RESEARCH ON STABILITY AND DESIGNING OF PROTECTIVE STRUCTURE OF TRANSport Vehicle FOR SMALL FARms

Abstract: The results of theoretical research on dynamic stability of newly developed transport vehicle for small farms are presented in the paper. The possibilities for safe operation of the vehicle when driving on horizontal roads with unevenness and on slopes were assessed.

Using the software "Solid Works" a model of "rollbar" protective structure to simulate situations of external impact, impacting encounters of structure with the ground when the vehicle overturns was developed. The dimensions of structural parts of protective structure and materials for their manufacturing are defined. On the bases of the results a protective structure for the transport vehicle "TK-215T" was worked-out, which is to be tested in laboratory conditions according to European directives.

Key words: dynamic stability, protective structure, roll-over, transport vehicle.

INTRODUCTION

Unevenness in the ground affects the stability of the mobile machines used in agricultural production. When running on horizontal road they can be dangerously tilted laterally due to the copying of irregularities as bump, ditch, furrow, etc. Violation of stability can occur when the vehicle runs on sloping terrain and there is a motion of centre of gravity down the slope caused by flowing of transporting load. In these and many other cases appear linear and angular accelerations, which are responsible for affecting the stability with possible negative consequences for the safe and efficient operation of mobile machinery.

The quality of mobile energetic machinery is determined not only by its power output and economic indicators, but also by created conditions for safe working of the operator. Major role in providing the latest play Roll-Over Protective Structures (ROPS). In agricultural tractors that are safe cab, protective frame and rollbar.

Constructive realization of the protective structure depends on the type of mobile means and possibility for attaching on it. The structure may change the shape for reducing the inertia loads acting in the moment of impact into the ground. However, it should provide an area (called "clearance zone") which remains intact to protect the operator. The type and size of this space are regulated by national and international regulations [5].

The object of study is a transport vehicle TK-215T, which is a modification of the family tractors for small farms "TK-215", designed in the Research Institute for Land Reclamation and Agricultural Mechanization – Sofia (Bulgaria). The engine is diesel, single cylinder, air cooled and with rated power 22 hp. Gear box is mechanical type, with six speeds, fully reversible. Vehicle’s four wheels are the same size, driven, steering, fitted with hydraulically actuated rim brakes. The driver seat is reversible. The loading platform of the vehicle fits in its dimensions and the width and length (1250 mm x 1650 mm) allow placement of two pallets. The height of the loading platform (350 mm) is consistent with the ability to

Resumen: La resolución de los resultados teóricos de la estabilidad dinámica de un nuevo vehículo de transporte para pequeñas granjas se presentan en el paper. Los posibilidades para operar de manera segura el vehículo cuando conduce en carreteras horizontales con irregularidades y pendientes se evaluaron.

Usando el software "Solid Works" se desarrolló un modelo de estructura protectora "rollbar" para simular situaciones de impacto externo, choques con la estructura del suelo cuando el vehículo se voltea. Las dimensiones de las partes estructurales de la estructura protectora y los materiales para su fabricación se definieron. Basándose en los resultados se diseñó una estructura protectora para el vehículo de transporte "TK-215T", que se debe probar en condiciones de laboratorio según las directivas europeas.

Palabras clave: estabilidad dinámica, estructura protectora, volcadura, vehículo de transporte.

Introducción

La irregularidad en el suelo afecta la estabilidad de las máquinas móviles utilizadas en la producción agrícola. Cuando circula en carreteras horizontales puede verse peligrosamente inclinada lateralmente debido a la copia de irregularidades como bache, zanja, surco, etc. La violación de la estabilidad puede ocurrir cuando el vehículo circula en terrenos pendientes y hay un movimiento del centro de gravedad hacia abajo por el peso del transporte. En estos y muchos otros casos aparecen aceleraciones lineales y angulares, que son responsables de afectar la estabilidad con consecuencias negativas posibles para el funcionamiento seguro y eficiente de la maquinaria móvil.

La calidad de la maquinaria energética móvil se determina no sólo por su rendimiento de potencia y indices económicos, sino también por las condiciones creadas para el trabajo seguro del operador. El papel principal se desempeña en la actualidad con la protección de los accidentes Volcaduras (ROPS). En los tractores agrícolas que son cabina segura, estructura protectora y rollbar.

La realización constructiva de la estructura protectora depende del tipo de máquina móvil y la posibilidad de acoplarla a ella. La estructura puede cambiar la forma para reducir los cargas de inercia actúan en el momento del impacto en el suelo. Sin embargo, debe permitir un área (llamada "zona de libertad") que permanezca intacta para proteger al operador. El tipo y el tamaño de este espacio se regulan por las regulaciones nacionales e internacionales [5].

El objeto de estudio es un vehículo de transporte TK-215T, que es una modificación de las familias de tractores para granjas pequeñas "TK-215", diseñado en el Instituto de Reclamación de Tierra y Mecanización Agrícola – Sofía (Bulgaria). El motor es diésel, monocilíndrico, enfriado por aire y con potencia nominal 22 hp. La caja de cambios es de tipo mécanico, con seis velocidades, totalmente reversible. Las cuatro ruedas del vehículo son del mismo tamaño, impulsadas, dirigidas, equipadas con frenos de tambor actuados hidráulicamente. El asiento del conductor es reversible. La plataforma de carga del vehículo se ajusta a sus dimensiones y el ancho y la longitud (1250 mm x 1650 mm) permiten la coloación de dos palets. La altura de la plataforma de carga (350 mm) es consistente con la capacidad de
transporting denser agricultural goods. For the carriage of volumetric loads are provided additional boards with a height of 400 mm. Maximum permissible load, which the vehicle can transport (600 kg) is consistent with wheels' carrying capacity (with twin wheels at the rear axle) and the conditions for safe stopping the mobile machines of this type. Its wheelbase and track width are respectively 2350 mm and 1480 mm, the clearance is 310 mm and the weight is 1080 kg (excluding protective structure). At the rated engine speed vehicle realizes movement with forward speeds in the range 1.9...25.1 km/h.

The aim of the study, results of which are presented in this publication, is to estimate the dynamic lateral stability of transport vehicle TK-215T and create a protective structure for the safe operation in mountainous and hilly areas.

MATERIALS AND METHODS

A number of researches on tractor’s stability and creating conditions for its assessment [1, 4, etc.] are dedicated over the years. Very often as an indicator of stability is used “the dynamic angle of lateral stability” \( \beta_{\text{dyn}} \), which is the angle of sloping terrain at which the dynamic roll-over occurs. According to data from experimental studies it is between 40 to 60 percent of the static angle of stability \( \beta_{\text{im}} \), where lower values are typical for cases with more intensive action of dynamic factors caused by the higher forward speeds. In this research the values of dynamic angle of lateral stability are determined using this relationship and the values of static angle of lateral stability, which are calculated by using the data for wheelbase, track width and coordinates of the centre of gravity of the vehicle.

In the process of investigation of the dynamic lateral stability of the transport vehicle "TK-215T" are considered situations, which are typical for farming practice, but presenting a risk to the safe operation of equipment, namely:

- movement on a horizontal road with unevenness;
- work on slopes with different types and quantity of loads in the loading platform.

In the case of movement on a horizontal road with unevenness the dynamic lateral stability was estimated with the limiting angle of inclination caused by the breakdown / raising the wheels on one side of the mobile machine, as a result of copying the uneven ground, and with the dangerous size of unevenness in the ground (height of the embankment, depth of the ditch, etc.), which can lead to its dynamic roll-over. Examined the variants of movement without load in the loading platform and with different in quantity and volume load in the loading platform within acceptable in technical data loading capacity 600 kg. Dangerous size of unevenness of the ground \( h_{\text{dyn}} \) is calculated using the well known in tractor theory [2, 3, ect.] formula (1), where \( B \) is the track width of the mobile machine, measured in millimeters.

\[
h_{\text{dyn}} = \frac{B}{2} \tan \frac{\beta_{\text{im}}}{2}.
\]

For the case of motion on a sloping terrain with different types and quantity of the loads in the loading platform has been evaluated the impact of:

- the quantity of evenly distributed load in the loading platform;
- the volume of evenly distributed load in the loading platform;
- flowing behavior of the load.

cape. The width \( a \) (350 mm) is connected with the possibility of the vehicle on the level, but with a consideration of the load in the loading platform. The maximum load is 600 kg. Nondeterministic on the transport means is 600 kg. The load capacity and the safety of the machine is ensured by the following two conditions:

1. Horizontal: The load is 600 kg. The load capacity is ensured by the following two conditions:

- the volume of evenly distributed load in the loading platform;
- the amount of evenly distributed load in the loading platform.

2. Vertical: The load is 600 kg. The load capacity is ensured by the following two conditions:

- the volume of evenly distributed load in the loading platform;
- the amount of evenly distributed load in the loading platform.

3. Sliding: The load is 600 kg. The load capacity is ensured by the following two conditions:

- the volume of evenly distributed load in the loading platform;
- the amount of evenly distributed load in the loading platform.
Using Excel software an approximation of the obtained results is made and formulas, which give the relationship between observed indicators (the dynamic angle of lateral stability and dangerous size of unevenness of the ground) and type and quantity of the load in the loading platform are worked out. The accuracy of the choice of approximating functions is assessed with the indicator R-squared ($R^2$), called in the statistical studies "coefficient of determination".

In the first phase of the study on protective structure’s developing, taking into account the statutory requirements about providing the necessary "clearance zone" and the structural characteristics of transport vehicle TK-215T, tentative sizes of its structural parts are predetermined. To specify them according to the possible materials for their manufacture, a simulation model for the selected type of protective structure was developed using the software “Solid Works”.

For investigation of influence of the external impact on protective structure some situations were modeled, imitating her encounters with the ground due to lateral roll-over of the transport vehicle. Some cases in which forces with different points of application act on the protective frame are discussed, namely:

- the forces are applied sideways and are distributed along the sloping part of the protective frame (fig.1.b);
- the forces are applied vertically along the horizontal part of the protective frame (fig.1.c).

Although real, the case where the forces are concentrated at one point (fig.1.a) is not analyzed because it is assumed as transient and is preceded the next on the same figure. It is not analyzed also the case in which the forces are applied vertically across sloping side of the protective frame (fig.1.d), because it is possible only during longitudinal roll-over of the transport vehicle TK-215T, which in practice is almost unrealizable in real conditions.

Taking into account the configuration and location of the protective frame on the vehicle the following assumptions about the values of the forces applied on protective structure were adopted:

- the maximum force that may act sideways on the protective frame in event of roll-over of the transport vehicle will not exceed half of the force created by vehicle’s weight of gravity;
- the maximum value that can reach the force, acting on the horizontal part of the protective frame, shall not exceed the force created by weight of gravity of less loaded axle of the transport vehicle (in our case – front axle).

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Fig. 1 - Places and modes of force application on the protection frame / Места и начини на прилагане на силите върху защитната рамка
With the developed simulation model of the protective structure, adopted loading schemes and maximum values of the forces was tested structure strength at various angular and linear dimensions of structural parts, types of materials for their manufacturing and etc. The assessment was carried out on the basis of results for linear displacements and maximum stresses that would occur in the protective structure in event of roll-over of the transport vehicle TK-215T.

RESULTS AND DISCUSSION

Results of the study on the dynamic lateral stability of TK-215T running on horizontal road with unevenness

Based on experimentally proven relationship between dynamic and static angles of lateral stability is established that in case of movement of the transport vehicle TK-215T without load the angle which can cause roll-over in result of unevenness in the road varies between 20° and 30°. Practically, lateral roll-over as a result of following of vehicle’s side wheels in ditch or furrow is excluded. The size of unevenness that would cause it (h_{dyn} = 346 mm) is bigger than the clearance, which means that the vehicle would rather "lying on stomach", before it rolls over.

Interesting for practice is a motion of the transport vehicle TK-215T with load in the loading platform. The results of determination using the formula (1) the size of maximum permissible unevenness of the ground for safe movement of the vehicle, depending on the weight of transported load, distributed in the loading platform, are presented in figure 2.

Fully consistent, the maximum size of unevenness, which the vehicle TK-215T can overcome without roll-over, is decreasing with increasing the amounts of transported load (more than 15% in case of movement with a maximum permissible load compared to movement without load in loading platform). The point here is that despite the worsening dynamic stability, its ability to run on uneven surfaces remains high enough, which is further confirmation of a well-reasoned design decisions made in its development.
loading platform of TK-215:

\[ \Delta_{\text{ground}} = -0.0861m_{\text{load}} + 342 \]  

The indicator assessing the accuracy of the choice of approximating function is \( R^2 = 0.9809 \). The results can serve as a reference when choosing a regime that ensures safe motion of the transport vehicle TK-215T with loads on an uneven surface.

Results of the study of the dynamic lateral stability of TK-215T on slopes

The formulas for assessing the vehicles stability when driving on slopes with different types and quantity of load in loading platform are presented in table 1. They are derived by taking into account the impact that each link in the chain "load - static angle - dynamic angle" appears to next one for the cases with more intensive action of dynamic factors. With their help on the bases of data for the weight of transported dense or flowing load and the coordinate of centre of gravity of volumetric load the size of the limiting angle, providing safe movement of transport vehicle on inclined terrains for each of the operational situations can determine.

### Table 1 / Таблица 1

<table>
<thead>
<tr>
<th>Operating condition / Експлоатационно услояе</th>
<th>Formulae / Функционална зависимост</th>
<th>Coefficient of determination / Коefficientът на определяемостта &quot;( R^2 )&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dense load distributed in the loading platform</td>
<td>( \beta_{\text{dyn.d.l.}} = -0.0045m_{\text{load}} + 19.85 ) / ( \beta_{\text{dyn.d.l.}} = -0.0045m_{\text{load}} + 19.85 )</td>
<td>( R^2 = 0.9828 ) / ( R^2 = 0.9828 )</td>
</tr>
<tr>
<td>Flowing load</td>
<td>( \beta_{\text{dyn.f.l.}} = -0.0064m_{\text{load}} + 19.792 ) / ( \beta_{\text{dyn.f.l.}} = -0.0064m_{\text{load}} + 19.792 )</td>
<td>( R^2 = 0.9786 ) / ( R^2 = 0.9786 )</td>
</tr>
<tr>
<td>Volumetric load with weight 600 kg, distributed in the loading platform</td>
<td>( \beta_{\text{dyn.v.l.}} = -0.045h_{\text{load}} + 18.086 ) / ( \beta_{\text{dyn.v.l.}} = -0.045h_{\text{load}} + 18.086 )</td>
<td>( R^2 = 0.9986 ) / ( R^2 = 0.9986 )</td>
</tr>
</tbody>
</table>

The appearance of the first two formulas talk about that increasing of load in the loading platform of the transport vehicle TK-215T reduces the value of the angle, which may cause its roll-over. The results obtained with their help show that when transporting a loads within the range from zero to maximum permissible load the dynamic lateral stability of the transport vehicle deteriorates to 15% when running with distributed load and to 20% with flowing load.

Dynamic stability of TK-215T deteriorates also with increasing vertical coordinate of centre of gravity of the load. When the height of centre of gravity of loads is near the middle of the height of the loading platform (as is desirable to have a volumetric distributed load), lowering the value of limiting angle is negligible - only about one degree, which is a good testimonial for the implemented design solutions in creating a vehicle.

Results of research on creating of roll-over protective structure

Based on international experience in creating protective structures for mobile means such as "TK-215T"
is adopted that the newly protective structure to be of type “rollbar”, and the protective frame of the structure to be work out of a tube with circular section. The shape of the protective frame is a result of searching the configuration, in which the element, bearing the main load in the event of a roll-over, is positioning as close as possible to the driver seat.

Suitable location for mounting the protective structure on the transport vehicle TK-215T is the sleeves of its front axle.

They are steel castings and have sufficient strength to bear additional loads that would arise in case of roll-over. Constructive implementation of the elements for attaching the protective frame to the vehicle is consistent with the presence of horizontal platforms with threaded holes on the front axle sleeves.

Joining the protective frame to each of the sleeves is carried out with the means of support, consisting of a spike on which the protective frame is placed and a plate, which by bolts is fixed to the axle sleeves. Fixing the protective frame to means of support is provided by two locking pins.

Using the developed simulation model different situations are modeled in order to optimize the structure design in strict compliance with the requirements about necessary “clearance zone”. Figure 3 presents the linear displacements (fig.3.a) and stresses (fig.3.b), emerging in the chosen type of structure, when 5 kN external forces are borne by the sloping side of the protective frame.

Recorded maximum values of these parameters in more loaded sections of the structure (approximately 45 mm for the linear displacements and 300 MPa for the stresses) were below the crucial limits of materials used for making up the structural parts. The results refer to the cases where the vehicle is unladen.

Impact that can have weight of the load, transported by TK-215T, was assessed by modeling the situation in which the external forces are of value 7.5 kN. The results are presented on fig.3.c and fig.3.d. The expected increasing of examined parameters’ values is within the permissible margins, which gives reason to believe that the driver’s safety will be guaranteed.

на “TK-215T” е прието новоразработваната защитна конструкция да е от тип “ролбар”, като защитната рамка се изработи от тръба с кръгло сечение. Формата на защитната рамка е резултат от търсенето на подходящата конфигурация за позициониране на елемента, поемащ основното натоварване в случай на преобърване, възможно най-близко до мястото на водача.

Подходящо място за монтиране на конструкцията за безопасност върху транспортно средство TK-215T са ръквите на предния му мост.

Последните са стоманени отливки и притежават достатъчна здравина за да поемат допълнителните натоварвания, които биха възникнали при евентуалното му преобърване. Конструктивното изпълнение на елементите за присъединяване на защитната рамка към транспортното средство е съобразено с наличието върху ръквите на предния мост на хоризонтални площадки за резбови отвори.

Присъединяването на защитната рамка към възки от ръквите на предния мост е осъществено с помощта на опора, състояща се от цил, на който се надява защитната рамка, и опорна плака, която с помощта на болтове се фиксира към хоризонталните площадки на ръквите на предния мост. За фиксиране на защитната рамка по отношение на опорите е предвиден фиксиращ цикф.

За оптимизиране на конструктивната разработка с помощта на разработения имитационен модел са моделирани различни ситуации. На фиг.3 са представени линейните премествания (фиг.3.a) и напреженията (фиг.3.b), възникващи в избраната за оптимална конструкция за безопасност, когато 5 kN-ови външни силови въздействия се поемат странично от наклонената част на защитната рамка.

Регистрираните максимални стойности за изследваните показатели в най-натоварените участъци на конструкцията (около 45 мм за линейни премествания и 300 МПа за възникващите напрежения) са под пределите за материалите, от които са изработени елементите на конструкцията. Резултатите се отнасят за случаите, когато транспортното средство е без товар.

Възприемайки, което може да окаже масата на превозвания товар, е оценоено с моделиране на ситуация, при която външните силови въздействия са със стойност 7.5 kN. Резултатите са представени на фиг.3.c и фиг.3.d.

Очакваното покачване на стойностите на изследванияте параметри е в границите на допустимото, което дава основание да се счита, че безопасността на водача също ще бъде гарантирана.
Fig. 3 - Linear displacements and stresses emerging in the protective structure, when external forces are borne by the sloping side of the protective frame / Линейни премествания и напрежения, възникнали в конструкцията за безопасност, когато външните сили въздействат се поемат странично от наклонената част на защитната рамка

\[ a, b = 5 \text{ kN}; c, d = 7.5 \text{ kN} \]

Similarly, the situation presented on fig.1.c was investigated. On the bases of the obtained results firstly suggested parameters of the frame and other parts of protective structure were adjusted.

Analysis of the results shows that with this configuration and design parameters the newly developed protective structure will provide needed “clearance zone” to protect the driver in case of rollover of the vehicle.

The specified optimal design parameters of the protective frame are presented in table 2.

Table 2 / Таблица 2

<table>
<thead>
<tr>
<th>Optimal parameters of the protective frame of protective structure for the transport vehicle TK-215T / Оптимални параметри на защитната рамка от конструкцията за безопасност за енергетичното транспортно средство TK-215Т</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design parameters / Конструктивни параметри</td>
</tr>
<tr>
<td>Dimensions / Габаритни размери, mm:</td>
</tr>
<tr>
<td>- Height / височина;</td>
</tr>
<tr>
<td>- Width / ширина.</td>
</tr>
<tr>
<td>Height of the vertical part / Височина на вертикалната част, mm</td>
</tr>
<tr>
<td>Angle of inclination of inclined part / Ъгъл на наклона на наклонената част от вертикалата, degree</td>
</tr>
<tr>
<td>Weight (with attachments) / Маса (заедно с присъединителните елементи), kg</td>
</tr>
</tbody>
</table>

On the bases of all results a technical documentation was developed and an experimental model of rollbar protective structure is worked-out. The newly created structure, mounted on the transport vehicle TK-215T, is presented in figure 4.

Fig. 4 - General view of transport vehicle for small farms TK-215T with the newly protective structure / Общ вид на енергетичното транспортно средство за малки земеделски стопанства TK-215Т с конструкцията за безопасност

После получените резултати е разработена техническа документация и е изработен опитен образец на конструкция за безопасност от тип "ролбар". Новосъздадената конструкция за безопасност, монтирана върху енергетичното транспортно средство TK-215Т, е представена на фиг.4.
CONCLUSIONS

The results of investigation on the dynamic lateral stability of the transport vehicle for small farms TK-215T confirmed the correctness of the design decisions made in its creation.

The obtained limiting values of the angle of inclination (between 20° and 30° when driving on the road with bumps) and of the unevenness on the ground, which can overcome the vehicle TK-215T (between 346 mm and 294 mm depending on the quantity of load at the loading platform) and formulas for assessing its stability may be useful in selection of modes for safe driving on sloping or uneven land surfaces, and in comparing it with mobile means with similar technical parameters and use. Analysis of the results on creation of protective structure for TK-215T showed that with the selected configuration and specified design parameters the newly developed rollover construction combines the opportunity for easy attaching and detaching and provides the necessary strength and reliability to protect the driver in event of roll-over of the vehicle.

Another advantage is that this protective structure can also be installed on the widened modification of the tractor family, which representative is TK-215T, and after simple structural changes on the narrow modification of the same family. In the near future it is to be tested in laboratory conditions according to European directives.

REFERENCES


ЗАКЛЮЧЕНИЕ:

Результатите от изследването на динамичната напречна устойчивост на транспортното средство за малки земеделски стопанства TK-215T потвърждават правилността на конструираните решения, реализирани при създаването му.

Получените гранични стойности за угла на наклона (между 20° и 30° при движение на път с неравности) и за размера на неравностите, които може да преодолее транспортното средство TK-215T без опасност от преобързване (между 346 mm и 294 mm в зависимост от количеството на товара в товарната платформа) и изведенните зависимости за оценка на неговата устойчивост могат да служат при избора на режими за безопасно движение по наклонени или с неравна повърхност терени, както и за сравняването му с аналогични по технически параметри и предназначение мобилни средства. Анализът на резултатите по създаването на конструкция за безопасност за TK-215T показва, че с избраната конфигурация и с уточнени конструктивни параметри новоизработената конструкция за безопасност от типа „ролбар” съчетава възможността за лесен монтаж и демонтаж и осигурява необходимата здравина и неразрушимост за да защища водач в случай на преобързване на транспортното средство.

Допълнително предимство на създадената защитна конструкция е факта, че може да бъде монтирана същът върху усъвършенстваната модификация от фамилията трактори, предоставен на компанията TK-215T, с непосредствен контрол и изключение на възможността за създаване на нова конструкция, създаваща предпоставка за безопасност в исследователските условия по утвърдени с европейските стандарти методики.

ЛИТЕРАТУРА