Experimental studies of ride quality of self-propelled combine harvester

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Abstract. The given work is devoted to the study of dynamic loads acting upon a combine harvester, which is one of the most vibration-loaded types of modern transport and technological machines. The results on the evaluation of dynamic loads and ride quality parameters of a self-propelled combine harvester when driving along gravel and bituminous surfaces under various operating conditions are presented based on complex experimental studies carried out with the help of tensor and vibrometry methods. The method and conditions of measurements are given. On the basis of the experimental studies, the acceleration spectrum on the main parts of the combine harvester are presented and their description is given. Using the methods of spectral analysis and statistical processing, a vibration modal analysis has been carried out during a combine harvester movement. According to the results of the analysis, the basic vibrational modes have been determined, and it has been shown that the self-propelled combine harvester movement dynamics is determined by vertical and longitudinal-angular vibrations of its core on pneumatic tires. Further scientific research directions to improve the ride quality and to decrease the dynamic loads on a considered class of self-propelled agricultural machines have been determined.

1 Introduction

At present and in the near future, the main means of labor-saving in crop products' harvesting, as one of the main labor and energy intensive stages in the implementation of agrotechnical processes, are combine harvesters, the operational efficiency of which is largely determined by the profitability of the agro-industrial complex [1-3]. Due to the design features, the presence of a large number of unbalanced mechanisms and deterministic processes in the mechanisms during the technological mass processing, as well as special operating conditions, these machines perceive significant dynamic loads during the movement [4-7]. To control these loads designers use various solutions leading, as a rule, to an increase in the machine mass [8] and, accordingly, to an increase in the ground pressure by the propellers, which affects agroecology negatively. In this regard, the

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research area and the development of means and systems to increase the ride quality of a combine harvester has sufficient scientific relevance and practical significance.

The ride quality of motor vehicles [8-10], road-building machinery and special transport [11] has always been of great importance, but there are not so many works on agricultural machinery. To a greater extent these works are devoted to the study of the tractors' ride quality with wheel and track propellers [12, 13], and in the known works on the dynamics of combine harvesters, attention is paid only to the vibration protection of the workplace and optimization of the propellers parameters and their drives [14-16]. The lack of such studies can be explained by the fact that the problem of ride quality of self-propelled combine harvesters appeared relatively recently, when the speed of modern models began to reach more than 30 km/h.

Creation of the most effective technical solutions that allow not only to improve operational efficiency and productivity of combine harvesters, but also to improve the working conditions of their operators, requires complex experimental studies of the existing loads on the considered class of machines. Therefore, the main objective of this research has been to determine, describe and identify the forms of dynamic loads acting upon the combine harvester and its main elements.

2 General part

Experimental measurements and studies of a number of functional parameters of the RSM S300 (Nova) combine harvester have been carried out to evaluate the level of dynamic loads acting upon the combine harvester and to describe the processes accompanying them. For this purpose, in various points of the combine harvester (Fig. 1) the acceleration in the vertical (z_{MBK}, z_{MYK}), longitudinal (x_{MBK}, x_{MYK}) and transverse (y_{MBK}, y_{MYK}) directions on the axle beam of the driving wheels and on the transverse axle beam of the steering wheels in the area of its attachment to the frame has been measured. Acceleration on the adapter in the area of its attachment to the feeder house or on the feeder house (z_A, x_A, y_A) has also been measured.

Fig. 1. The location of the acceleration measuring points on the combine harvester and its dynamic model to study the vibration modes

The measurements have been carried out at various movement speeds on polygons with gravel and bituminous surfaces, with and without an adapter installed. In some cases, in order to reproduce the operating mode, the combine harvester's hopper has been filled with cargo.

Due to the design features, when the combine harvester is in the transport mode, the movement of the feeder house relative to the core is blocked, and the movements of the adapter relative to the feeder house in the longitudinal plane are not significant, then to detect and to study the vibrational modes the combine harvester has been considered as a single mass dynamic model with two axes equipped with elastic propellers (Fig. 1). It is known that such self-propelled machines perform vertical and longitudinal-angular vibrations, which are expedient to describe by vertical movements of the center of mass (z_0) and longitudinal-angular vibrations of the core (φ) (Fig. 1) [10]. Transverse (y_0), longitudinal (x_0), as well as transverse-angular vibrations of the core (β) have not been considered in this paper, since the previous studies [7] show that such parameters as z_0 и φ primarily affect the ride quality of the considered type of self-propelled machines.

The angular vibrations of the combine harvester, as a machine with two axes of propellers, have been determined using the equation [10]

$$\varphi = (z_{MBK} - z_{MYK})/L, \quad (1)$$

where L – is a combine harvester base.

The vertical displacement of the center of mass (the center of elasticity) of the combine harvester has been evaluated according to [10]

$$z_0 = (z_{MYK}l_1 - z_{MBK}l_2)/L, \quad (2)$$

where l_1 and l_2 – respectively, are the distance from the axis of the front and rear wheels to the vertical from the center of mass of the combine harvester (Fig. 3).

The values of L , l_1 и l_2 correspond to the dimensions of the RSM S300 combine harvester. To determine the vibrational mode of the core of the combine harvester, in accordance with equations (1 and 2), the calculation of the vertical displacements of the center of mass, as well as of the angular vibrations of the core have been made. To perform calculations, oscillograms and spectra of φ and z_0 , the PowerGraph 3.3 Professional software package has been used.

Figures 2 and 3 show the acceleration spectra in the vertical direction on the adapter (Fig. 2, a; 3, a), on the axle beam of the driving wheels (Fig. 2, b; 3, b) and on the axle beam of the steering wheels (Fig. 2, c; 3, c) when the combine harvester moves along the gravel (Fig. 2) and bituminous surfaces (Fig. 3). It has been established that the combine harvester experience the greatest acceleration when driving at high speed along the gravel surface with an adapter and an empty hopper (Fig. 2). When the combine harvester moves in this mode, the acceleration that acts on the adapter is concentrated in a narrow frequency domain (Fig. 2a), in which it is possible to determine the fundamental harmonic at $f = 1.26$ Hz with an amplitude of up to 1 m/s^2 .

On the axle beam of the steering wheels and axle beam of the driving wheels, primary loads also operate at frequencies from 1 to 2 Hz, but on the obtained spectra two harmonics are distinguished at $f = 1.26$ and 1.75 Hz. On the axle beam of the driving wheels, the acceleration amplitudes at both frequencies are comparable and are equal to $0.42\text{-}0.44 \text{ m/s}^2$. On the axle beam of the steering wheels, the acceleration amplitudes are higher: at a lower frequency harmonic 0.51 m/s^2 , and at a higher frequency – 0.6 m/s^2 .

a

b

c

Fig. 2. The accelerations spectrum in the vertical direction on the adapter (a), on the axle beam of the driving wheels (b) and on the axle beam of the steering wheels (c) when the combine harvester moves along a gravel surface at a speed of 10-12 km/h.

Fig. 3. The acceleration spectra in the vertical direction on the feeder house (a), on the axle beam of the driving wheels (b) and on the axle beam of the steering wheels (c) when the combine harvester moves along the bituminous surface at a speed of 26 km/h without an adapter.

If the combine harvester moves in the transport mode at a speed of 26 km/h without an adapter, the frequencies of the active vibrations in all controlled points of the combine harvester increase (Fig. 3), which is caused by a decrease in mass and inertia moments. At the control points, two active harmonics are clearly distinguished, but at

$f = 1.37$ and 2.05 Hz. Despite the increase in the speed relative to the motion mode along the gravel surface, the overall level of accelerations has significantly decreased, which may indicate the importance of the bearing surface parameters on the dynamics of the combine harvester movement. At a frequency of 2.05 Hz on the feeder house, the acceleration amplitude has not exceed 0.25 m/s^2 , on the axle beam of the driving wheels 0.33 m/s^2 , and on the axle beam of the steering wheels 0.6 m/s^2 . The acceleration amplitudes with a frequency of 1.37 Hz on the feeder house reached 0.4 m/s^2 that has been significantly greater than on the axle beam of the steering wheels (0.25 m/s^2) and on the axle beam of the driving wheels (0.2 m/s^2) (Fig. 3).

The obtained results make it possible to evaluate the overall level of the existing loads on the combine harvester core. However, in order to develop technical solutions to increase the ride quality, it is necessary to clearly distinguish the vibrational modes of the combine as a single mass dynamic model. For this purpose, a calculation has been made with the help of the available implementations of the accelerations on the axle beam of the steering wheels and on the axle beam of the driving wheels, in accordance with equations 1 and 2 and the corresponding spectra of the vertical center-of-mass acceleration (Fig. 4, a and c) and the angular vibrations of the combine harvester core have been constructed (Fig. 4, b and c).

It has been established that in all considered modes both vibrational modes operate at clearly distinguished frequencies. Depending on the motion modes the combine harvester center of mass vibrations in the vertical direction predominantly occurs at frequencies of 1.26 to 1.36 Hz (Fig. 4a, c), and the longitudinal-angular vibrations of the core occur at $-1.75 \div 2.05$ Hz (Figure 4 a, c). These vibrational modes appear quite clearly on the spectra of accelerations at the combine harvester.

Fig. 4. The vertical vibrations spectrum of the center of mass of the combine harvester (a, c) and the angular vibrations of the core (b, d) when the combine harvester moves at a speed of 10-12 km/h along the gravel surface with an adapter (a, b) and at a speed of 26 km/h along the bituminous surface without an adapter (c, d).

3 Conclusion

1. The experimental data obtained in real conditions make it possible to determine the processes' input parameters in the mathematical description of a combine harvester as a single or multi-mass dynamic systems, and also provide an opportunity to substantiate the fundamental principles and assumptions adopted in the development of a mathematical model describing the dynamics of the combine harvester movement.

2. A characteristic feature of the considered spectra is the concentration of process energy at low frequencies. When driving in all the investigated modes of the combine harvester, the greater part of the vibration energy of the core in the vertical and horizontal planes is concentrated at frequencies up to 2.1 Hz. In this regard, the developed means of vibration damping may have low speed index.

3. In all investigated motion modes, the ride quality of the combine harvester is determined by two vibrational modes of the core: the first corresponds to vertical vibrations with a frequency of 1.26 to 1.36 Hz, and the second corresponds to the longitudinal-angular-vibration of the core with a frequency of 1.75-2.05 Hz.

4. The absence of the suspension wheels system of the combine harvester does not allow the application of known methods to improve the ride quality of the self-propelled machines. In this connection, it is necessary to consider other ways to reduce dynamic loads on the core of the combine harvester during its movement, for example, by optimizing the damping characteristics of the tires, active or semi-active suspension control of the adapter with a feeder house, etc.

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