, at 25 degrees and 55% humidity. Testing the plants at different values of the humidity content, stems have been brought at wanted values through saturation or drying. Cutting blade of the Instron Universal Testing Machine had an inclination angle of 30° and the angle of cutting blade of 60°. In accordance with the humidity content and area of cutting section, the cutting resistance and cutting energy of sugarcane stems were determined. Conclusions of these tests showed an optimum cutting resistance when the humidity content was between 50-75%.

Using a similar knife, V shaped, in [20] Miscanthus stems cutting resistance was determined.

Cutting blades (shearing) had an opening angle of 30°, and different sharpening angles (i=10, 20, 30, 40, 50°). It was observed that the cutting force drops from the base to the top of the plant, together with a drop in average stem diameter, curve of cutting variation presenting a decreasing exponential variation.

Similarly, using a cutting blade with a 50° opening angle in [10] the authors realized experimental researches regarding miscanthus plant cutting resistance. Conclusions of the tests have showed a drop in cutting force values until the angle of 30-40°, after which the force rises for cutting angles of over 40°.

In paper [5] the authors have determined a cutting resistance of reed stalks using 6 knives with different blade inclination angles.

Lamele de tăiere (forfecoare) au avut un unghi de deschidere de 30°, si unghii de ascutire diferite (i=10, 20, 30, 40 50°). S-a constatat că forţa de tăiere scade de la bază spre vârful plantei, odată cu scăderea diametrului mediu al tulpinii, curba de variaţie a forţei de tăiere prezintând o variaţie exponenţială descrescătoare.

Similar folosind o lamă de tăiere cu un unghi de deschidere de 50° în [10] autori au realizat cercetări experimentale privind rezistenţa la tăiere a plantelor de miscanthus. Concluziile testelor au evidenţiat o scădere a valorilor forţei de tăiere a plantelor de miscanthus până la un unghi de 30 – 40°, după care forţa creşte pentru unghii de ascutire de peste 40°.


Fig. 2 - Miscanthus stem cutting V shaped blade [20]

Fig. 3 – Knives with different blade cutting angles [5]
Conclusions refer to the fact that the consumed energy values during the moment of cutting operation have not presented large variations for different cutting blades [5]. Similarly, in [6] the authors used hemp stems for testing. Cutting resistance presented values between 11.8 and 19.4 N/mm². Also, the lowest energy value consumed was for the blade angles of 25 and 45°. For all knives used during experimental testing the maximum cutting force dropped with 40% for knives inclined from 0 to 20°.

Other studies determined that the cutting speed and the blade configuration play a critical role in crops harvesting process. Maughan J.D. et al. (2014), [9] investigated the effects of cutting speed, blades bevel angle and fixation on the power consumption during Miscanthus harvesting. Authors used a rotary platform with only one cutting end, driven by a hydraulic motor with measuring instruments of stalk bending force and cutting speed. The results indicated that the cutting speed and the blades angle directly influence the power and efficiency of the Miscanthus harvesting machines. Instead it was determined that the way to fix the blade was insignificant.

Compression resistance

Another property of energetic plants analysed by researchers is plant compression resistance. Thus, in paper [11] Miscanthus plant stems were subjected to tests. The Hounsfield apparatus was fitted with an adaptor connected to a loading cell. Data resulted have showed the influence of stem diameter on tests, namely the bigger the diameter of the stem the larger the necessary compression force.

Concluziile evidențiate fac referire la faptul că valorile energiei consumate în momentul operației de tăiere nu a prezentat variații mari pentru diferite lame de tăiere [5].

Similar în [6] authorii au supus testelor de tăiere tulpi din cânepă. Rezistența la tăiere a prezentat valori cuprinse între 11.8 și 19.4 N/mm². De asemenea, cel mai scăzut consum de energie s-a constatat a fi pentru lamele cu unghi de tăiere de 25 și 45°. Pentru toate cutiile folosite în timpul testelor experimentale forța maximă de tăiere a scăzut cu aproximativ 40% pentru cutiile cu lame de tăiere inclinate de la 0 la 20°.


Rezistența la compresiune


Other studies [22] showed the miscanthus plant behavior subjected to compression tests through compression stress determinations and Young module. Knowing the loading feed and the contact surface for each loading feed (2 rectangular surfaces, superior and inferior, equal at the sample contact with the apparatus mass and with the pressure plate were considered), the compression stress was determined. Through regression analysis the 2 parameters were determined. Test conclusions as for deformation until crushing at transversal compression stresses are necessary for static loads larger than 2.5 daN.

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During the process of transversal compression process the plant deforms, and this deformation keeps a certain value after removing the load pressure. So as a
result, the miscanthus plant stem has a plastic-elastic behavior during the process of compression which assumes an energy quantity accumulated in the plant without being transformed in smaller parts, thus without being crushed until rupture, this behavior being showed in [16].

In [8], there were used different compaction speeds for the oak sawdust in the limits of 0.24–5.0 MPa/s. It was concluded that the density of compacted dry material measured at 2 min after compression decreases with the increasing compaction rate up to 3 MPa/s, above this value the compression speed not being detected any significant influences regarding the density of the compacted material.

CONCLUSIONS

It is necessary to know the mechanical properties of energetic plant due to the influence that it has on the processing stage.

In this purpose, the fact that initial properties are necessary for realizing high performance equipment and with a low energy cost is also mentioned in previous papers. Also, knowing mechanical properties of different types of energetic plants contributes to the design of the machines. Tension and cutting resistance values, compression, shearing, bending differ according to the humidity content of the plants, considerably influencing equipment rotor, the action angle of the shearing/cutting blades, feed flow, applied forces, etc.

It must be mentioned that the physical properties of energetic plants influence the technological process.

ACKNOWLEDGEMENT

The work has been funded by the Sectoral Operational Programme Human Resources Development 2007-2013 of the Ministry of European Funds through the Financial Agreement POSDRU/159/1.5/S/132395 and with the support of the University “Politehnica” from Bucharest.

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Rezultat asadar ca tulpinile plantei de miscanthus au o comportarea elasto-plastica în timpul procesului de comprimare ceea ce presupune o cantitate de energie acumulata in planta fara ca acesta sa fie transformata in particule mai mici, deci fara a fi strivita pana la rupere, acest comportament elasto-plastic fiind evidențiat și în [16].

În [8], s-au folosit diferite viteză de compactare pentru rumegusul de stejar în limitele 0.24–5.0 MPa/s. A fost concluzionat faptul că densitatea materialului uscat compactat masurat la 2 min după compresie a scăzut odata cu creșterea ratei de compactare de pana la 3MPa/s, peste aceasta valoare nu s-au mai detectat alte influente semnificative legate de densitatea materialului compactat.

CONCLUZII

Este necesar a cunoaște proprietățile mecanice ale plantelor energetic datorită influenței pe care acestea o exercită asupra proceselor de prelucrare.

În aceste sens, este menționat și în lucrările prezentate anterior faptul că proprietățile inițiale ale plantelor sunt necesare pentru realizarea unor echipamente performante și cu un consum redus de energie. Totodată, cunoașterea proprietățile mecanice ale diferitelor tipuri de plante energetic contribuie la designul mașinilor. Valorile tensiunilor și rezistențelor la tăiere, comprimare, forfecare, încovoiere diferă în funcție de conținutul de umiditate al plantelor, influențând considerabil turația rotorului echipamentului, unghiul de acțiune al lamelor de tăiere/forfecare, feed flow, forțele aplicate etc.

Trebuie menționat faptul că și proprietățile fizice ale plantelor energetic influențează procesul tehnologic.

MULTUMIRI

Rezultatele prezentate în acest articol au fost obținute cu sprijinul Ministerului Fondurilor Europene prin Programul Operatiional Sectorial Dezvoltarea Resurselor Umane 2007-2013, Contract nr. POSDRU/159/1.5/S/132395 si al Universității Politehnica în București.

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MATHEMATICAL MODEL BASED ON WARNER – BRATZLER ANALYSIS METHOD CONCERNING TENDERIZED PORK BONELESS LOIN IN ORDER TO PRODUCE ROMANIAN TRADITIONAL PRODUCT “COTLET PERPELIT” TYPE

MODEL MATHEMATICAL BASED ON METHOD TO ANALYZE WARNER – BRATZLER PRIVIND FRĂGEZIREA COTLETULUI DE PORC ÎN VEDEREA PRODUCERII PRODUSULUI TRADITIONAL ROMÂNESC DE TIP “COTLET PERPELIT”

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Abstract: The paper presents a mathematical model to produce Romanian traditional cured-cooked-smoked pork boneless loin product “Cotlet Perpelit” type made after raw meat’s mechanical tenderizing. The tenderizing process performed to decrease the duration of cured marinating period consists in passing several times the raw meat among rollers with cutting prongs, and cyclic impulsive pressing of the meat, respectively. The mathematical model is based on force - extension diagrams obtained by using Werner-Bratzler testing method both for raw meat and final product, too, for no tenderized raw meat, and after raw meat mechanical tenderizing. The mathematical model consists in the geometric linear transforming of the characteristic diagrams obtained by using Werner-Bratzler method for the tenderized meat in comparison with the initial no tenderized meat. The model can be used to predict the mechanical characteristics of “Cotlet Perpelit”, after raw meat mechanical tenderizing.

Keywords: raw meat tenderizing, Cotlet Perpelit, Warner-Bratzler testing method, mathematical model, linear geometric transformation

INTRODUCTION

In principle, meat’s tenderization represents the resultant of dynamic interdisciplinary processes consisting in chemical, biochemical and mechanical phenomena, [8]. To estimate tenderizing machine’s and process’ performances, it is necessary to determine tenderized meat’s mechanical characteristics, which could describe the meat qualitative transformations, [1, 18]. Thus, a mathematical model, expressed by a unified system of relationships and variables, could be used to analyze meat’s mechanical tenderizing, [1]. For example, Graiver proposed a mathematical model for the absorption of curing salts in pork’s meat, [2].

According to previous research papers, the variables parameters of the mathematical model have to be based on experimental research data of meat diagrams determined by using Warner-Bratzler testing method, [9, 10, 11, and 12].

According to Iacob [3], taking into account only the mechanical phenomena, a dynamic system involves different transformations of its internal parts under the action of given external forces. The mathematical models of the meat tenderizing process could be studied in further theoretical researches by applying the automatic systems theory, [4].

SC AVI-GIIS SRL, Stuparei is a small enterprise for meat products in Valcea County, which was initially specialized in commercial cured-raw meats and cured - smoked products. In the last years SC AVI-GIIS SRL focused its effort to produce Romanian traditional cured-cooked-smoked pork boneless loin product “Cotlet Perpelit” type. In principle, the processing technology of this traditional cured-smoked-cooked product type consists in: wet curing phase of entire pieces of muscle meat in 15-20% curing


Cuvinte cheie: frăgezirea cărnii, Cotlet Perpelit, metode de testare Warner-Bratzler, model matematic, transformarea geometrică liniară

INTRODUCERE

În principiu, frăgezirea cărnii reprezintă rezultanta unor procese dinamice interdisciplinare care constă în fenomene chimice, biochimice și mecanice, [8]. Evaluarea performanțelor mașinilor și proceselor de frăgezire este posibilă prin determinarea caracteristicilor mecanice ale cărnii după operația de frăgezire, care pot descrie transformările calitative ale cărnii, [1, 18]. Deci un model matematic reprezentat printr-un sistem unificat de relații și variabile, ar putea fi utilizat pentru analiza frăgezii mecanice a cărnii, [1]. Spre exemplu, Graiver a propus un model matematic al absorbției de saramură în carnea de porc, [2].

Conform unor lucrări de cercetare anterioare, parametrii variabilii ai modelului matematic trebuie să aibă la bază rezultate experimentale determinate prin testarea cărnii prin metoda Warner-Bratzler, [9, 10, 11, 12].

Conform Iacob [3], avind în vedere numai fenomenele mecanice, un sistem dinamic presupune diferite transformări interne sub acțiunea unor forțe exterioare cunoscute. Modelul matematic pentru frăgezirea mecanică a cărnii ar putea fi studiat în viitoare cercetări teoretice prin aplicarea teoriei de control a sistemelor automate, [4].

SC AVI-GIIS SRL, Stuparei din județul Valcea este o firmă mică specializată inițial pentru realizarea de produs din carne sărată, respectiv sârat - afumată. În ultimii ani, firma și-a concentrat eforturile pentru producerea sortimentului sărat - prăjit - afumat din cotlet de porc dezosat, tip "Cotlet Perpelit". În principiu, procesul tehnologic al acestui produs tradițional constă în: saramurarea uomedă (12-15% concentrație) a bucăților de
In order to determine the influence of tenderizing process on pork boneless loin used to produce traditional cured-smoked-cooked product “Cotlet Perpelit”, 6 samples (raw meat, and “Cotlet Perpelit” final product) were processed.

cotlet deozosat timp de 2-3 săptămâni; zvântarea in aer rece ventilat timp de 6-8 ore; afumarea rece (aprox. 20°C) timp de 2-3 zile, urmată de afumarea caldă (aprox. 20°C) timp de 4-6 ore, [12].

In conformitate cu legislația internațională și din România, la producerea produselor tradiționale este interzisă utilizarea nitrilor, nitratațiilor (NaNO₂; NaNO₃, KNO₃), precum și saramurarea prin injectare, [5, 6, 7, 13].

În vederea reducerii duratei de saramurare umedă, firma SC AVI-GIIS SRL a realizat și testat a două tipuri de mașini de frăgezire mecanică: mașina de frăgezire cu două perechi de cilindri profilăți pentru perforare, respectiv mașina de frăgezire prin pressare ciclică dinamică, [12, 13].

MATERIALE ŞI METODĂ
Metodă și echipament experimental

În vederea determinării influenței metodei de frăgezire mecanică asupra materiei prime (cotlet de porc dezosat), au fost utilizate două tipuri de mașini: mașina de frăgezire cu două perechi de cilindri profilăți pentru perforare, respectiv mașina de frăgezire prin pressare ciclică dinamică.

Mașina de frăgezire cu două perechi de cilindri profilăți pentru perforare este concepută pentru creșterea suprafeței de extragere a proteinelor din carne, în timpul unor procese succive de compresiune și perforare. În timpul acestei operații, carnea trece prin două perechi de valtură rotative cu dinți profilăți care realizează perforații de anumită adâncime în bucata de carne. În principiu, mașina constă din două perechi de valturi paralele (prevăzute cu dinți de perforare), dispuse la o anumită distanță, care se rotesc în direcții opuse prin intermediul unei transmisii electromecanice (fig. 1), [12, 13].

Mașina de frăgezire prin pressare ciclică dinamică este o mașină pentru presarea discontinuu a carmii înainte de saramurare. Dacă bucată de carne este presată cu o anumită forță, aceasta se va frăgezi, iar saramura va fi absorbită de teșuturile cărmii fără să mai fie necesară vacumarea, [15, 16, 17, 19].

Această mașină este compusă dintr-un echipament mecano-pneumatic, și un automat programabil.

În principiu (fig. 2), echipamentul mecano-pneumatic este compus dintr-un sistem electropneumatic (compresor, electroventile, cilindru pneumatic), și două plăci de presare (inferioară / fixă, respectiv superioară / mobili). Pentru îmbunătățirea procesului de frăgezire, fiecare din cele două plăci (cu plăci food grade Teflon) sunt prevăzute cu dinți piramidali (6 · 6 · 6 mm), [12, 13].

**Fig. 1** - Four roller tenderizer machine (with pyramidal cutting prongs)

**Fig. 2** - Cyclic impulsive pressing machine (food grade Teflon pads with pyramidal prongs)
according to four methods:
- no tenderized pork boneless loin (NO TEND);
- pork boneless loin tenderized by six times successive passing amongst the cutting prongs of the Four roller tenderizer machine (FRT 6x);
- pork boneless loin tenderized by Cyclic impulsive pressing machine in 5 pressing cycles, each consisting in 0.5s pressing periods, and 0.5s pauses periods (CIP 5-0.5);
- pork boneless loin tenderized by Cyclic impulsive pressing machine in 20 pressing cycles, each consisting in 0.5s pressing periods, and 0.5s pauses periods (CIP 20-0.5).

To produce “Cotlet Perpelit” by using no-tenderized pork boneless loin, there were followed certain traditional phases: wet curing phase of entire pieces of muscle meat (12% curing salt concentration), during 2 weeks; drying / ripening phase in cold air ventilation for 6 hours; cold smoke (approx. 20°C) for 10 hours, followed by 4 hours hot smoke (approx. 80°C).

To produce “Cotlet Perpelit” by using tenderized pork boneless loin, the tenderized meat was processed in following phases: wet curing (12% curing salt concentration), during 4 days; drying / ripening phase in cold air ventilation for 6 hours; cold smoke (approx. 20°C) for 10 hours, followed by 4 hours hot smoke (approx. 80°C), [12].

Tenderness evaluation by using Warner-Bratzler method
The most relevant and utilized methods to estimate meat’s tenderness are compression test, and Warner - Bratzler shear test method. During Warner-Bratzler test the shear blade achieves simultaneously both compression and slicing / shearing of the product, [5, 7, 14, 15, 16, 17]. To perform interdisciplinary researches concerning general texture and tenderness analysis, universal testing machine Lloyd Instruments LRX Plus 5 (Unconventional Technologies and Equipment for Agro-Food Industry Laboratory - UTEFIL, within Faculty of Agriculture and Horticulture in Craiova) was used. Due to collaboration between UTEFIL and Environmental Eng. Laboratory within Faculty of Electrical Engineering, a Warner - Bratzler experimental equipment was made: special rigid frame (food-grade Teflon) that permits fast fitting of inter-changeable Warner - Bratzler shear blades (DIN W1.4571), [9, 10, 11]. During these experiments, 100mm/min cutting speed was used.

Representative Warner - Bratzler test diagrams for pork boneless loin tenderized by using FRT 6x method, and for “Cotlet Perpelit” obtained by using this tenderized meat, are presented in fig. 3, and fig. 4, respectively.

Evaluating the frægezimii prin metoda Warner-Bratzler

Diagrame Warner - Bratzler reprezentative pentru cotlet de porc dezosat frægezit prin metoda FRT 6x, și pentru “Cotlet ‘ul Perpelit” obținut din această carne frægezată, sunt prezentate în fig. 3 și respectiv în fig. 4.
RESULTS
Tenderizing mathematical model

The mathematical model for studying the tenderizing effect is based on the hypothesis that any meat’s final product material can be characterized by numerical curves obtained by mechanical characteristics experimentally determined for each tenderizing method. Resulting numerical curves could differ more or less from those of no tenderized meat samples.

In fig. 3 and fig. 4 it can be observed the maximum shear force that characterizes each type of pork boneless loin, and “Cotlet Perpelit” tenderness.

Due to the inhomogeneous character of the meat’s tissues, the maximum shear force cannot describe all the cutting / shearing process.

Therefore for each un-tenderized / tenderized pork boneless loin sample, and for each “Cotlet Perpelit” obtained by using these meat pieces, too, average curves that describe all evolution of the shearing diagrams obtained by using Warner - Bratzler method were numerical determined (fig. 5 and fig. 6).

REZULTATE
Model matematic pentru frăgezire

Modelul matematic pentru studiul efectului frăgezirii are la bază ipoteza că materialul oricărui produs din carne poate fi caracterizat prin curbe numerice obținute din diagramele caracteristicilor mecanice determinate experimental pentru fiecare tip de metodă de frăgezire. Curbele numerice rezultate pot să difere mai mult sau mai puțin de cele obținute pentru probele nefrăgezite.

În fig. 3 și fig. 4 se pot observa valori maxime ale forței de tăiere care caracterizează frăgezimea fiecărui tip de cotet de porc dezosat, și de “Cotlet Perpelit”.

Datorită caracterului neomogen al ţesuturilor cărnii, valoarea forței maxime de tăiere nu poate descrie întregul proces de tăiere.

De aceea, pentru fiecare probă nefrăgezită / frăgezită de cotet de porc dezosat, și pentru fiecare probă de “Cotlet Perpelit” obținut din aceste bucăți de carne, au fost determinate numeric curbele medii care descriu toată evoluția diagramei forței de tăiere obținută experimental prin metoda Warner - Bratzler (fig. 5 și fig. 6).

The proposed mathematical model is based on the hypothesis that the characteristic curve of the sample (no tenderized, or tenderized by using mechanical methods), is obtained as a linear transformation that can be described by the vector equation, \[ [1, 3, 8] \]:

\[
\begin{bmatrix}
\text{Load, N} \\
\text{extension, mm}
\end{bmatrix} = \begin{bmatrix}
F \\
x
\end{bmatrix}
\]

where: \( F \) is the shear force in N, \( x \) is the cutting length /extension in mm, before tenderizing (characteristic curve

Modelul matematic propus se bazează pe ipoteza conform căreia curba caracteristică a fiecărei probe (nfrăgezită, sau frăgezită prin metode mecanice), este obținută ca o transformare liniară care poate fi descrisă de ecuația vectorială, \([1, 3, 8]\):

\[
\begin{bmatrix}
\text{Load, N} \\
\text{extension, mm}
\end{bmatrix} = \begin{bmatrix}
F \\
x
\end{bmatrix}
\]

unde: \( F \) este forța de tăiere în N, \( x \) este cursa de tăiere / extensia în mm, înainte de frăgezire (coordonatele curbei
coordinates of the meat sample, before tenderizing); $F'$ and $x'$ represent the shear force and the cutting length / extension of the same meat sample type (characteristic curve coordinates, after tenderizing). $T$ is the linear transformation given by the matrix:

$$T = \begin{pmatrix} t_{1,1} & t_{1,2} \\ t_{2,1} & t_{2,2} \end{pmatrix}$$  \hspace{1cm} (2)

where $t_{ij}, i=1,2; j=1,2$ are real numbers.

It must be noticed that each force $F$ is represented by a pair of coordinates $(x, F)$, $i=1, N$, and each force $F'$ is represented by a pair of coordinates $(x', F')$, $i=1, N$. The matrix elements $T$ are calculated considering minimizing condition of the functional:

$$\mathcal{A}(t_{1,1}, t_{1,2}, t_{2,1}, t_{2,2}) = \sum_{i=1}^{N} \left[ (t_{1,1}x_i + t_{1,2}F_i - x_j)^2 + (t_{2,1}x_i + t_{2,2}F_i - F'_i)^2 \right]$$  \hspace{1cm} (3)

Based on described linear transformation, for pork boneless loin tenderizer by using each method, the matrix $T$ elements are:

- pork boneless loin tenderized by *Cyclic impulsive pressing machine* in 5 pressing cycles, each consisting in 0.5s pressing periods, and 0.5s pauses periods, (CIP 5-0.5).

$$T = \begin{pmatrix} 0.998 & 0.000007079 \\ -0.048 & 0.986 \end{pmatrix}$$  \hspace{1cm} (4)

- pork boneless loin tenderized by *Cyclic impulsive pressing machine* in 20 pressing cycles, each consisting in 0.5s pressing periods, and 0.5s pauses periods, (CIP 20-0.5).

$$T = \begin{pmatrix} 0.998 & 0.000003448 \\ 0.18 & 0.935 \end{pmatrix}$$  \hspace{1cm} (5)

- pork boneless loin tenderized by passing 6 successive times amongst the cutting prongs of the *Four roller tenderizer machine*, (FRT 6x).

$$T = \begin{pmatrix} 0.989 & 0.00004522 \\ -0.326 & 0.773 \end{pmatrix}$$  \hspace{1cm} (6)

The numerical tenderizing curves for pork boneless loin obtained by using the mathematical model are presented in fig. 7, fig. 8 and fig. 9, respectively.

In fig. 7, fig. 8 and fig. 9, respectively, it can be observed that the configurations and the maximum amounts of the numerical tenderizing curves are similar with the average curves experimentally determined (fig. 5). All these similarities validate the mathematical model based on proposed linear transformation.

![Graph](image)

**Fig. 7** - Numerical tenderizing CIP 5-0.5 curves obtained by using the mathematical model
Based on described linear transformation, for "Cotlet Perpelit" tenderized by using each method, the matrix $T$ elements are:

- "Cotlet Perpelit" tenderized by using Cyclic impulsive pressing machine in 5 pressing cycles, each consisting in 0.5s pressing periods, and 0.5s pauses periods, (CP - CIP 5 – 0.5);

$$
T = \begin{pmatrix}
1.002 & -0.0002219 \\
-0.048 & 0.689
\end{pmatrix}
$$

(7)

- "Cotlet Perpelit" tenderized by using Cyclic impulsive pressing machine in 20 pressing cycles, each consisting in 0.5s pressing periods, and 0.5s pauses periods, (CP - CIP 20 – 0.5);

$$
T = \begin{pmatrix}
0.999 & -0.0005576 \\
0.331 & 0.534
\end{pmatrix}
$$

(8)

- "Cotlet Perpelit" tenderized by passing 6 successive times amongst the cutting prongs of the Four roller tenderizer machine (CP - FRT 6x).

$$
T = \begin{pmatrix}
1.001 & -0.0005576 \\
0.696 & 0.478
\end{pmatrix}
$$

(9)

The numerical tenderizing curves for "Cotlet Perpelit" obtained by using the mathematical model are presented in fig. 10, fig. 11 and fig. 12, respectively.

In fig. 10, fig. 11 and fig. 12, respectively, it can be observed that the configurations and the maximum amounts of the numerical tenderizing curves are similar with the average curves experimentally determined (fig. 6).

All these similarities validate the correctness of mathematical model based on proposed linear transformation.

The numerical tenderizing curves for "Cotlet Perpelit" obtained by using the mathematical model are presented in fig. 10, fig. 11 and fig. 12, respectively.

In fig. 10, fig. 11 and fig. 12, respectively, it can be observed that the configurations and the maximum amounts of the numerical tenderizing curves are similar with the average curves experimentally determined (fig. 6).

All these similarities validate the correctness of mathematical model based on proposed linear transformation.
CONCLUSIONS

Considering physically issues, mechanical tenderizing is a process that has to reduce the meat’s mechanical characteristics amounts of the final product. Each tenderizing method produces significant changes of specific strain within the meat’s tissues, which determines the tenderness’ improvement.

The main conclusion drawn in this paper refers to the correctness of the mathematical model based on proposed linear transformation, proved both by the curves’ configurations and the maximum amounts similarities’ between the numerical tenderizing curves, too, and the average curves experimentally determined, respectively.

Further general and specific conclusions could be draw after this mathematical model will be applied for other types of meat, before and after other mechanical tenderizing methods.

The data presented in this paper can be important for all the specialists interested in decreasing the wet currying period of the traditional meat products.

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[17] www.lloyd-instruments.co.uk (2013);
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 Solidsus 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.

RESULTS should be presented with clarity and precision. The results should be written in the past tense when describing findings in the authors' experiments. Results should be explained, but largely without referring to the literature. Discussion, speculation and detailed interpretation of data should not be included in the Results but should be put into the Conclusions section. Subheadings should be used.

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.

Acknowledgments of people, grants, funds, etc. should be brief (if necessarily).

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 (/).

Figure legends should be typed in numerical order. Graphics should be prepared using applications capable of

INTRODUCEREA trebuie să ofere o expunere clară a problemei, esenţa relevantă a subiectului şi abordarea propusă sau soluţia. Aceasta trebuie să poată fi înţelesă de către colegi din diferite domenii știinţifice.


REZULTATELE trebuie prezentate cu claritate şi precizie. Acestea trebuie scrise la timpul trecut, atunci când descriu constatărilor în experimentele autorilor. Rezultatele trebuie să fie explicite, dar în mare măsură, fără a se face referire la literatura de specialitate. Discuţiile, speculaţiile şi interpretarea detaliată a datelor nu trebuie să fie incluse în rezultate, ci trebuie încluse în capitolul Concluzii. Subcapitolele trebuie utilizate.

CONCLUZIILE trebuie să interpreteze constatărilor în ceea ce priveşte rezultatele obţinute în această lucrare şi în studiile anterioare pe această temă. Concluziile generale vor fi prezentate în câteva fraze la sfârşitul lucrării. Rezultatele şi discuţiile pot include subpoziţii, şi atunci când este cazul, ambele secţiuni pot fi combine.

Multumirile către oameni, cei care au acordat bursa, fonduri, etc., trebuie să fie scurte (dacă este necesar).

Tabelele trebuie menţionate la un nivel minim şi să fie proiectate pentru a fi cât mai simple posibil. Tabelele vor fi scrise la un rând, inclusiv titlurile şi notele de subcolom. Fiecare tabel trebuie scris pe întreaga lătură a paginii, între textul în care se face trimite; coloanele sunt eliminate - o singură coloană (vezi ataşat modelul). Tabelele trebuie să fie auto-explicative, fără referire la text. Detaliile cu privire la metodele utilizate în experimente trebuie să fie, de preferinţă, descrise în legătură cu textul. Aceleaşi date nu trebuie prezentate atât în tabel cât şi sub formă grafică (decat dacă este absolut necesar) sau repetate în text. Titlul tabelului va fi scris centrat, bold (în engleză) şi bold italic (în limba maternă), separat de un slash (/). In tabel, fiecare rând va fi scris în limba engleză (9 pt., normal) / limba maternă (9 pt., italic). Tabelului şi numărul acestuia se scrie aliniat la dreapta, bold - în limba engleză şi bold italic în limba maternă, desparte de un slash (/).

Figurile trebuie scrisre în ordine numerică. Graphele trebuie realizate utilizând aplicaţiile care să genereze JPEG de
generating high resolution JPEG before 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).

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").

Mathematics

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).

REFERENCES: are made in the text; a reference identified by [1], [2], ... [n] is written in the order that was placed at the end of the work - alphabetically. Example:

[1], [2], [3], ..., [n]

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.

Examples:

Journal / Magazine:


Conference / Symposium:


Book:


Book Chapter:


Exemplu:

Fig. 1 - Test stand / Stand de testare (mărimea: 8 pt.)

Figurile introduse trebuie să fie "In line with text" - Center, nu "Square": "Tight": "Behind text" or "In front of text" (din "Format picture" - butonul dreapta mouse pe figură și apoi "Layout").

Formuile matematice, ecuațiile: autorii trebuie să furnizeze instrucțiuni privind modul de simbolizare și de ecuațiile stabilite și utilizate. Ecuațiile trebuie numerotate secvențial, în partea dreaptă și în paranteze. Ele trebuie menționate în text ca ecuația (4) sau Ex. (4). Fiecare ecuație trebuie scrisă pe întreaga lătime a paginii, în text, acolo unde se face referire, o singură coloană (vezi atașat model).

REFERINȚELE: se fac în text; o referință identificată prin intermediul [1], [2], ...[n], se scrie în ordine in care a fost trecută la sfârșitul lucrării - ordine alfabetică. Exemplu:

[1], [2], [3], ..., [n]

Referințele trebuie prezentate la sfârșitul lucrării în ordine alfabetică. Articole în curs de pregătire sau articole trimise spre publicare, observațiile repuse, comunicările cu caracter personal, etc. nu trebuie incluse în lista de referință, dar pot fi menționate în textul lucrării (exemplu, A. Danciu, Universitatea din București, România, comunicare personală). Autorii sunt pe deplin responsabili pentru exactitatea referințelor. Exemplu:

Jurnal / Revistă


Conferință / Simpozion


Carte


Dissertation / Thesis:

Units, Abbreviations, Acronyms
- Units should be metric, generally SI, and expressed in standard abbreviated form.
- Acronyms may be acceptable, but must be defined at first usage.

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.

3. REVIEWS
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.


Disertații / Teze de doctorat

Unități, Abrevieri, Acronime
- unitățile metrice trebuie să fie, în general, SI, și 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 și 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 și la comunicările scurte, cu următoarele diferențe: (1) Rezumatul este limitat la 100 cuvinte; (2) capitolele Materiale și Metode, Procedurile experimentale pot fi scrise împreună, încorporând figurile și tabelele; (3) Rezultatele și Concluziile pot fi combinate într-o singură secțiune.

3. SINTEZELE
Sintezele, comentariile și perspectivele acoperind subiecte de interes din domeniul sunt încurajate și acceptate spre publicare. Sintezele trebuie să fie concise și nu mai mari 8 pagini. Toate celelalte condiții sunt similare cu cele de la articolele normale (obișnuite), enumerate mai sus.