

On the assessment of vibroloading of vehicle drivers in agricultural production

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Abstract. In order to ensure safe working conditions for drivers, strict requirements are imposed on the smooth running of agricultural vehicles. The purpose of this research was to study the vibration load on the driver's seat when driving vehicle under agricultural conditions. Studies have revealed that the standard KamAZ-43255 car seat string system effectively damps vibrations with the frequency of more than 16 Hz, and practically does not damp vibrations below 4 Hz. It was determined that: at all speeds, the maximum values of vibration acceleration in the vertical plane are located in the second octave at the frequency of 2.0 Hz; peak values of vibration acceleration of the driver's seat in the horizontal plane are located in the third octave at frequencies of 3.15 ... 4.1 Hz; maximum mean square accelerations in the vertical plane are 3.76 times higher than the maximum permissible standards; at vehicle speed of $V = 20$ km/h, the acceleration of the driver's seat in the vertical plane exceeds the permissible values in 3.9 times, in the horizontal plane it exceeds the permissible values in 2.75 ... 2.79 times. Therefore, on agricultural vehicles, it is necessary to install spring systems that are adaptive to operating conditions.

1 Introduction

Road transport is an essential component of production, processing and distribution of agricultural products. In the agricultural sector of the Russian Federation, road transport exceeds 72% of the total volume of inter-farm transportation and up to 60% of on-farm transportation. The share of transport costs accounts for up to 38% of the total cost of agricultural products [1]. In this regard, reducing the cost of agricultural transportation, increasing the efficiency of using road transport at agricultural enterprises is the most important national economic task.

2 A problem statement

The operation of road transport in agricultural production is characterized by a number of factors that adversely affect the efficiency of their use [2, 3, 4, 5]. In the first place it is due

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to road and traffic conditions. Given to the specific nature of agricultural production, vehicles are mostly used on dirt roads and soil backgrounds.

Improving the efficiency of rolling transport on deformable supporting base is partially solved by coordinating the parameters of tires, transmission and chassis with driving conditions [6]. In particular, issues of automatic regulation of air pressure in tires are solved, pneumatic rollers with ultra-low pressure are developed and introduced, methods for automatic differential blocking are improved.

However, most scientific papers are devoted to solving problems of increasing the cross-country ability of vehicles and reducing the compacting effect of undercarriage on the soil. Research studies aimed at improving the ride quality of vehicles operating in agricultural production is clearly not enough. At the same time, in the works devoted to the study of the ride quality of vehicles when driving on agricultural background, there is a significant increase in dynamic loads on the elements of the undercarriage and the suspension. According to research studies[6, 7], dynamic loads on the elements of the undercarriage and the suspension of a vehicle when moving on agricultural backgrounds can be 4.5 ... 5.5 times higher than static ones.

At the same time, the vibroloading of drivers of vehicles who are engaged in the transportation of agricultural products may be 2.5 ... 3.5 times higher than the normative indicators established by Sanitary Code 2.2.4 / 2.1.8.566-96 [8, 9, 10]. According to studies [1, 5, 9, 11], the acceleration of the driver's seat in a vertical plane when moving along dirt roads can reach 4 m/s^2 .

This point of view is also noted in the reports of machine test stations subordinate to the Ministry of Agriculture of the Russian Federation. According to machine test stations subordinate to the Ministry of Agriculture of the Russian Federation. More than 50% of the machines submitted for state testing do not meet the technical specifications for many functional characteristics. This is due to the lack of information on the comparative effectiveness of technology and its functional characteristics, as well as there is failure to take account of specific operating conditions.

Currently, agricultural vehicles use passive suspensions due to the simplicity of design, high reliability and low cost. However, the vibration-proof properties of such suspensions currently do not meet the requirements of current standards.

This is due to two factors. Firstly, when designing passive suspensions, one has to face the problem of contradicting suspension requirements with regard to quality ride, as well as handling and driving stability. So, to ensure high ride quality, the suspension must have «soft» adjustments. On the other hand, in order to ensure good controllability and stability of movement, the adjustments should be sufficiently «rigid».

Therefore, the characteristics of the passive suspension system of the primary suspension are selected based on the average operating conditions. The existing design modes of loading suspension elements and the driver's seat, described in existing standards, are determined for conditions as close as possible to road operating conditions. However, these standards are ineffective for assessing the functional qualities of suspension systems for automobiles operating in agricultural production. A small step of irregularity, change in the elastic-damping characteristics of the suspension under the influence of operational factors, lead to the occurrence of off-design modes of movement, an increase in dynamic loads on the suspension elements and the driver's seat. The rheological properties of the supporting base, the nature of the distribution of stresses in the zone of contact of the wheel with the supporting base [6], the elastic-damping characteristics of tires, which are also not constant, have a great influence on the nature of external influences.

It should be noted that there are almost no economic prerequisites for improving the primary and secondary suspension systems for agricultural vehicles.

As practice shows, the economic effect obtained from introducing new technical solutions of the primary and secondary suspensions often does not justify the financial costs of their development.

As practice shows, the economic effect obtained from the introduction of new technical solutions of the primary and secondary suspensions often does not justify the financial costs of their development. However, the practice of operating motor transport shows that the lack of normal working conditions for the driver both directly and indirectly affects the technical and economic indicators of using a vehicle. At high amplitudes of oscillations, the driver is forced to reduce vehicle speed, which is accompanied by a decrease in the average line speed and consequently by the productivity of transport performance. In addition, under conditions of vibrations in the external disturbance the specific fuel consumption of the engine and the fuel efficiency of the vehicle increase as a whole [5].

A high level of vibroloading of the driver's seat affects his health, causing fatigue and loss of concentration. This leads to a decrease in the average speed on the line, and is one of the main causes of road traffic accidents.

The seriousness of this problem is also noted in GOST 12.1.012-2004, which obliges manufacturers of self-propelled vehicles to indicate in the technical documentation numerical indicators of vibration characteristics.

GOST 12.1.012-2004 are allowed not to give the numerical indicators of the vibration characteristics of transport and technological machines only if the maximum value of the full corrected acceleration for the total vibration does not exceed $0,25 \text{ m/s}^2$, for local vibration – $1,25 \text{ m/s}^2$. However, in this case instructions for use should take low vibration activity of a machine into account.

Therefore, from this point of view providing a comfortable working environment for the driver allows us to increase the average speed on the line, to use the performance of vehicles more efficiently [1, 2, 3, 4, 5, 9, 10, etc.].

The solution to this problem requires the development of new active primary and secondary suspensions that could change their elastic-damping characteristics depending on traffic conditions and nature of the external disturbing force.

The development of such suspensions requires comprehensive research and analysis of the nature of the disturbance effects on a vehicle in the conditions of agricultural production, research and search for ways to reduce vibroloading of a driver's seat.

The use of modern engineering and calculation programs such as Ansys, Adams, LMS Virtual, used to determine the level of vibrations, do not allow to fully assess the vibroloading of a driver and transported goods [12]. Moreover, as many researchers have noted, it is advisable to use calculation methods in cases of the simplest modes of movement. This is due to both many assumptions made in the development of simulation models, and the inability to take into account all the nuances encountered when operating a vehicle in real conditions. When studying the dynamics of the «vehicle – road – driver» system, and in particular the vibroloading of the driver. Despite the high cost, preference should be given to field tests.

This position is also substantiated in GOST 12.1.012-2004, which allows monitoring the vibrations of the operator's seat by calculating the monitored parameter only in cases where the vibrations do not change significantly when operating conditions and operating modes changing.

The objective of the research paper is to assess the vibroloading of the driver's seat of a terrain vehicle KamAZ while driving on an agricultural background during harvesting and field work.

3 Research methods

The studies were conducted when a vehicle was moving along the stubble from under the cereal ears. The general characteristics of the soil background and the test conditions were determined in accordance with the requirements of GOST 20915-2011.

The statistical indicators of the agricultural background were obtained by recording the microprofile of the field immediately after harvesting cereal crops. The writing of the smoothed microprofile of the stubble was carried out using special equipment based on the MTZ-80 tractor, developed at the Azov-Black Sea Engineering Institute.

To process the oscillograms, we have used the technique proposed by A.A. Silaev.

The statistical indicators of the microprofile of the agricultural background used for studies are presented in Table 1.

Table 1. Statistical indicators of the microprofile of the agricultural background.

Point No.	Indicators of the Agricultural Background	Value of Indicators
1	Maximum height of irregularities, m	0.0719
2	Minimum height of irregularities, m	0.0445
3	Standard deviation, m	0.0241
4	Dispersion, m ²	0.000594

The methodology for measuring and estimating vibrations effecting the driver's seat met the requirements of GOST 31319-2006 (EN 14253: 2003). The experimental determination of the accelerations of the cab and the driver's seat was carried out using the sound level analyzer spectrum OKTAVA-101 AM.

To measure the accelerations of the driver's seat, the AR 98 vibration transducer was used, which was designed to measure root-mean-square, equivalent, and peak vibration accelerations in the frequency range of external influences from 0.8 to 123.0 Hz. The device allows us to measure and record accelerations in the vertical, horizontally transverse, and also longitudinally horizontal planes.

Measurement of vibration accelerations of the driver's seat was carried out in the «General vibration» mode.

To measure the vertical accelerations of the cab, the AP 98 vibration sensor was mounted directly on the cab floor under the driver's seat.

To measure the acceleration of the driver's seat, the AP 98 vibration transducer was mounted on an intermediate disk placed on the seat under the driver's supporting base. To eliminate the possibility of loss of contact from the driver's seat, the disk was fixed using double-sided adhesive tape.

The installation location, the attachment of the semi-rigid disk, as well as the driver's weight, met the requirements of GOST ISO 10326-1 - 2002.

The time of the experiment was set on the control panel and amounted to

60 s. To calculate the multiplicity of experiments, D.A. Dospekhova's method [13] was used. The track traveled by the vehicle during the experiment depended on the speed and amounted to 150 ... 600 m. During the test, the vehicle was moving uniformly along the diagonal of the field. Previously, the speed was determined by the speedometer, and at the end of the experiment it was specified by the length of the track traveled by the vehicle during the experiment. The track traveled by the vehicle during the experiment was determined by the readings of the track measuring wheel.

To reduce system errors during the experiment, the operation instructions for measuring equipment were strictly observed. The measurement error of the OKTAVA-101 AM device during the experiments corresponded to the requirements of GOST 17187-2010.

The software made it possible to save the results of measurements in the operational memory of the device with the possibility of subsequent printing on a printer.

Discussion of research results. As a result of the tests, octave and third octave spectra of vibration accelerations of the vehicle's cab were obtained, as well as the driver's seat in the vertical, horizontally longitudinal and horizontally transverse planes.

A preliminary analysis of the results of the tests showed that the high-frequency components of the driver's seat accelerations did not go beyond the measured range. At all vehicle speeds, there was no overload of the measuring system.

Peak accelerations of the driver's seat did not exceed the acceleration of gravity $g = 9,81 \text{ m/s}^2$, which confirmed the absence of loss of contact between the driver and the vehicle seat.

In addition, in order to reduce measurement errors, during the experiment the driver was strictly forbidden to get up from the seat, and also to change the pressure on the supporting leg when the vehicle operating.

The maximum acceleration of the cab in the vertical plane obtained as a result of field tests was $2,83 \text{ m/s}^2$ at a frequency of external influences of $\omega = 1.59 \text{ Hz}$.

The results of the studies indicated to a low damping ability of the suspension of the cab of terrain vehicles KamAZ. As the studies showed, the suspension of the KamAZ cab hardly dampens high-frequency oscillations and almost passes low-frequency oscillations and oscillations with an average frequency. So, at the frequency of external influences of $\omega = 3,6 \text{ Hz}$, the acceleration of the cab accounted to $1,48 \text{ m/s}^2$ with acceleration of the front axle equal to $j_1 = 1,51 \text{ m/s}^2$.

Two criteria were used to assess the vibroloading of the driver's seat: the vibration spectrum (the mean square value of the vibration acceleration in third octave bandwidth) and the frequency-adjusted vibration accelerations effecting the driver's seat. Both criteria were compared with hygiene standards established by the requirements of Sanitary Code 2.2.4 / 2.1.8.566-96. Therefore, the levels of rms accelerations of the driver's seat were determined in the vertical, longitudinally horizontal and longitudinally transverse planes when the vehicle was moving at different speeds.

The dependences of the rms vertical accelerations of the driver's seat on the frequency of external influences at various speeds are presented in Figure 1.

An analysis of the obtained results of field tests showed that the standard suspensions for the cab and the seat of KamAZ drivers do not ensure compliance with the Sanitary Code 2.2.4 / 2.1.8.566-96.

As one can see from Figure 1, at all speeds the maximum values of accelerations in the vertical plane are located in the second octave at frequencies of external influences of $=1,9...2,1 \text{ Hz}$. The nature of the flow of the acceleration curves in the vertical plane indicates the presence of a marked resonance regime at these frequencies. The maximum root-mean-square acceleration of the driver's seat in the vertical plane at speed = 20 km/h was 1.69 m/s^2 , which is 3.76 times more than the maximum permissible value established by the requirements of Sanitary Code 2.2.4 / 2.1 .8.566-96.

At a speed of = 30 km/h the rms acceleration of the driver's seat in the vertical plane was $1,18 \text{ m/s}^2$, which is 2.28 times higher than the maximum permissible values.

The dependences of the rms accelerations of the driver's seat in the horizontally longitudinal plane on the frequency of external influences at different vehicle speeds are presented in Figure 2.

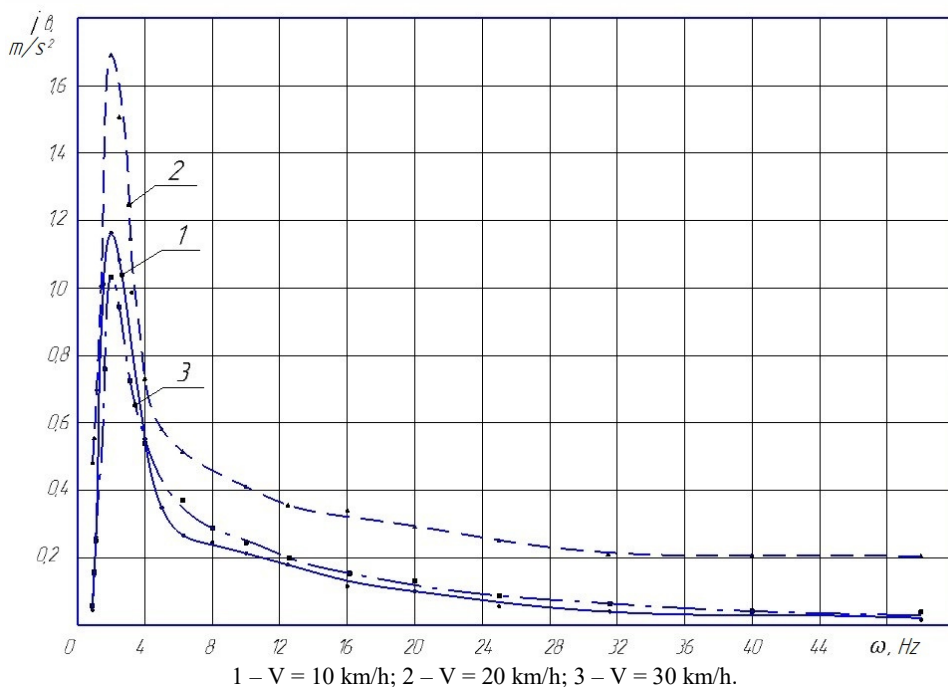


Fig. 1. The dependence of the rms values vertical accelerations of the driver's seat on the frequency of external influences at various speeds.

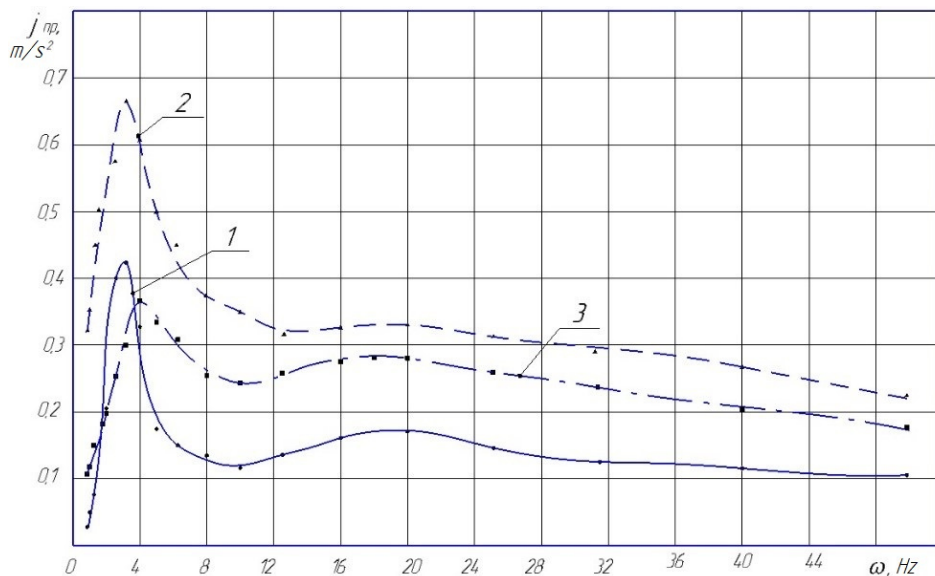


Fig. 2. The dependence of the rms acceleration driver's seats in the horizontal plane on the frequency of external influences at various speeds.

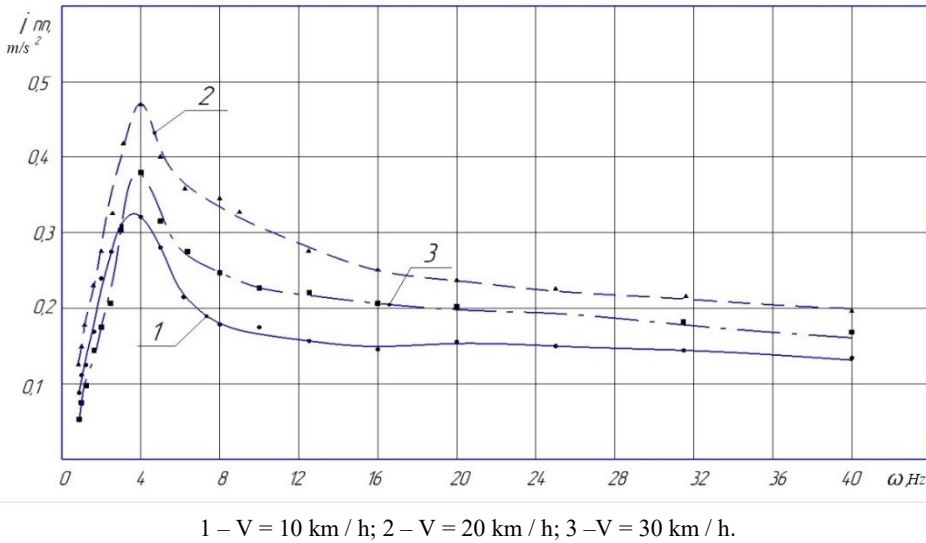


Fig. 3. The dependence of the rms accelerations of a driver's seat in the horizontally transverse plane on the frequency of external influences at various speeds.

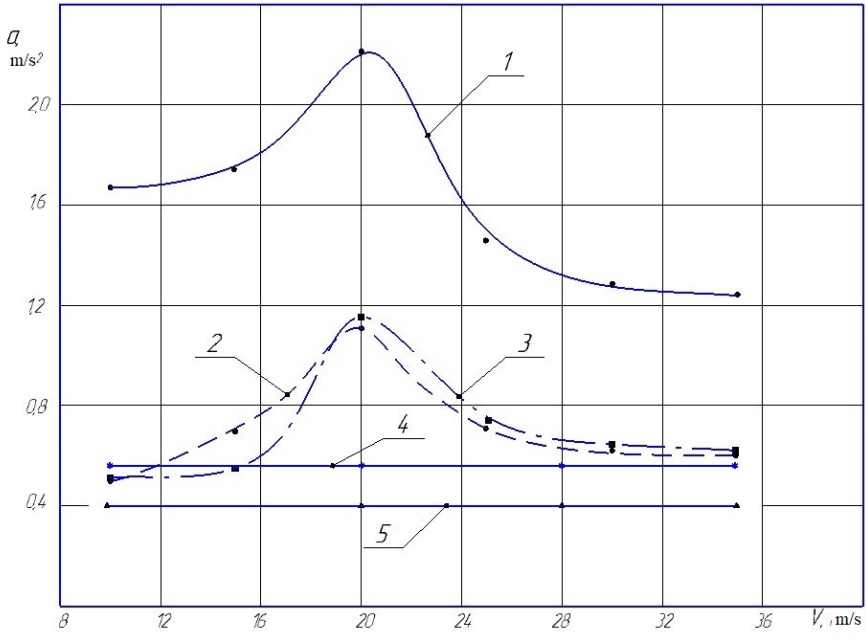
As one can see from Figure 3, the absolute peak values of the maximum accelerations of the driver's seat in the horizontally transverse plane are less than the peak accelerations in both horizontally longitudinal and vertical planes.

Peak values of the rms vibration acceleration of the driver's seat in the horizontally transverse plane, as well as vibration accelerations in the horizontally longitudinal plane, which are located in the third octave at frequencies from 3.15 to 4.0 Hz.

In the entire frequency range of external influences, the maximum values of vibration accelerations in the horizontally transverse plane are also marked at a speed of 20 km/h.

At a speed of = 20 km/h the maximum value of vibration accelerations in the horizontally transverse plane was 0,47 m/s², which is 17.5% higher than the maximum permissible values of vibration accelerations in the horizontally transverse plane established by the requirements of Sanitary Code 2.2.4 / 2.1.8.566-96.

The minimum values of vibration accelerations of the driver's seat in the horizontally transverse plane are observed at a speed of 10 km/h. The peak value of vibration accelerations in the horizontally transverse plane was 0.32 m/s², which is 15% less than the permissible values.



1 – accelerations in a vertical plane; 2 – horizontally longitudinal accelerations; 3 – horizontally transverse acceleration; 4 – permissible value of accelerations in a vertical plane; 5 – permissible value of acceleration in the horizontal plane.

Fig. 4. Dependencies of equivalent adjusted vibration accelerations of the driver’s seat on the vehicle speed V .

The frequency corrected vibration acceleration of the driver’s seat was determined in accordance with the requirements of Sanitary Code 2.2.4 / 2.1.8.566-96.

$$\tilde{a} = \sqrt{\sum_{i=1}^n \frac{(j_i \cdot K_i)^2}{n}} \quad (1)$$

where \tilde{a} – the frequency corrected value of vibration accelerations, m/s^2 ;

j_i – root mean square of vibration acceleration in the frequency band, m/s^2 ;

K_i – weight coefficient for the frequency band for the root mean square value of vibration acceleration;

n – the number of frequency bands in the normalized range.

Processing of test results was carried out using a specially designed program. The values of the weight coefficients for each type of vibration were taken in accordance with the recommendations of Sanitary Code 2.2.4 / 2.1.8.566-96.

The dependences of the equivalent corrected vibration accelerations in the vertical, horizontally longitudinal and horizontally transverse planes on the vehicle speed are shown in Figure 4.

As one can be see from Figure 4, the entire range of speeds, the calculated corrected vibration accelerations exceed the permissible values established by the requirements of Sanitary Code.

At a speed of $v = 20$ km / h, acceleration in the vertical plane exceeds 3.9 times, in the horizontal plane – 2.75-2.79 times more than the permissible values.

4 Conclusion

Field tests of the vibroloading of the driver's seat when driving on the agricultural background allowed the following conclusions:

1. The vibroloading of the driver's seat when driving on the agricultural background depends on the speed V . The maximum vibration accelerations of the driver's seat in the vertical and horizontal planes are observed at a speed of $V = 20$ km/h.

2. The cab suspension of terrain vehicles KamAZ hardly dampens high frequency oscillations and almost passes low-frequency oscillations and oscillations with an average frequency.

3. The curves of the rms accelerations of the driver's seat in the vertical plane have a marked maximum in the second octave at an average frequency of external influences of $\omega = 2.0$ Hz.

4. The maximum values of rms accelerations in the vertical plane j_B are 3.76 times higher than the permissible values established by the requirements of Sanitary Code 2.2.4 / 2.1.8.566-96.

5. The maximum root-mean-square accelerations in the horizontal plane are observed in the third octave band at frequencies of external effects ω from 3.15 to 4.0 Hz. The rms accelerations in the horizontal plane $j_{\text{гн}}$ exceed the maximum permissible values by 17.5%.

6. The regular system of the suspension of the driver's seat of the terrain vehicle KamAZ effectively dampens high-frequency oscillations with a frequency of ω over 16 Hz. The suspension system of the driver's seat leaks and barely dampens low-frequency oscillations and medium-frequency oscillations.

7. The standard system of suspension of the cab and driver's seat of the terrain vehicle KamAZ-43255 does not meet the requirements of Sanitary Code 2.2.4 / 2.1.8.566-96 in terms of equivalent corrected vibration speeds in vertical and horizontal planes, and requires serious revision

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