Information system for controlling transport-technological unit with variable mass

Yevhen Kalinin[1[0000-0001-6191-8446]], Dmytro Klets[2[0000-0001-7463-1030]], Mykhailo Shuliak[1[0000-0001-7286-6602]], Anton Kholodov[2[0000-0002-4120-4654]]

[1] Kharkiv Petro Vasylenko National Technical University of Agriculture,44 Alchevskykh Str., Kharkiv, Ukraine
[2] Kharkiv National Automobile and Highway University, 25 Yaroslava Mudrogo Str., Kharkiv, Ukraine

kalininhntusg@gmail.com, d.m.klets@gmail.com, m.l.shulyak@gmail.com, antonkholodov23@gmail.com

Abstract. The movement of the system "tractor - transport-technological machine of variable mass" is considered in the context of the movement of the center of mass of the system, given the equality of the internal forces of this system among themselves. Using the obtained dependences, it is possible to determine the effect of changes in the acceleration of the centre of mass of the transport-technological unit with variable mass on the load of the tractor's transmission parts. The tractor control algorithm is synthesized in the rational area of transmission elements loading and a program for its implementation in the field is developed. The developed application is an information system, the purpose of which is to inform the operator of the presence of stress in the transmission`s elements of the tractor, which cause it overloading and, therefore, reduce the resource of its parts. If the strength condition for fatigue failure is not met, the operator of the transport-technological unit is offered to change the driving mode to reduce the load on the transmission elements.

Keywords: Controlling, Variable Mass, Information System, Transport-Technological Unit.

1 Introduction

Transport Service System that combines transportation technologies, transport-technological units and organization of technological works is one of the most important components of the agricultural system. Improvement of the Transport Service System is possible using modern information control and diagnostic systems that reduce the probability of error due to the human factor. A number of works are devoted to these problems. The paper [1] considers problems pertaining to operational diagnosis of transport facility operator (driver), describes a basis algorithm of physiological operator's characteristics with the purpose to control his activity during non-standard situations. Introduction of a system activity with use of modern satellite technologies allows to lower transportation costs, to increase efficiency of use of agricultural machinery is considered in the work [2].

The issue of designing the machine tractor movement trajectory is relevant today because its optimization significantly reduces the transport costs [3]. Comparative study of the usability of directional commands for two different conceptions of agricultural machinery is conducted in the work [4]. The clarification of the normal reactions distribution between the axles allows to choose more rational forces distribution between the axles. It has a significant impact on the stability against skidding and the wheeled tractor braking effectiveness. [5] The dependence of the influence of vertical accelerations on the dynamic loads on the axle of the tractor front and rear axles is determined in the article [6].

However, research on the use of tractors on the transport and technological agricultural operations were identified unsolved problems, which include: dynamics of a variable mass aggregate, energy saving [7], formation of system properties of the unit elements [8]. The general principles of forming the time to failure due to deviations from the nominal values of external perturbations do not justified [9, 10]. The problem of dynamics of transport-technological unit with variable mass is not solved in terms of their energy efficiency and performance [11].

2 The acceleration of the centre of mass as a quantity forms the energy of the movement of the unit

The movement of the system "tractor - transport-technological machine of variable mass" can be considered in the context of the movement of the centre of mass of the system, given the equality of the internal forces of this system among themselves.

Then, it can said that the movement of the centre of mass of the given system at each moment of time is equivalent to the movement of a material point with a mass equal to the mass of the system at a given moment of time, which is affected by a force equal to the resulting forces applied to the system:

$$\frac{d\left(m' \cdot v_c\right)}{dt} = F_\Sigma, \tag{1}$$

where v_c - the velocity of the center of mass of the system;

m' - the mass of the system at a given time (quasistatic mass);

F_Σ - the main vector of the system of forces, which is applied to the unit.

Multiplying equation (1) by the displacement of the centre of mass of the system, which is caused by a change in the mass of the transport-technological unit dS_{var} and it`s displacement in space dS_{con} over the considered time interval:

$$\frac{d\left(m'\cdot v_c\right)}{dt}\left(dS_{con}+dS_{\mathrm{var}}\right)=F_{\Sigma}\left(dS_{con}+dS_{\mathrm{var}}\right), \tag{2}$$

Opening the brackets and taking out the quasistatic mass beyond the differential sign, got:

$$m'\frac{dv_c}{dt}dS_{con}+m'\frac{dv_c}{dt}dS_{\mathrm{var}}=F_{\Sigma}dS_{con}+F_{\Sigma}dS_{\mathrm{var}}. \tag{3}$$

Considering that $dA_{con}=F_{\Sigma}dS_{con}$, and $dA_{\mathrm{var}}=F_{\Sigma}dS_{\mathrm{var}}$, it can be written:

$$dA_{con}=m'\frac{dv_c}{dt}dS_{con}; \tag{4}$$

$$dA_{\mathrm{var}}=\Delta m\frac{dv_c}{dt}dS_{\mathrm{var}}. \tag{5}$$

where Δm - changes in weight of the transport-technological unit.

The value $A_{con}=m'\cdot a_{unit}\cdot S_{unit}$ determined by dependence (4) represents the work required for the self-movement of the transport-technological unit in space at a distance S_{unit} with acceleration a_{unit}, which is determined according to the tractor's traction balance.

Value $A_{\mathrm{var}}=\Delta m\cdot a_c\cdot S_c$ - the work spent by the unit on moving S_c the center of mass of the unit with acceleration a_c as a result of changes in its mass.

Thus, it can be argued that there is a direct proportion link between the work expended by the unit, and the acceleration of the center of mass. Therefore, using known definition of safety margin and accepting $a_{unit}\to 0$, it can be obtained the condition of fatigue strength of transmission`s parts, taking into account the acceleration of the center of mass a_c at a certain displacement S_c

$$a_c\le\frac{l\cdot W_p^2\cdot K_F^2\cdot K_d^2\cdot\tau_{-1}^2\cdot\sigma_{-1}}{3,4\cdot G\cdot J_p\cdot\Delta m_{unit}\cdot S_c\cdot\left(K_{\sigma}^2\cdot\tau_{-1}^2+K_{\tau}^2\cdot\sigma_{-1}^2\right)}. \tag{6}$$

Using the obtained dependence, it is possible to determine the effect of changes in the acceleration of the centre of mass of the transport-technological unit with variable mass on the load of the tractor's transmission parts.

3 Ensuring the fatigue strength of transmission elements, taking into account the energy losses of the unit

The strength of materials under impact loads variables characterized fatigue curve. It presents the link between the highest values of variable cyclic stress in a material σ_a and the number of cycles these stresses *N* to destruction.

When building the dependence of the number of cycles of alternating strength in the material of the part to destruction from changing them amplitudes in logarithmic coordinates $\lg\sigma_a - \lg N$, the fatigue curve is represented like a broken line, the left branch of which is inclined to the abscissa axis at an angle, and the right branch is conventionally assumed horizontal due to its small inclination in reality and propagation to such a large number of load change cycles, which is assumed to be rare due to the limited service life of the tractor's transmission.

The common form of the fatigue curves for various materials and samples allowed us to use their analytical expression and compare the characteristics of fatigue strength not by comparing the curves as a whole, but by comparing individual numerical indicators.

Stepped dependency is the most common analytical description of a fatigue curve:

$$\sigma_a^m \cdot N = A, \tag{7}$$

where *A* – constant.

For the discrete repeatability of stress cycles in the part material, the mathematical expression of the linear accumulation of fatigue damage has the form:

$$\sum_{i=1}^{r} \frac{n_i}{N_i} = L, \tag{8}$$

where n_i - is the number of cycles with the amplitude of the *i*-th level, during the process; N_i - the number of cycles with amplitude of the *i*-th level, with continuous action of which the material is destroyed; *r* - the number of strength levels, covers the entire range of changes during the process; *L* - indicator of damage.

According to this cumulative hypothesis, destruction in the material occurs when $L = 1$. However, numerous experimental researches show that the indicator of damage *L* during breakage is different from 1. Moreover, formula (8) becomes:

$$\sum_{i=1}^{r} \frac{n_i}{N_i} = a. \tag{9}$$

The value *a* depends mainly on the material of the part and partially on the parameters of the spectrum of stress amplitudes. In this regard, for calculating the equivalent stress, the condition for summing the damaging effects of various cycles, while maintaining linearity, is attributed to a certain calculated fatigue curve that differs from the initial degree in terms of degree *m*.

When calculating the absolute durability of accounting for such an amendment is very significant. When calculating the comparative durability, the spread of the indicator *a* in the usual range for steels (0,8 ... 1,4) leads to small differences in the degree of the calculated fatigue curve from the real one.

Thus, it can concluded that the use of relator in comparative calculations does not give large errors even when the parameters of the specter amplitude of the compared modes will differ significantly.

We introduce two modes of transmission elements loading: for the movement of a transport-technological unit of constant and variable masses. Then, for the moment when the accumulated damage in the metal is equal, we get:

$$L_{cons} = L_{\mathrm{var}}, \tag{10}$$

and taking into account expression (8) it can be can written:

$$\sum_{i=1}^{r_{cons}} \frac{n_{i\,cons}}{N_i} = \sum_{i=1}^{r_{\mathrm{var}}} \frac{n_{i\,\mathrm{var}}}{N_i}. \tag{11}$$

Since the calculation of the transmission elements loading is carried out according to the stresses, which are defined in accordance with the law of fatigue failure, for cycles of any level, it can be written:

$$\sigma_{a\,i}^{m} \cdot N_i = \sigma_{-1}^{m} \cdot N_0, \tag{12}$$

where σ_{-1} – the endurance limit.

Then

$$N_i = \left(\frac{\sigma_{-1}}{\sigma_{a\,i}} \right)^m \cdot N_0, \tag{13}$$

and from the expression (11):

$$\sum_{i=1}^{r_{cons}} \frac{n_{i\,cons}}{\left(\frac{\sigma_{-1}}{\sigma_{a\,i}} \right)_{cons}^m \cdot N_0} = \sum_{i=1}^{r_{\mathrm{var}}} \frac{n_{i\,\mathrm{var}}}{\left(\frac{\sigma_{-1}}{\sigma_{a\,i}} \right)_{cons}^m \cdot N_0}. \tag{14}$$

Taking into account the fact that, for a given part, the values σ_{-1} and N_0 are independent of the load conditions, expression (14) takes the form:

$$\sum_{i=1}^{r_{cons}} n_{i\,cons}\sigma_{a\,i}^{m} = \sum_{i=1}^{r_{\mathrm{var}}} n_{i\,\mathrm{var}}\sigma_{a\,i}^{m}. \tag{15}$$

Let the transport-technological unit carry out the technological process with a certain value of the expended work *A*, and the work to a comparable degree of damage to the material is equal A^*.

Then the number of cycles of each observed level until the moment of comparison on the compared operating modes of the transport-technological unit can be expressed through the results of experimental studies in the form:

$$n_{i\,cons} = n'_{i\,cons}\frac{A^*_{cons}}{A_{cons}}, \tag{16}$$

$$n_{i\,\mathrm{var}} = n'_{i\,\mathrm{var}}\frac{A^*_{\mathrm{var}}}{A_{\mathrm{var}}} \tag{17}$$

where the dash indicates that the corresponding value obtained on the basis of realized process.

Substitute (17) in (16):

$$\frac{A^*_{cons}}{A_{cons}}\sum_{i=1}^{r_{cons}} n'_{i\,cons}\sigma_{a\,i}^{m} = \frac{A^*_{\mathrm{var}}}{A_{\mathrm{var}}}\sum_{i=1}^{r_{\mathrm{var}}} n'_{i\,\mathrm{var}}\sigma_{a\,i}^{m}. \tag{18}$$

Then the ratio of work on these modes:

$$\frac{A^*_{cons}}{A^*_{\mathrm{var}}} = \frac{A_{cons}\sum_{i=1}^{r_{cons}} n'_{i\,cons}\sigma_{a\,i}^{m}}{A_{\mathrm{var}}\sum_{i=1}^{r_{\mathrm{var}}} n'_{i\,\mathrm{var}}\sigma_{a\,i}^{m}}. \tag{19}$$

The resulting expression can be considered as the coefficient of equivalence of the work spent on moving the transport-technological unit with constant and variable masses. Denoting it by the letter k_e, will get:

$$A^*_{cons} = k_e \cdot A^*_{\mathrm{var}}. \tag{20}$$

The given stress of the steady state σ_{np}, equivalent to that in the unsteady mode, is determined from the dependence of the form:

$$\sigma_{np} = \frac{1}{\sqrt[m]{a}}\cdot\sqrt[m]{\left(\frac{1}{N_0}\right)\cdot\sum_i\left(\sigma_i^m \cdot n_i\right)}. \tag{21}$$

Then, the safety margin can be determined from an equation of the form:

$$n = \frac{\sigma_{-1}}{\sigma_{np}} = \frac{\sigma_{-1} \cdot \sqrt[m]{a}}{\sqrt[m]{\left(\frac{1}{N_0}\right) \cdot \sum_i \left(\sigma_i^m \cdot n_i\right)}}. \tag{22}$$

4 Experimental study

To test of the transport-technological unit with variable mass based on the KhTZ-17221 tractor as part of an aggregate with a machine for applying liquid organic fertilizers MZHT-10, the experimental researches of the overload signaling device of the tractor's transmission unit were carried out, developed on the Android platform. The developed application is an information system, the purpose of which is to inform the operator of the presence of stress in the transmission`s elements of the tractor, which cause it overloading and, therefore, reduce the resource of its parts. The main application window consists of four main zones (Fig. 1).

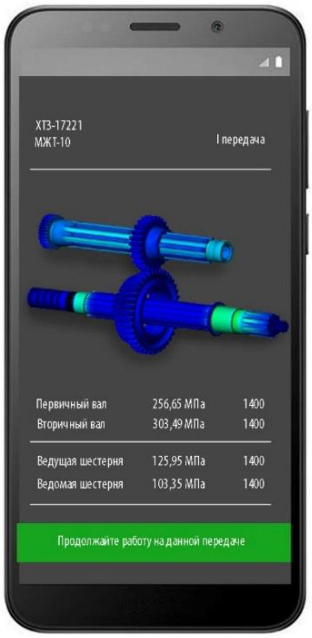

Fig. 1. General view of the application window for controlling transport-technological unit with variable mass

The top part of the main application window is a menu for adjusting the view of the transmission`s elements and the selection of the constituent elements of a transport-technological unit with the variable mass. When the model of tractor and agricultural machine are selected, the program independently, using the existing database, generates mass-geometric indicators of the transport-technological unit for the future calculations.

The second (middle) part of the main application window displays the load distribution in the transmission`s elements. Because of the smartphones architecture, the visualization of transmission elements is a set of frame-by-frame animation of load redistribution.

Second (middle) part the main window the programs are designed for visualization distribution load elements transmission installation. Given features architecture smartphones visualization elements transmission is a set of time-lapse animation redistribution loaded.

The third part of the main application window displays basic information about the values of stresses caused by the torque in the transmission elements, and the value of the cycles to fatigue failure.

Moreover, if the stress value exceeds the permissible limits, and the value of the residual number of cycles is critical, the fourth part of the main application window (information panel) changes its color from green (see Fig. 1) to orange (Fig. 2), and the inscription “Continue to work on this gear ”is replaced by the inscription“ Need to change gear ”(see Fig. 2).

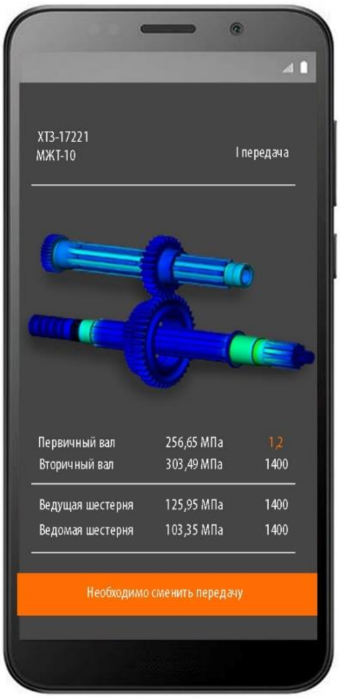

Fig. 2. General view of the application window for controlling the transport-technological unit with variable mass when the transmission is overloaded

The developed application uses input data from its own database (the mass of the transport-technological unit, transmission ratios and engine characteristics), as well as acceleration of the centre of gravity along three coordinate axes.

To attract the operator`s attention, when the elements of the transmission are overloaded and the operation mode needs to be changed, an audio signal is given, and it turns off only after the transmission loading mode returns to rational.

Conclusions

According to the results of a comprehensive analysis of the energy losses of the transport-technological unit with the variable mass, when performing the technological process, the concept of a systematic approach is substantiated, which is the scientific novelty of the study, increasing the operability of the unit, which, unlike the known ones, is based on the proved statement, ensuring a minimum of energy losses on oscillatory the motion of the center of mass.

The tractor control algorithm is synthesized in the rational area of transmission elements loading and a program for its implementation in the field is developed. The principle of the application is based on the algorithm and use an acceleration sensor built into the phone. Because the application is designed on an open operating system Android, it can be said that it is available for almost all existing smart phones.

The main condition for the correct functioning of the program is the location of the phone so that at least one of the axes of its accelerometer coincides with the direction of movement of the transport-technological unit with the variable mass.

Obtained results can be extended and used on other types of vehicles. In the future, it is planned to expand the amount of source data for the application, which will increase the accuracy in determining the optimal modes of operation.

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