Substantiation of the range of changes in the elastic-damping and inertial characteristics of the oscillatory system of agricultural MES with mounted technological equipment

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Abstract. This article discusses the issue of substantiating the range of changes in the elastic-damping and mass-inertial characteristics of agricultural mobile power equipment (MES) with mounted technological equipment. Substantiation of the range of changes in the elastic-damping and inertial characteristics of an oscillatory system is an important stage in the design process of various mechanical systems and equipment. In this article, the authors present experimental data necessary for further studies of the springing system and present a study aimed at ensuring optimal operating conditions of the system, minimizing the level of vibrations and vibrations, predicting the behavior of the system in various operating conditions and modes. The article describes the research methods used, presents the results and draws conclusions. The research plays an important role in the design of agricultural MEAS aggregated with various technological equipment.

1 Introduction

Substantiation of the range of changes in the elastic-damping and mass-inertial characteristics of an oscillatory system is an important stage in the design process of various mechanical systems and equipment. The purpose of our research is to ensure optimal performance of the system, as well as to minimize the level of vibrations and vibrations that can lead to premature wear and destruction of the structure. Justification of the range of variation of the characteristics of the oscillatory system of the MES allows:

- to assess the impact of changes in system parameters on its vibration behavior and possible negative consequences;
- develop recommendations for adjusting parameters to achieve the specified performance indicators of the system;
- predict the behavior of the system under various operating conditions and external influences;

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- develop methods and algorithms for controlling system fluctuations for its reliable and long-term operation;
- reduce the cost of maintenance and repair of systems by optimizing their characteristics and taking into account possible vibration problems at the early stages of design.

In general, our research is aimed at substantiating the range of changes in the characteristics of the oscillatory system and plays an important role in ensuring the effectiveness of the adaptive springing system of the MES, and as a result, reducing the level of dynamic loading of the structure from the effects of road surface irregularities.

The dynamics of the MES is always an oscillatory process, estimated by the intensity of vertical, longitudinal and angular vibrations of the sprung masses, and depends not only on the basic design parameters of components and assemblies, including tires, but also on the efficiency of the adaptive running system [1-4].

When expanding knowledge on the study of the dynamic characteristics of agricultural MES, it is necessary to set loads. Calculations are usually carried out by comparing the results obtained with the standard and then draw conclusions [2-4]. Carrying out calculations on the simulation mathematical model of the dynamic system under study should give results in the form of the obtained characteristics of the oscillatory system – mass movements, natural frequencies of the system, amplitude-frequency characteristics. The study of the oscillatory system becomes more complicated in the case of the presence of nonlinear elements, which requires the use of complex modeling methods [5].

The reduction of dynamic loads on suspension and power transmission elements has a positive effect on the reliability and durability of the entire complete MES [2-6]. The effective interaction of the undercarriage of the machine with the support surface also contributes to an increase in productivity and a reduction in fuel consumption [5-7].

Works [8-14] are devoted to the issue of modeling dynamic processes of mobile machines. In them, the authors considered the formation of the basic operational properties of mobile wheeled vehicles, developed software tools and methods for determining the parameters of the suspension elements during bench tests, including tests of mobile equipment with an automated control system [15,16].

A large number of studies have been conducted to study and create an effective system for springing mobile cars operating in off-road conditions [5-12, 14]. In these works, the authors investigated the effect of vibrations with a wide spectrum of the frequency range. These works are mainly aimed at ensuring smooth running under the required conditions and driving modes. According to the authors, this largely depends on the dynamic behavior of the car body, which is subjected to a combination of vertical, longitudinal-angular and transverse-angular vibrations during operation. It is possible to reduce these fluctuations by using special suspension structural elements, which are described and tested in detail in [15-19].

Reducing the dynamic load on the frame of the machine allows, based on the theory of linear damage accumulation [20 – 22], 15-20 % to increase the durability of metal structures, which is also an important criterion in agricultural machinery [23].

Research in [20-27] shows the relevance in the field of reducing the vibration load of agricultural MEAS and other mobile machines operating in severe field and road conditions. Scientific research related to the study of the dynamics of motion and the criteria for its quantitative assessment, including those obtained during a staged experiment, are given in [28-33].

2 Materials and Methods

In the analysis of the data obtained, the laws of the theory of theoretical mechanics, the theory of oscillations and mathematical statistics are applied. Experimental verification was based on the support of generally established and specialized techniques prepared by the authors for specific situations and conditions.

An equivalent calculation scheme of the oscillatory system is used to model the oscillations of the MES, which is described in detail by us in [28]. An equivalent system of vibrations of the MES during its movement is reduced to a system with concentrated masses connected to elastic elements without mass, including the elasticity of suspension and shock absorbers, for example, as described in the works [5, 6-10]. The equivalent scheme also takes into account the damping characteristics of the masses and connections.

The object of the study is the springing system of a tractor of traction class 3 "Agromash TK-3-180". The external disturbing factors of the dynamic system are the impact from the support surface [28]. The load (elastic) characteristic of the pneumatic element installed on the tractor – $F = f(h)$ is shown in Figure 1 (*on the left* – rebound, *on the right* – compression) was presented by us in [28]. The characteristic is used as input data for simulation modeling of dynamic processes.

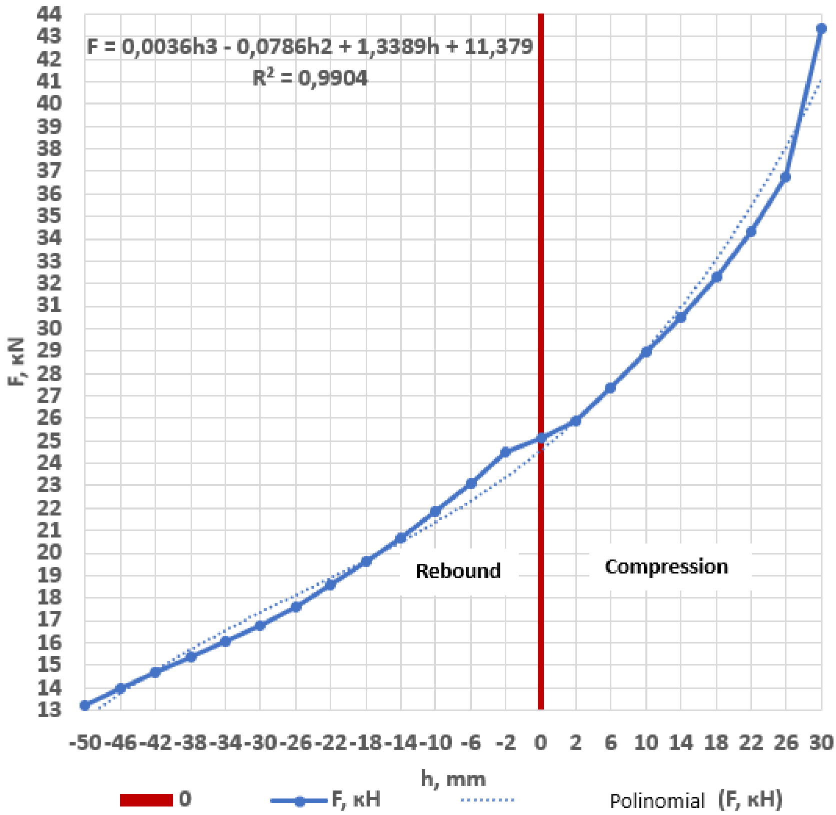

Fig.1 Load characteristics of the pneumatic element used on the springing system of a wheeled tractor of traction class 3 [28]

This article presents experimental data necessary for further studies of the springing system.

3 Results and discussion

To obtain the load characteristics of a new experimental pneumatic element, a special stand is used, which allows to obtain load characteristics. A general view of the airbag test bench is shown in Figure 2.

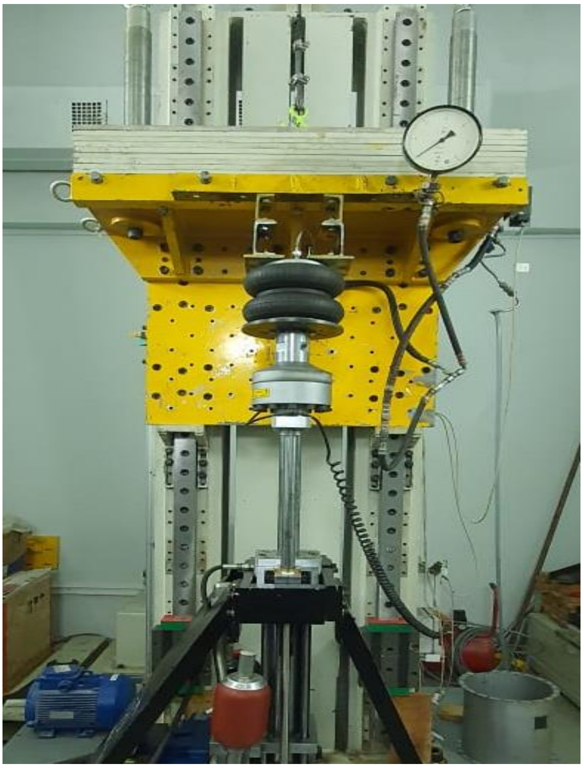

Fig. 2. General view of the test bench for pneumatic elements (air bags)

Performing manipulations on the stand during the testing of the pneumatic element, various load characteristics are obtained. The load characteristic of the air bag is necessary to determine its ability to withstand various loads and pressures, as well as to assess its durability and efficiency. This important parameter allows you to determine how suitable the pneumatic element is for use in the specified conditions and what load it can withstand without losing its properties. Below are the load characteristics of the pneumatic element at different pressures inside the cord (Figures 3-6).

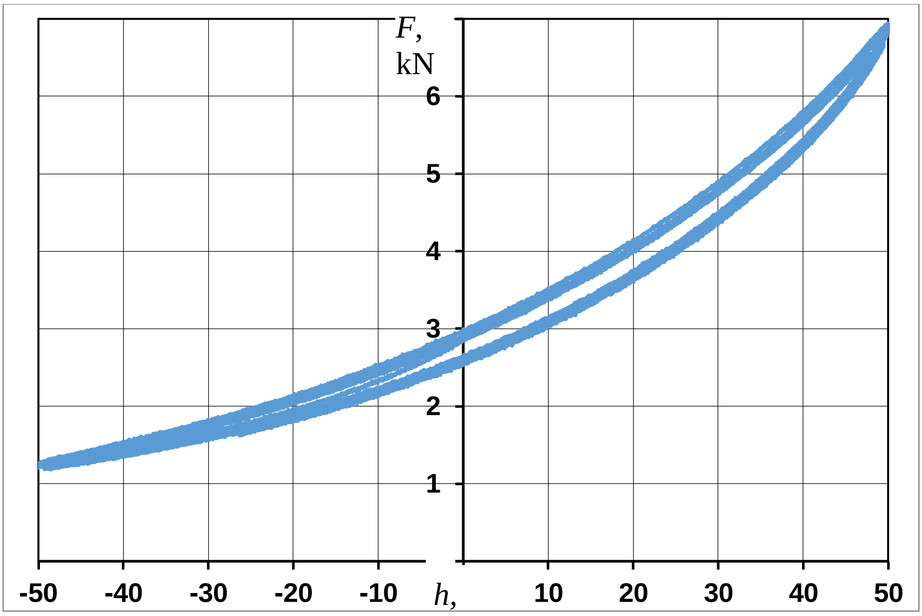

Fig. 3. The load characteristic of the pneumatic element at a pressure inside the cord of 1 atm.

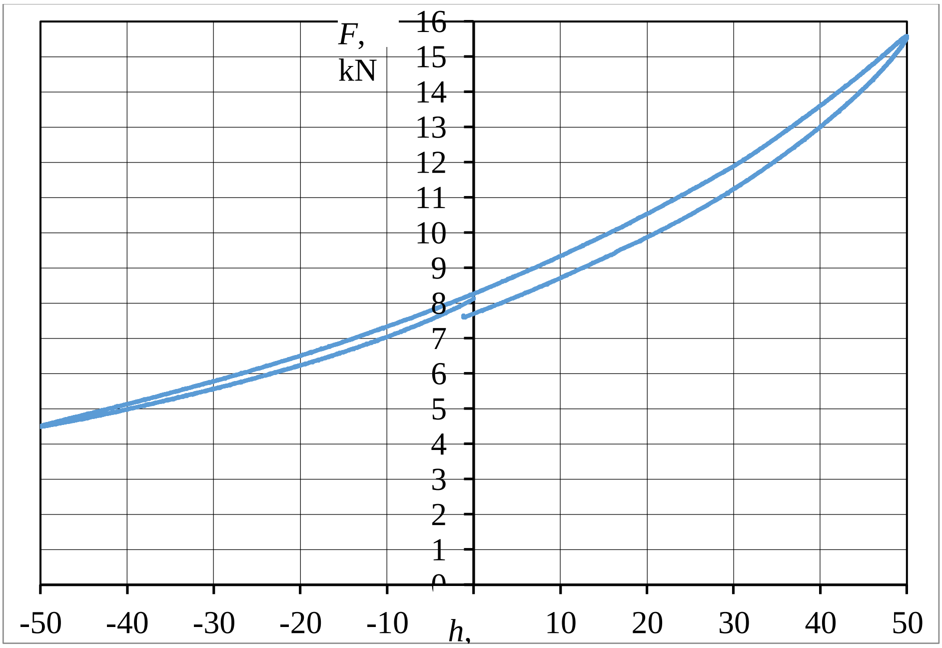

Fig. 4. The load characteristic of the pneumatic element at a pressure inside the cord of 3 atm.

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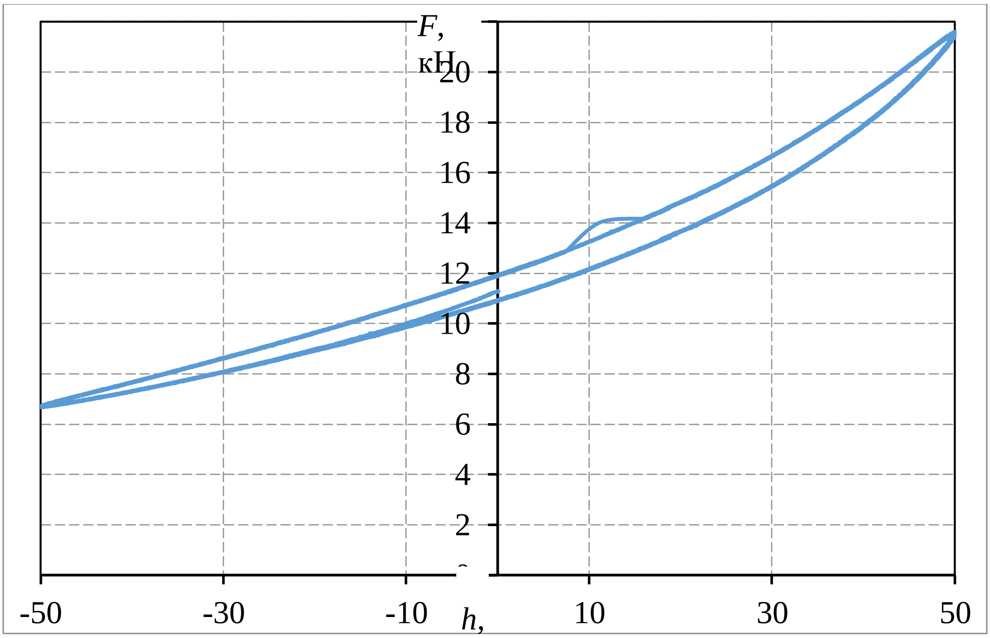

Fig. 5. The load characteristic of the pneumatic element at a pressure inside the cord of 4 atm.

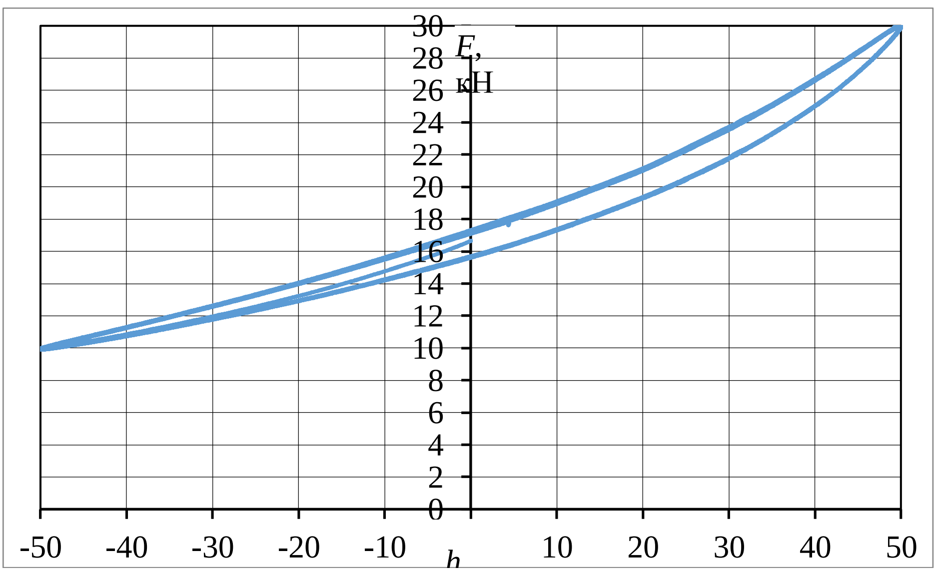

Fig. 6. The load characteristic of the pneumatic element at a pressure inside the cord of 6 atm.

In the above load characteristics, we observe a hysteresis loop. The hysteresis loop of the pneumatic element shows the relationship between the air pressure in the pneumatic element and its deformation. It allows you to assess the rigidity of the pneumatic element, its ability to return to its original state after removing the load, as well as the presence of energy losses due to internal friction.

A characteristic feature of the load characteristic is that with increasing pressure, it clearly shows how elastic properties, such as stiffness, change (which indicates the ability of the pneumatic element to absorb the energy of vertical vibrations).

For example, at a pressure of 1 atm. (in fig. 3) the stiffness is less, and the damping coefficient will be greater. In another example (in Figure 6), at 6 atm. the applied deformation force is higher, the pressure is higher, therefore the rigidity of the pneumatic element increases and the damping coefficient decreases. It follows that we can change the rigidity of the pneumatic element **-** so we have a tool for controlling the oscillatory process.

Due to the fact that the oscillating system is exposed to external influences, and this is usually a support base (roads, fields, etc.), it becomes necessary, especially when developing springing systems, to know the statistical characteristics of the microprofile of roads and fields.

Quantitative characteristics of the micro profile of roads and fields are determined to assess the condition of the surface and determine the need for work. The micro profile of a road or field is a set of surface irregularities that can be caused by various reasons, such as wear of the coating, weather conditions, uneven compaction of the soil, etc.[30]

The determination of the quantitative characteristics of the microprofile includes measuring the height and length of the irregularities, as well as assessing their distribution over the surface. This allows you to identify problem areas, determine the degree of their unevenness and choose the most appropriate method of repairing or improving the surface. [4]

In addition, the quantitative characteristics of the microprofile are used to assess the comfort of vehicles and the patency of agricultural machinery. The smaller the irregularities on the surface, the less vibration and shaking experienced by drivers or operators of self-propelled vehicles.

In continuation of the research, we determined the quantitative characteristics of the microprofile of roads and fields on specific backgrounds of technological agricultural operations. This will allow you to choose and justify the rigidity of the springing system.

Table 1 shows the statistical characteristics of the microprofile of roads and fields used by us to simulate traffic on the support base.

Table 1. Statistical characteristics of the micro profile of roads and fields

No.	Name of the indicator	Un. meas.	Value
	Plowed field (low furrows)		
1	Average value of irregularities	cm	0.966
2	Median	cm	0.968
3	Standard deviation	cm	0.389
4	Minimum	cm	-2.192
5	Maximum	cm	2.374
	Wet dirt road		
1	Average value of irregularities	cm	0.9955
2	Median	cm	0.9970
3	Standard deviation	cm	0.1367
4	Minimum	cm	1.08002
5	Maximum	cm	2.0868
	Dirt country road		
1	Average value of irregularities	cm	0.9425
2	Median	cm	0.9657
3	Standard deviation	cm	0.5736
4	Minimum	cm	-2.5408
5	Maximum	cm	2.7209

The data in Table 1 are obtained on the basis of previously recorded waveforms of real profiles of roads and fields. Figures 7-12 show spectral characteristics - histograms of the density distribution of the heights of the irregularities of the measured profile and random ordinates of the irregularities of roads and fields.

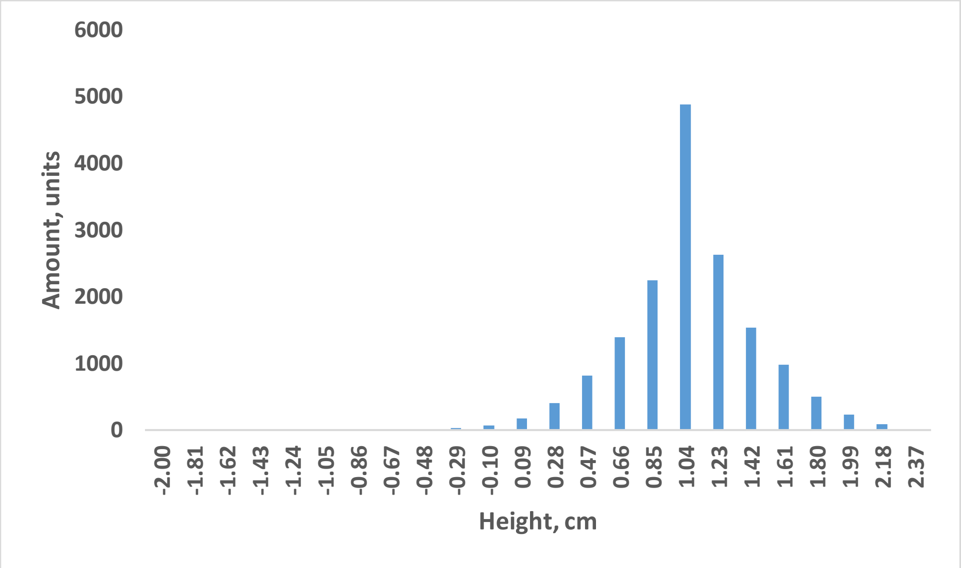

Fig. 7. A histogram of the density of the distribution of the height of the irregularities of the low furrows of the plowed field.

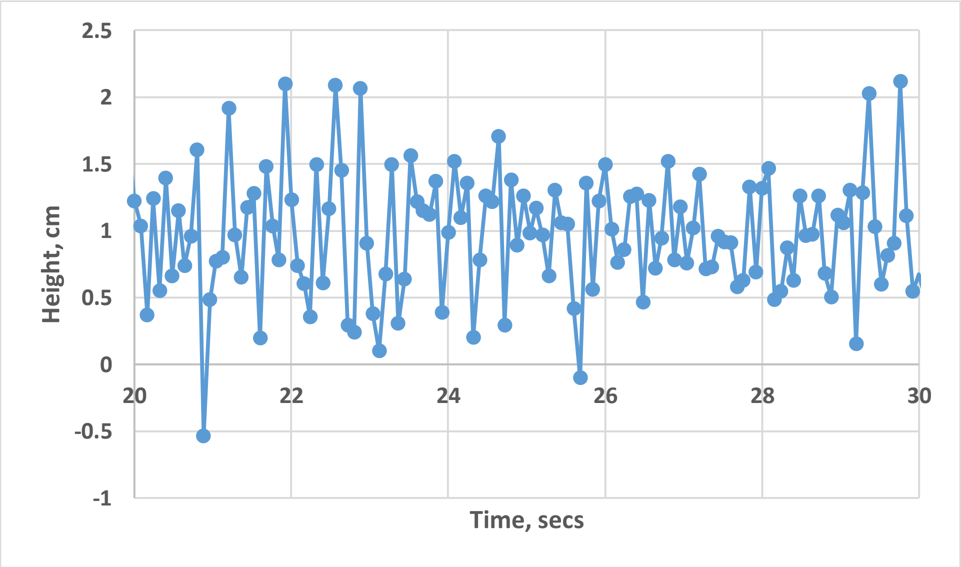

Fig. 8. The implementation of the process is the coordinates of random ordinates of the height of the irregularities of the low furrows of the plowed field.

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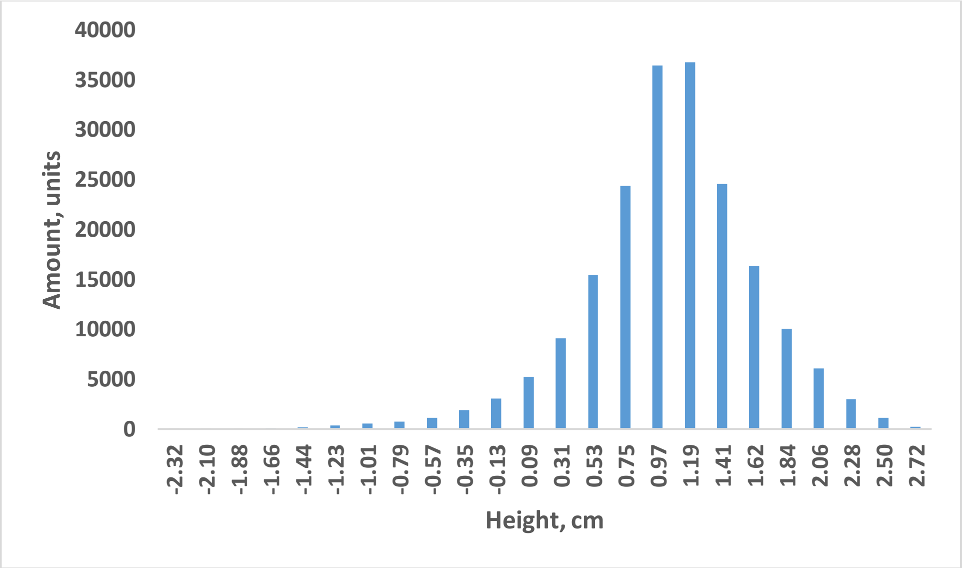

Fig. 9. Histogram of the density of the distribution of the height of the irregularities of a dirt country road.

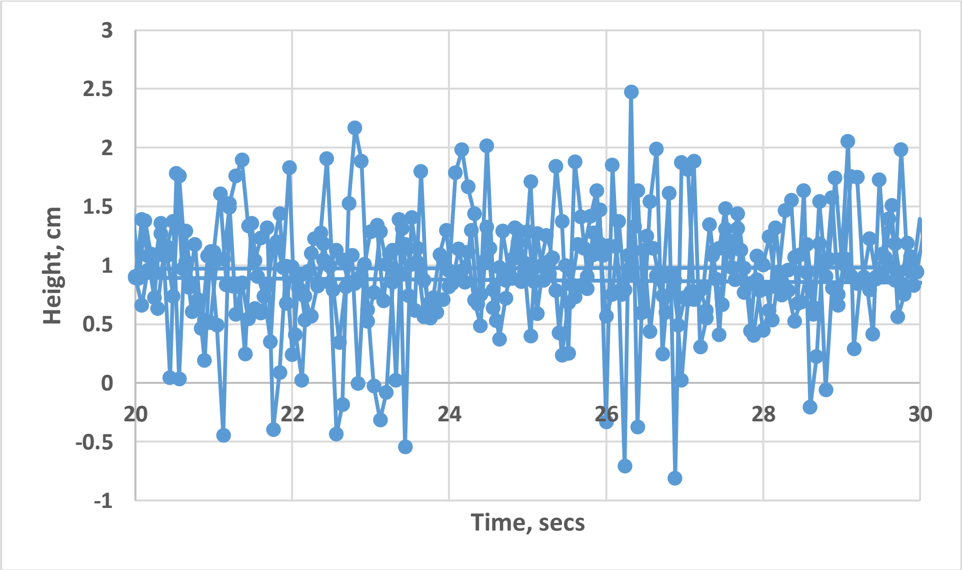

Fig. 10. Implementation of the process – coordinates of random ordinates of a dirt country road

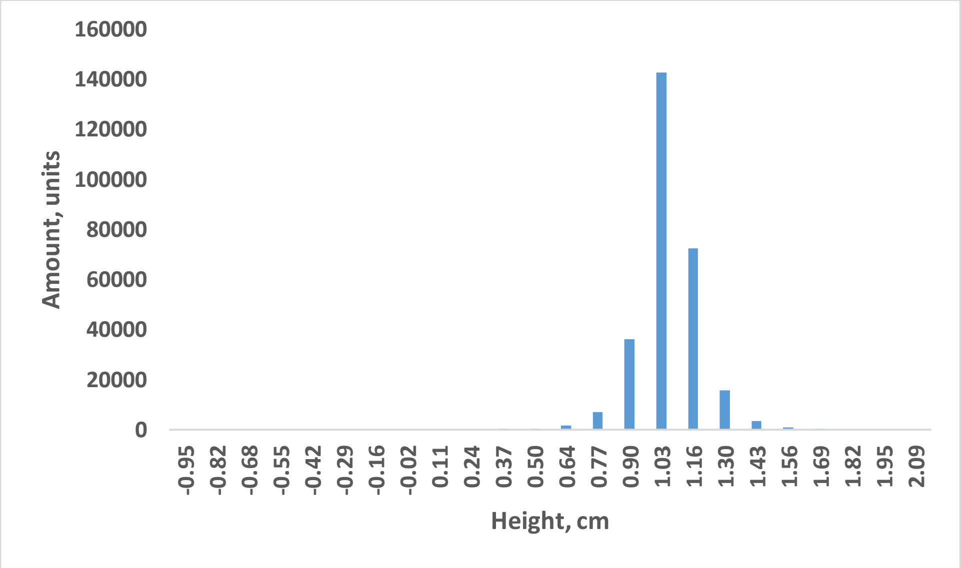

Fig. 11. Histogram of the density distribution of the height of the roughness of a wet dirt road

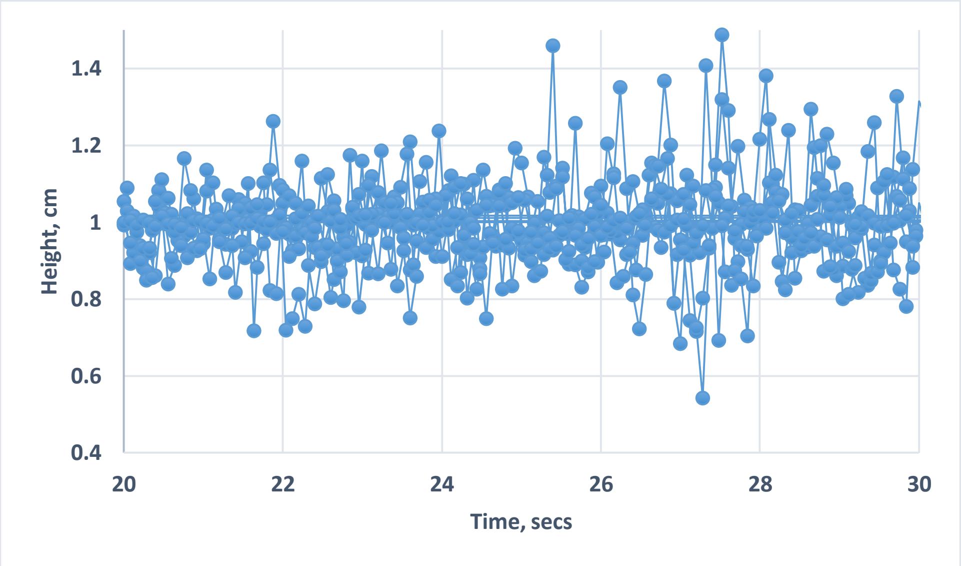

Fig. 12. Implementation of the process – coordinates of random ordinates of a wet dirt road

Using the method of testing statistical hypotheses, calculations were made on the correspondence of experimental histograms of the distribution of the height of road irregularities and fields to theoretical ones. With a confidence probability of 90%, it can be argued that the experimental histograms can be approximated by the normal distribution law.

The above research results will be used in the development and implementation of tractor axle springing systems, both in terms of the choice of controlled stiffness, and in terms of simulating disturbances from the pavement on the stand. The selected characteristics are inherent in rural areas and rural roads, including the fields on which the mobile power facility will move. These characteristics will be used to simulate disturbing effects from the support surface when modeling the oscillatory system on the stand.

4 Conclusion

In the above load characteristics, we observe a hysteresis loop, which indicates the ability of the pneumatic element to absorb the energy of vertical vibrations. Its characteristic feature is that with increasing pressure, the damping and elastic characteristics of the pneumatic element change. Over the entire range of increasing intracordial pressure, the load characteristics of the pneumatic element have a non-linear character. The obtained load characteristics are the basis for choosing the optimal value of the elastic-damping characteristics of the pneumatic element used in the test bench, and in the future in the adaptive springing system of the MES.

The selected design of the pneumatic element allows changing its elastic damping characteristics from 1 kN to 30 kN, respectively, when the pressure inside the pneumatic element cord changes from 1 atm. to 6 atm. There is also an increase in the area of the hysteresis loop (energy loss due to internal friction) at these corresponding pressures.

Experimental data of histograms of the density distribution of the height of road and field irregularities can be approximated by the normal distribution law with a confidence probability of 90%.

Statistical characteristics of the microprofile, as a disturbing effect on the "Road-Frame-Cab-Operator" system, are used to calculate the dynamic characteristics of the MES and select the control effect of the adaptive springing system when driving along various microprofiles. The presented characteristics relate to rural roads and fields in the central regions of Russia.

The obtained statistical characteristics of the microprofile of fields and roads showed that the adaptive springing system being created should be configured for a microprofile varying from the background type with the corresponding mathematical expectation from 0.94 cm to 0.99 cm with a standard deviation from 0.39 to 0.57.

The further direction of the research may include studying the influence of various parameters of the pneumatic element on its characteristics, as well as ensuring the development of effective methods for controlling vertical-angular oscillatory processes in MES when performing agricultural technological operations.

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