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Methodology for experimental study of soil microrelief on ruts in bridge farming

Abstract. The study of issues related to the research of the soil's state on the surface of the most constant technological track is relevant, since the movement of running wheels along narrow tracks determines the traction and coupling properties of the machine-tractor units, their vibrations, the stability of movement and the controllability of movement. The purpose of this study was to increase the efficiency of the process of profiling the microroughnesses of the soil surface located in areas that form a track along which the running wheels of machine-tractor units will move, by substantiating a new scheme of an automated profilograph and developing methods for its use. For this study, modern methods of experimental researches based on IT technologies were used. In particular, an automated complex has been developed for measuring and evaluating the microprofile of soil surface irregularities on the very track of the tramline. The results of experimental studies in this matter have shown that the standard deviation of the soil surface irregularities reaches ±0.84 cm. This gives reason to consider the harmonic components of these functions as damped, having normalized correlation functions. The graphs constructed using PC have showed that most of the dispersions of soil surface irregularities on the ruts are concentrated in the range of 0...0.3 cm^{-1}. It has been established that the generator of the formation of irregularities in the longitudinal profile of traces of a permanent technological track acts as parameters of the treads of the wheels of machines moving along it. The obtained results of the study can be used when selecting the protectors of pneumatic tires of the running wheels of machine-tractor units moving on two tracks

Keywords: track vehicle; irregularities; oscillations; correlation function; spectral density

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INTRODUCTION

The traditional farming system has reached the limits of its ability regarding the increase in the crop yields, energy costs of the growing and harvesting process and overall efficiency, as a result of excessive compaction of the topsoil. A wide variety of technical means, their significant weight, the intensive impact of their running systems (propulsion) on the soil, the repeated passes through the fields lead to soil compaction, a decrease in the soil fertility and biodegradation. Restoring the natural state of the soil is very problematic.

Therefore, the so-called bridge farming system is becoming more and more widespread in the world; its main basis lies in the movement of energy resources along two rather narrow tracks, which are used repeatedly and are actually taken out of the usable area on which crops are grown.

For this purpose, new designs of bridge power facilities were developed in researches [1-3], and their theoretical and experimental studies were carried out. According to them, the same transport and technological tracks for the movement of vehicles and energy vehicles are used for tillage, sowing of plants, spraying and harvesting [4-6]. In the works [7-9], it is described the process of formation of compacted and aligned traces of a constant technological track that consists in its laying on the field area with a given step, either as a result of repeated

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passes of agricultural machinery, or with the help of special tools [7-9]. The microrelief (irregularities of the longitudinal profile) of the constant technological track formed in this way is an important characteristic, which has been analized in the articles [10; 11]. Because the intensity of external disturbances acting on the power and transport vehicles moving along it significantly depends on it (microrelief) and largely determines their operational and technological parameters, reliability, smoothness of movement, vibration conditions of the operators' work.

Back in the day [7; 8], it was developed and tested a prototype of an agricultural tool for laying a permanent technological track. The basis of this tool is the middle section of the spring harrow BP-8, which is equipped with additional support wheels, two plow bodies with a width of 0.35 cm each and hydrogenated markers. S-shaped tools of the instrument are turned 180° and are equipped with lancet tines with a working width of 150 mm for better loosening of the soil. After laying the specified tool a constant tramline, the main share of dispersion of its longitudinal profile oscillations was concentrated in the frequency range of 0...2.5 m^{-1}, and the dispersion value of these vibrations was 3.8 cm^2 [8].

It should be noted [12-14] that the methodology of profiling of soil-road backgrounds is well developed based many years of practice. However, in most cases, scientists use either direct discrete measurement of the heights of irregularities of the path micro-profile, or mechanical profilographs with recording the ordinates of irregularities on a paper tape. Thus, traditional methods of measuring track profile irregularities by rails or mechanical self-recording profilographs due to their high labor intensity, as well as due to the lack of automation of measurements are already obsolete.

The modern scientific and technical level of experimental research allows directly and remotely recording the implementation of processes on a PC using analog-to-digital converters with simultaneous automatic processing of results, adjusting the process of experimental research, which significantly increases the accuracy of measurements.

Automated profilographs and profilometers are a promising direction of creation of such devices of new generation, which allow measuring directly the surface micro-profile of the longitudinal profile of the track. These devices can be mounted on a transport or energy vehicle. Such measuring equipment can be equipped with laser, optical, ultrasonic non-contact and other sensors together with the accelerometer and gyroscopes, as well as sensors of angular displacements, etc. However, not enough attention is paid to the issue of creating such devices in the popular science literature.

The purpose of this study is to develop an improved technique for laboratory study of soil irregularities on the tracks along which the running wheels of bridge agricultural vehicles move, which increases the efficiency of profiling through the use of a new design of an automated profilograph.

MATERIALS AND METHODS

Obtaining the reliable information about the unevenness of soil surface is possible in case of using a device-profiler, i.e. a device that is used to assess the irregularities along the length of the distance traversed by any scoring section. Under the guidance of Volodymyr Bulgakov (National University of Bioresources and Nature Management of Ukraine), it has been designed such a profiler, which makes it possible to automate the process of taking information about irregularities, the soil surface, which are present on the traces of track, on which the bridge agricultural vehicle moves. The Figure 1 shows a general view of this profiler, which is a mechanical part in the form of main body 1, which has the ability to freely slide along the guide 2 or fix its location anywhere on the guide 2. The main body 1 contains a mechanism for fixing the unevenness of soil surface on the track in the form of roller 4 freely mounted on the axis, which is located at the end of the arcuate lever 6. The main body 1 moves along the guide 2, while the roller 4 freely rolls along the uneven surface of the soil 5 without crushing the surface soil layer and without deforming it. The arcuate lever 6 is made in the form of a two-arm lever and it is rotatably mounted in a cylindrical hinge. In this case, the second end of the lever 6 is connected to the reohing sensor 3 (the sensor is manufactured industrially and has the brand SP-3A), which rotates when the second (short) part of the arcuate lever 6 is turned as a two-arm lever. When the sensor 3 is rotated, its electrical resistance changes and an alternating electrical signal is transmitted to the electrical part of this device, i.e. to analog-to-digital converter 7 (also produced by the industry and has the PK-9 brand). Converter 7 is connected to a personal computer 9, which (according to the developed program) processes the signal, captures it and transforms the signal in the form of graphs. This measuring system receives electrical power from battery 8. The mechanical and electrical parts of this measuring device were preliminarily configured. The proposed measurements of the unevenness of soil surface were calibrated and the programs of personal computer were adjusted. The measurement and fixation of soil surface irregularities on the tracks of a bridge agricultural vehicle of constant size were carried out when the main body 1 moved at a translational speed of 0.5 $m \cdot s^{-1}$ along the guide 2 from the one end to another.

The signal from the profilograph was processed using Power Graph 2.1, both in analog and digital forms.

The profiler was calibrated (see Fig. 1) on a flat surface, placing plates of different thicknesses under its wheel. Roller 4, freely mounted on the axis and placed at the end of the arcuate lever 6, slid along these plates, turning the SP-3A sensor at fixed angles. In this case, these angles were recorded by a PK-9 transducer and an electrical signal was transmitted to a personal computer. The calibration dependence of the output signal readings (*v*) in the Power Graph 2.1 environment on the actual ordinates (*h*, cm) of the profiler irregularities looked like:

$$h=38.8 \cdot v-5.52. \quad (1)$$

Comparing the results of multiple measurements during calibration and similar measurements of fixed heights of soil surface irregularities, their registration and computer processing by this profiler design (see Fig. 1), it has been found that the relative measurement error is no more than 3% (2.5%), which indicates a sufficiently high measurement accuracy.

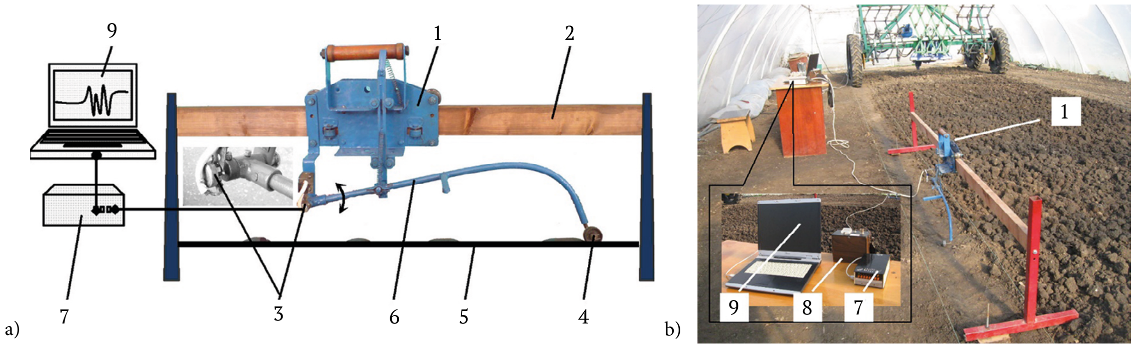

Figure 1. Automated profilograph (a) and hardware-measuring complex (b) for assessing the unevenness of the longitudinal profile of the traces of a permanent technological track and: 1 – profilograph body; 2 – rail; 3 – rheochord sensor; 4 – profiler wheel; 5 – unevenness of the longitudinal profile of the track; 6 – profilograph lever; 7 – analog-digital converter; 8 – battery; 9 – PC

Then, with the help of specially developed program for calculating and constructing the correlation-spectral characteristics of the inequalities of microprofile of soil and road backgrounds in Microsoft Office Excel, it was carried out the mathematical analysis of the data obtained.

The normalized correlation function $\rho(l)$ of the fluctuations of microtrack irregularities of the constant process track was calculated as the ratio of the correlation function to the variance [14]:

$$\rho(l) = \frac{1}{D_h(n-m)} \sum_{i=1}^{n-m} (h_i - m_h)(h_{i+m} - m_h), \quad (2)$$

where n – the number of measurements; m – the number of points of correlation function, m=0, 1, 2, ...; h_i – ordinate of inequality, cm, i = 1, 2, ..., m; m_h – mathematical expectation of ordinates of inequalities, cm; D_h – dispersion profile background, cm^2. The normalized spectral density $s(\omega)$ of the oscillations of micro-profile irregularities of the traces of a constant technological track was determined by the ratio of spectral density to the variance of the random function [14]:

$$s(\omega) = \frac{\Delta l}{\pi}\left[1 + 2\sum_{i=1}^{m} \rho_i(l) \cos(m_i \cdot \Delta\omega)\right], \quad (3)$$

where Δl – profile measurement measurement interval, cm; $\Delta\omega = \frac{\pi}{m \cdot \Delta l}$ – step frequency of profile inequalities, cm^{-1}.

In the theories of probability, the equations (2) and (3) that relate a cross-correlation function to a spectral density function, are called "cosine-Fourier transforms". Thus, the normalized correlation function and spectral density are expressed one by one via the "Fourier transform".

Experimental studies were conducted in a greenhouse complex (Fig. 2), on the basis of which the laboratory was specially equipped for testing a bridge agricultural tool, specially designed for its use in the track agriculture. Under the conditions of this laboratory, a permanent technological track was artificially created on the soil. The longitudinal profile of its irregularities was finally formed by means of repeated passes of the engines of the newly constructed axle-driven agricultural machine over it.

Figure 2. Laboratory for testing a new construction bridge agricultural machine with a permanent technological track

Thus, it was reproduced an actual production situation under the laboratory conditions, when a bridge power tool, repeatedly moving its running wheels along the narrow tracks (on both sides) in both directions of movement and performing a real technological process of harrowing the soil, formed the surface layer of soil with the treads of pneumatic tires of its wheels right on the tracks. It was under the influence of real soil resistance during harrowing by this bridge power tool that the pneumatic tire treads of its wheels realized epy real traction properties and thereby formed a structure and corresponding surface irregularities in the surface soil layer.

After 5-6 passes of the bridge power tool, the corresponding surface profile remained on the ruts during the process of harrowing the soil, which was later measured using the developed profiler, and further processed and studied using a personal computer.

It is quite obvious that when performing another technological process (for example, plowing), the bridge power tool, overcoming significant traction resistance, will form irregularities on the surface soil layer in each track with its pneumatic tire treads, which will have different statistical indicators. In this case, the irregularities can be sufficiently smoothed (due to the slipping of the propellers), and their ordinates will be small; the surface layer of the soil can be significantly crushed, and so on.

However, in this experimental study, the statistical characteristics of unevenness of the soil surface were studied precisely during the harrowing of the soil by a bridge power tool.

RESULTS AND DISCUSSION

To study the statistical characteristics of the longitudinal microrelief of soil surface irregularities in the system of track farming, a new method was developed for automated obtaining of the statistical characteristics of these irregularities using the developed profilograph of a new design, consisting of mechanical and electrical parts and a personal computer.

The developed method of experimental study of soil microrelief on tracks in bridge farming makes it possible to obtain reliable values of statistical characteristics with minimal cost and with a high degree of accuracy, which can later be successfully used in studying the dynamics of movement of bridge agricultural machine units equipped with various agricultural machines and implements.

According to the steps of this methodology, i.e. to obtain such results, it is planned to simulate a section of the track technology of tillage in the laboratory and prepare technological tracks along which the running wheels of the bridge power vehicle under study will move. This is a prerequisite: the formation of track by the running wheels when the bridge power tool performs a real technological process, which corresponds to the actual tillage or a particular used agricultural implement. In this case, the studies were carried out during the technological operation of harrowing the soil in the inter-track space. The fulfillment of this condition according to the developed methodology is mandatory, since the running wheels of the bridge power tool are capable of forming the surface layers of track, because the real transmitted torques, real traction forces, real traction properties of the pneumatic tires of the running wheels, as well as the shapes and sizes of the treads of these pneumatic tires will form the external view, geometric dimensions and properties of the longitudinal profile of the unevenness of soil surface on two tracks along which the bridge power vehicle will move.

The repeated movement of running wheels of the bridge power tool makes it possible to form a surface layer of ruts and irregularities as a result of the passage when the technological process is performed in two directions. This is precisely due to the fact that the primary pass will only contribute to the formation of tramline on both sides, and the second pass will form the properties of track. Thus, the passage of bridge power tool in the opposite direction will reflect the real state of unevenness of the soil surface during their subsequent longitudinal measurement. Movements in these directions are carried out under the same external conditions, i.e. the same temperature, air humidity and soil.

Subsequent passes of the experimental bridge energy facility in excess of those indicated will contribute to a strong smoothing of the microrelief precisely on the tramlines. There will be rolling and compaction of the soil surface on the ruts, which will eventually give a distorted picture of unevenness of the soil surface on the ruts. At the same time, it is not mandatory the removal of high-frequency irregularities of the soil surface on the tracks for a bridge power tool for agricultural purposes due to a fairly soft and loose surface layer.

After the passage of this bridge power unit along the tracks, the bridge power tool was stopped according to the specified methodology; using the developed profilometer, it was assessed the state of unevenness of the soil surface located on both sides of the tracks; the measurements were made in the test areas; computer processing of the measurement results was carried out.

Thus, the main results obtained with the help of a new design profiler on the assessment of statistical characteristics of the soil surface irregularities on the tracks along which the running wheels of the bridge agricultural vehicle move, refer only to the data obtained when the bridge power tool performs the technological process of harrowing the soil in the inter-track space. In the case of performing other agricultural work with this bridge power tool, the pattern of unevenness of the soil surface on the tracks will be different.

It should be noted that the running wheels of the bridge power tool during laboratory experimental studies were equipped with pneumatic tires brand 9.5R32 (two wheels on each side), and the harrowing of the field surface in the inter-track space was carried out by three tine harrows brand BZSS-1.0, overlapping the entire width of the inter-track space.

According to the results of experimental studies and their processing on a personal computer, it has been constructed the graphs that should be attributed precisely to this type of agricultural work and this type of wheels and pneumatic tires, which amounted to 2 unites on each side on the studied bridge power facility.

The conducted laboratory experimental studies made it possible to obtain such data. As a result of profiling the irregularities of longitudinal profile of the soil traces of a constant tramline, it has been found that the main statistical indicator (as a standard deviation) in this case reaches ±0.82...0.84 cm. In essence, these are the damped periodic oscillations, as it is shown in the form of a curve of the normalized correlation function (Fig. 3). It should be noted that the form of normalized correlation function shows that the length of correlation connection of the heights of unevenness of the soil surface on the tracks reaches 0.18 m, which is due to the distance between the protrusions of treads of pneumatic tires of the running wheels of the bridge power vehicle. In this case, the bridge power vehicle is equipped with 9.5R32 pneumatic tires, in which the distance between the lugs of tread reaches exactly 0.175 m at normal air pressure inside the tire.

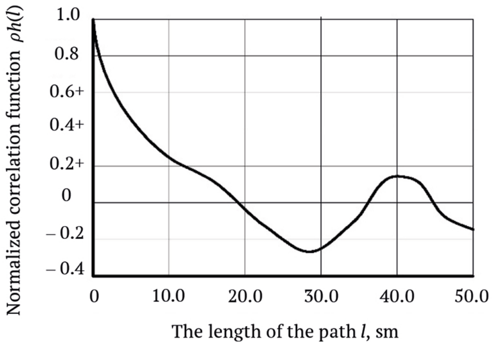

Figure 3. Dependence of the normalized correlation function $\rho_h(l)$ of the roughness of the soil surface of track along which the power tool moves on the length of traveled path

The normalized spectral density of the oscillatory process is the second most important statistical characteristic. After processing the results of experimental study, a new frequency spectrum has been obtained, which characterizes the random function of unevenness of the soil surface in the ruts along which the running wheels of the bridge power vehicle move. The dependence of normalized spectral density of the ordinates of roughness of the soil surface on the oscillation frequency is shown in the Figure 4. As it can be seen on this graph, the cutoff frequency of the oscillatory process under consideration reaches 0.3 cm^{-1}, provided that the main scattering fraction is precisely in the range from 0 to 0.3 cm^{-1}. This is confirmed by the size of depressions in the tread of pneumatic tires of the running wheels of the bridge power tool. It has also been found that the standard deviation of the ordinates of roughness of the soil surface on the tracks is also consistent with the height of tread of the pneumatic tires of the running wheels of the bridge power vehicle. Namely, the dimensions of tread protrusions of a 9.5R32 pneumatic tire are 0.03 m at an average air pressure inside the tires.

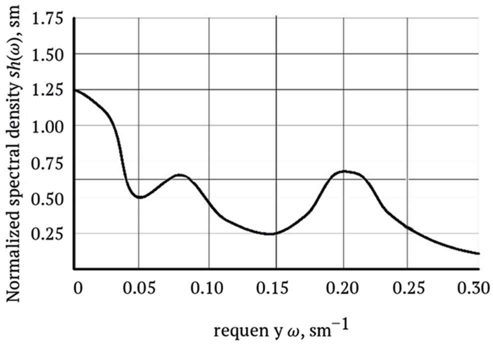

Figure 4. Normalized spectral functions $s_h(\omega)$ of the profiles of bumps in the traces of a constant technological track

The above-mentioned analysis of characteristics of the profile irregularities of traces of the permanent tramlines indicates that the parameters of tire treads of the axle agricultural machine of new construction are the generator of formation of these irregularities.

Thus, the indicated statistical characteristics of the soil surface irregularities on the tracks along which the running wheels of bridge power vehicles move have been obtained and calculated in accordance with the recommendations [14; 15]. The use of such statistical characteristics has been successfully used in the study of movement and the dynamics of other agricultural machines and machine units, which is confirmed in the previously published works [16-18].

It should be emphasized that the formation of unevenness of the soil surface on the tracks along which the running wheels of bridge power vehicles move (due to the passages precisely during the technological process of harrowing the soil) is very important. This is due to the fact that it is the early spring harrowing of the soil (which will form the longitudinal relief of the ruts) that will continue to exist without significant changes until the autumn tillage. This means that the data obtained in the spring on the unevenness of soil surface on the tracks can be successfully used throughout the entire period of growing crops (spring harrowing, sowing, care, harvesting, autumn tillage), which is very important when using a precision farming system.

Thus, the results obtained are confirmed by not only the similar findings from other authors [15; 17; 18]; this fact confirms their reliability and also indicate their significance in the introduction of "High Technologies" into agricultural production. The obtained results of laboratory field studies, in particular, the normalized correlation and spectral functions, their graphical representation, also coincide with similar results presented in the works accompanying this research topic [19; 20]. This also gives grounds to consider the results of the study as reliable.

Obtaining statistical information on the unevenness of soil surface on the tracks along which the running wheels of the bridge power tool move, and the vibrations of agricultural machines, which are used in this case, will make it possible (using the methods of theory of automatic control) to study the dynamics of machine-tractor units more deeply, such as the study of the object behavior in the presence of "input" and "output" signals. This will ultimately make it possible to improve the dynamic characteristics of agricultural machine-tractor units, including bridge units. In general, this will make it possible to significantly improve the quality of products grown in the fields, including the use of bridge farming technologies.

CONCLUSIONS

Devices and methods have been developed for the experimental study of the microrelief of unevenness of the soil surface in the traces of a constant technological track in the bridge farming, which make it possible to immediately obtain its statistical characteristics. This is achieved by the following fact: with the help of a new profiler of the developed design, a statistical calculation program and a personal computer, it is possible to take reliable information, process it and immediately obtain the necessary experimental data to assess the vibrational processes of machines and tools used in such agriculture.

According to the data of multiple experimental studies conducted to determine the statistical characteristics of traces of a constant gauge of a bridge power tool, when reproducing real conditions of the soil harrowing (i.e. after passing along the tracks of the running wheels), the standard deviation of soil surface irregularities is within 0.82...0.84 cm. At the same time, the analysis of obtained graphs has shown that the internal structure of the track surface irregularities, recorded by a profiler and processed on a personal computer, can be characterized as a function containing harmonic damped periodic oscillations, in the presence of random components. The graph of the normalized correlation function has shown that the length of correlation connection of the ordinates of roughness of the soil surface on the traces of a constant technological track, approximately corresponds to the dimensions of height of the treads of the pneumatic tires of the running wheels of the power vehicle.

As a result of profiling the irregularities of the longitudinal profile of the soil surface during laboratory experimental studies according to the program of a multifactorial experiment, it was found that the energy and vehicles of a bridge agricultural machine of a new design moving along it, the running wheels of which move along the traces of the track, the main part of the dispersion is in the range from 0 to 0.3 cm^{-1}. This is confirmed by the size of depressions in the tread of pneumatic tires of the running wheels of the power vehicle.

Further research should be focused on the development of technical means and methods for recording the vibrations of the working bodies of agricultural machines using the similar measuring equipment, which will make it possible to simultaneously evaluate the statistical characteristics of the roughness of soil surface (as an input action) and the characteristics of vibrations of the working bodies, which will act as the reactions to this input. The use of results of the real oscillatory processes at the input in the form of irregularities of the soil surface on narrow tracks along which the bridge vehicle moves, and at the output in the form of vibrations of aggregated agricultural machines, will make it possible to design complex dynamic systems (machine-tractor units) and bridge farming with optimal parameters.

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Методика експериментального дослідження мікрорельєфу ґрунту на коліях при мостовому землеробстві

Анотація. Вивчення питань, пов’язаних з дослідженням стану ґрунту на поверхні найбільш постійної технологічної колії є актуальним, оскільки рух ходових коліс по вузьких коліях визначає тягово-зчіпні властивості машинно-тракторних агрегатів, їх вібрації, стійкість руху і керованість рухом. Метою даного дослідження було підвищення ефективності процесу профілювання мікронерівностей поверхні ґрунту, розташованих на ділянках, що утворюють колію, по якій рухатимуться ходові колеса машинно-тракторних агрегатів, шляхом обґрунтування нової схеми автоматизованого профілографа та розробка методики його використання. Для даного дослідження були використані сучасні методи експериментальних досліджень на основі IT-технологій. Зокрема, розроблено автоматизований комплекс для вимірювання та оцінки мікропрофілю нерівностей поверхні ґрунту на самій колії технологічної колії. Результати експериментальних досліджень у цьому питанні показали, що стандартне відхилення нерівностей поверхні ґрунту досягає ±0,84 см. Це дає підстави розглядати гармонічні складові цих функцій як затухаючі, що мають нормовані кореляційні функції. Побудовані за допомогою ПК графіки показали, що більшість дисперсій нерівностей поверхні ґрунту на самих коліях зосереджено в діапазоні 0…0,3 $см^{-1}$. Встановлено, що генератором утворення нерівностей поздовжнього профілю слідів постійної технологічної колії є параметри протекторів коліс машин, що рухаються по ній. Отримані результати дослідження можуть бути використані при виборі протекторів пневматичних шин ходових коліс машинно-тракторних агрегатів, що рухаються по двох коліях

Ключові слова: колійний засіб; нерівності; коливання; кореляційна функція; спектральна щільність