PL ISSN 0033-2097, e-ISSN 2449-9544

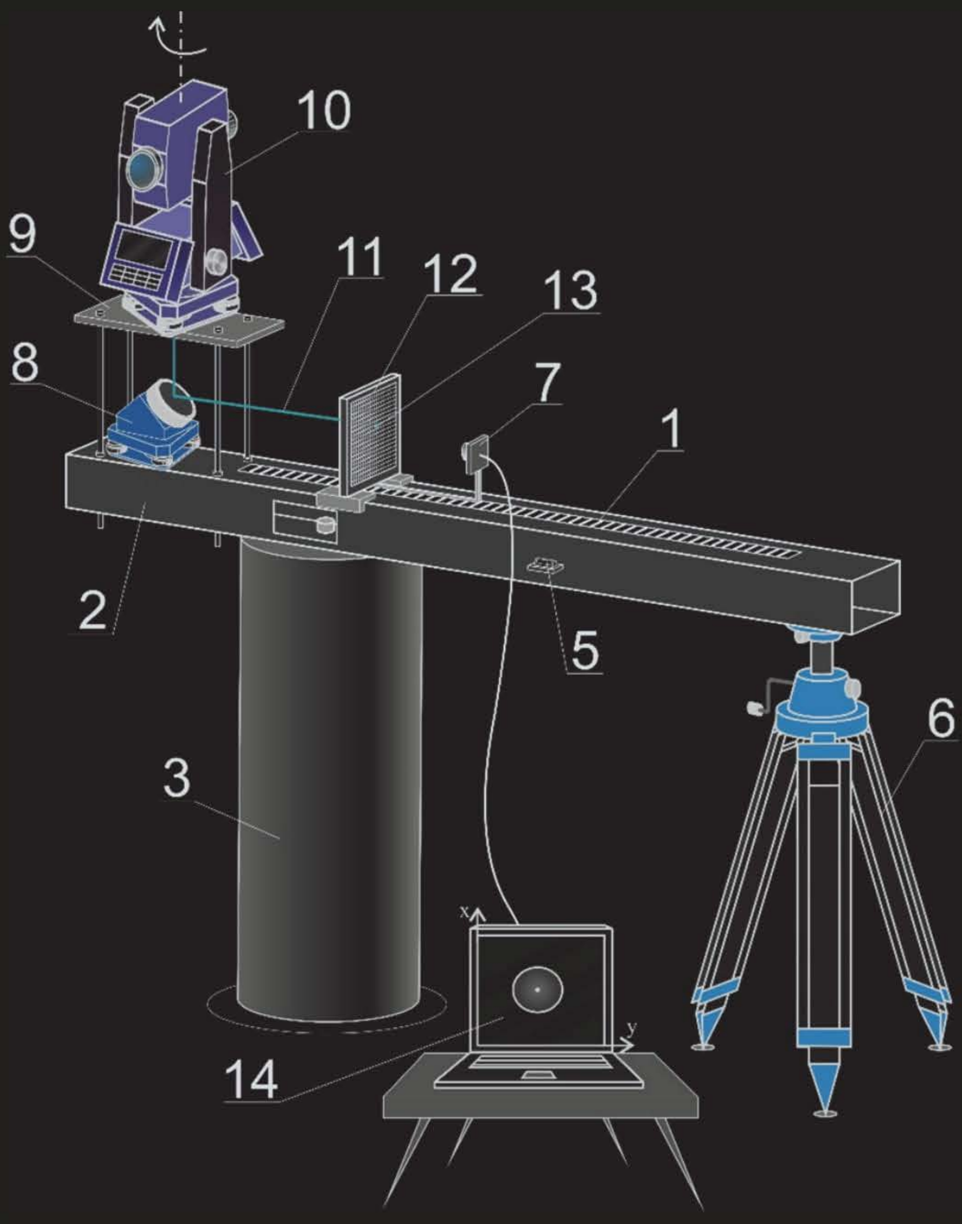
10'2021

PRZEGLĄD ELEKTROTECHNICZNY

ROK XCVII

WYDAWNICTWO SIGMA-NOT

cena 58 zł
(w tym 8% VAT)



W numerze:
Wybrane prace Krajowej Konferencji Metrologii

PRZEGLĄD ELEKTROTECHNICZNY Vol 2021, No 10

Contents

PRZEGLĄD ELEKTROTECHNICZNY Vol 2021, Nr 10

Spis treści

1. Dmytro Borysiuk[1], 2. Anatoly Spirin[2], 3. Ihor Kupchuk[2], 4. Ihor Tverdokhlib[2], 5. Viacheslav Zelinskyi[1], 6. Yevhenii Smyrnov[1], 7. Vitaliy Ognevyy[1]

Vinnytsia National Technical University (1), Vinnytsia National Agrarian University (2) Ukraine
ORCID: 1. 0000-0001-8572-6959, 2. 0000-0002-4642-6205. 3. 0000-0002-2973-6914, 4. 0000-0003-1350-3232, 5. 0000-0002-7785-2629, 6. 0000-0002-6878-7183, 7. 0000-0001-8334-6709

doi:10.15199/48.2021.10.09

The methodology of determining the place of installation of accelerometers during vibrodiagnostic of controlled axes of wheeled tractors

Abstract. *When driving on a road with an uneven surface, the tractor receives shocks and oscillates. The main components that protect the tractor from the dynamic action of the road and reduce fluctuarions and vibrations to an acceptable level are the steered axle and tires. A serviceable steered axle of a wheeled tractor provides optimal controllability, traffic safety, durability and reliability of work. The work with faulty components of the steered axle impairs the controllability and stability of the tractor, reduces the safety of its movement, impairs ergonomic indications. A faulty steered axle contributes to the vibration of the tractor frame, as a result of which riveted and threaded connections are weakened, the alignment of the engine and gearbox is disturbed, and additional loads occur in the body parts. Vibration of the whole tractor accelerates wear and causes breakage of many parts. Therefore, monitoring the technical condition of the steered axle of a wheeled tractor is an actual task in the field of exploitation and repair of equipments. The article presents a method for determining the location of accelerometers for vibration diagnostics of steered axles of wheeled tractors.*

Streszczenie*. Podczas jazdy po drodze o nierównej nawierzchni ciągnik ulega wstrząsom i drganiom. Głównymi elementami, które chronią ciągnik przed dynamicznym działaniem drogi i redukują do akceptowalnego poziomu wahania i wibracje, są oś kierowana i opony. Sprawna oś skrętna ciągnika kołowego zapewnia optymalną sterowność, bezpieczeństwo ruchu, trwałość i niezawodność pracy. Praca z wadliwymi elementami osi pogarsza sterowność i stabilność ciągnika, zmniejsza bezpieczeństwo jego poruszania się, pogarsza ergonomię wskazań. Wadliwa oś przyczynia się do wibracji ramy ciągnika, w wyniku czego osłabione są połączenia nitowane i gwintowane, zaburzone jest osiowanie silnika i skrzyni biegów, a w częściach nadwozia występują dodatkowe obciążenia. Dlatego monitorowanie stanu technicznego osi ciągnika kołowego jest rzeczywistym zadaniem w zakresie eksploatacji i naprawy urządzeń. W artykule przedstawiono metodę wyznaczania położenia akcelerometrów do diagnostyki drganiowej osi k ciągników.* ***(Metodyka wyznaczania miejsca montażu akcelerometrów podczas wibrodiagnostyki sterowanych osi ciągników kołowych)***

Keywords: vibration, accelerometer, vibration diagnostics, controlled axle, tractor, amplitude of oscillations, registered signal, error.
Słowa kluczowe:wibracje, diagnostyka, akcelerometr, ciągnik.

Introduction

Diagnosing and forecasting the life of machines is one of the important areas of research in the field of exploitation, technical service and repair of tractors, trucks and other machines.

Diagnosing tractors allows you to more purposefully carry out maintenance work, make full use of the capabilities of individual components, while preventing at the same time their emergency condition, timely eliminate technical problems. According to the experience of using technical diagnostics in the operation of mobile devices in our country and abroad, this is an important condition for improving the use of mobile devices. This results in lower spare parts costs, operating costs and premature repairs. The efficiency of diagnosis will increase as the means and methods of its implementation and the adaptability of tractors and their components to the diagnosis. With the improvement of agricultural equipment with modern technology, diagnosis is becoming increasingly important when using it. It largely depends on the rational organization of the process and maintenance of energy resources.

Formulation of the problem

The dependence of the recorded signal on the location of the accelerometer is an important factor for the appropriate choice of the point of removal of the signal on the body of the mechanism and to determine the allowable mounting error when installing the accelerometer on the mechanism [1, 2].

The mechanism, as a speaker system, has a very complex structure, so it is impossible to provide specific recommendations for choosing the place where the accelerometer should be mounted. The decision should be made on the basis of sound experimental research [3].

Analysis of recent research and publications

The mechanism of vibration processes in the units of controlled axles of wheeled tractors has specific features [4, 5], which are determined by internal and external factors caused by dynamic modes of operation. As a result, in the controlled axle of the tractor there is a set of interconnected vibration processes, which are conventionally divided into forced, free, parametric and nonlinear [6].

Methods for separating sources of vibration signals during diagnosis were developed in [5, 6], however, according to the author of [7], when diagnosing tractors there are a number of specific issues that require development and improvement, especially the impact of accelerometer location on signal registration.

The aim of the study

The purpose of the study is to determine the impact of locationinstallation of the vibration acceleration sensor on reliability of record of oscillating processes of the controlled axle of a wheeled tractor.

Presentation of the main material of theoretical research

Consider a monochromatic wave with frequency ω, given in the mechanism of the studied kinematic pair. The wave will expand to the sensor in many ways (there are many such ways). At the point of removal of the signal, the waves will be formed and the sensor will perceive their resulting effect [8, 9]. From all possible ways we will allocate the following two.

Let the distances traveled by the waves along these paths from the perturbation site to the sensor be r_1 and r_2.

Then the amplitudes of the sensor oscillations caused by each of the waves can be expressed as follows [10-16]:

(1) $$s_1(t) = \frac{A_0}{r_1}\cos(\omega t - kr_1);$$

(2) $$s_2(t) = \frac{A_0}{r_2}\cos(\omega t - kr_2),$$

where A_0 - is the amplitude of oscillations of the controlled axle of the tractor dirrctly after perturbation; $k = \omega / c = 2\pi / \lambda$ - wave number; λ - is the wavelength of the vibration signal; c - is the speed of spreading of the vibration signal wave.

The phase difference at the location of the sensor is equal to

(3) $$\Delta r = r_1 - r_2.$$

The amplitude A of the resulting signal is determined by the following ratio [3]:

(4) $$A = \sqrt{A_0\left(\frac{1}{r_1^2} + \frac{1}{r_2^2} + \frac{2}{r_1 r_2}\cos k\Delta r\right)}.$$

In cases where the difference in stroke Δr is such that $k\Delta r = \pm 2\pi n$ or $\Delta r = \pm n\lambda$; n = 1, 2,…, the amplitude of the resulting oscillation is equal to the sum

(5) $$A = \frac{A_0}{r_1} + \frac{A_0}{r_2}.$$

If $k\Delta r = (2n+1)\pi$ or $\Delta r = \pm(2n+1)\frac{\lambda}{2}$, the amplitude of the signal perceived by the sensor will be equal to the difference

(6) $$A = \frac{A_0}{r_1} - \frac{A_0}{r_2}.$$

Thus, the maxima correspond to the frequencies at which the amplitudes of the waves traveling to the sensor in different ways. On the contrary, areas of high attenuation are located at those frequencies at which the waves come to the sensor in antiphase.

Moving the sensor, change the ways in which the perturbations from the kinematic pairs. The position of the maxima of the frequency characterization will change. In principle, it is possible to find on the mechanism such a point at which the interference maxima of the frequency characteristics of the channels belonging to different kinematic pairs, which will not overlap. This will allow the frequency division of the signal. But there is no general method of finding such a point on the mechanism. It is only possible to predict with a kno PRZEGLĄD ELEKTROTECHNICZNY, ISSN 0033-2097, R. 97 NR 10/2021wn approximation the distance Δr to which the sensor should be moved so that the resonant peak ω from the frequency characterization is shifted by the value of $\Delta\omega$. From expressions (3) - (6) it follows that $\Delta\omega$ and Δr are related by the ratio

(7) $$\Delta r = \frac{2\pi cn}{\omega + \Delta\omega};\ n = 1, 2, \ldots.$$

However, ratio (7) does not indicate the direction in which you want to move the sensor, and some difficulties are caused by the choice of the value of c, because the speed of distribution of perturbations in the final media depends on many factors.

The dependence of the frequency characteristics of the acoustic channels on the location of the sensor is a positive fact, because it allows you to adjust the characteristics, but at the same time it contains a negative point that must be taken into account. The sensor can be installed at a given point only with some approximation and associated with certain signal distortions. Find out how the error in the installation of the sensor affects the output signal [15-18].

Consider a monochromatic wave

(8) $$\psi(r,t) = U(r)\sin\omega t,$$

where ψ (r, t) - is a value that characterizes the amplitude of the wave vector r at time t.

The argument of the function $U(r)$ is the vector r, which specifies the position of the point of removal of the signal. We choose the most unfavorable case when the direction of error Δr in the sensor setting coincides with the direction of the gradient of the function $U(r)$. Then let the function $U(r) = A \sin kr$, where r - is the modulus of the vector, and k is the wave number.

The amplitudes of oscillations of two points at a distance Δr will differ between them in magnitude

(9) $$\Delta A = A\sin kr - A\sin k(r - \Delta r) = 2A\cos k\left(r + \frac{\Delta r}{2}\right)\sin\frac{k\Delta r}{2}.$$

Hence the relative change in amplitude

(10) $$\delta = \frac{\Delta A}{A} = 2\cos k\left(r + \frac{\Delta r}{2}\right)\sin\frac{k\Delta r}{2}.$$

For small Δr we have

(11) $$\delta = \sin k\Delta r = k\Delta r = \frac{\omega}{c}\Delta r.$$

Given a certain value of the allowable relative error δ in the signal amplitude and the width of the operating frequency range, you can set the formula (11) allowable error in the installation of the sensor Δr.

Experimental equipment

For fulfilling operation vibrodiagnosis steered axle is developed a system (Fig. 1, a) based on a personal electronic computer and standard piezoceramic accelerometers KD-35 (accelerometers) was developed to perform vibration diagnostics operations of controlled axles of wheeled tractors [19].

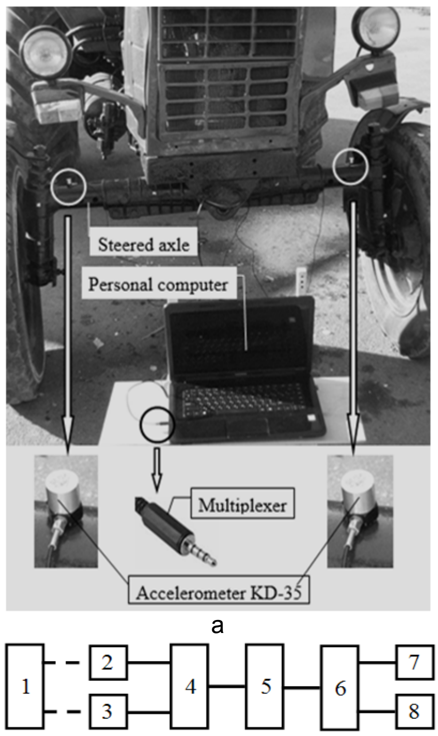


Fig. 1. System for diagnosing steered axles of wheeled tractors: a - general view; b - structural diagram; 1 - steered tractor axle; 2, 3 - accelerometers; 4 - multiplexer; 5 - analog-to-digital converter; 6 - computing device; 7 - monitor; 8 - printing devicea

The developed system for diagnosing steered axles of wheeled tractors (Fig. 1, b) consists of two accelerometers, which are mounted on the retractable tubes of the front axle (the first accelerometer - left, second - right), multiplexer, analog-to-digital converter, computing device, the result of which can be displayed on the monitor and printing device.

Accelerometers KD-35 company "VEB Robotron-Meßelektronik Dresden" (Germany) are vibration acceleration sensors that convert mechanical oscillations of the object into an electrical signal proportional to the vibration acceleration (Fig. 2). The sensing element of the accelerometer consists of one or more disks or plates made of piezoelectric materials. Above the sensitive element is an inertial mass pressed by a pin (rigid spring) [20].

Since piezoelectric sensors are active sensors that generate an electrical signal proportional to the acceleration of mechanical oscillations, no power supply is required during their operation. The absence of movable structural elements eliminates the possibility of wear and guarantees exceptional durability of piezoelectric sensors.

Technical characteristics of the accelerometer KD-35 are presented in Table 1.

To obtain the vibration acceleration curves of the steered axle of a wheeled tractor, connect a set of accelerometers with a plug, which is connected to the sound card of a personal computer via a microphone connector. The scheme of connection of accelerometers to a sound card of the personal computer is presented in Fig. 3.

Table 1. Technical characteristics of the accelerometer KD-35

Indicator	Indicator value
Transmission ratio	5,03 mV/msec^2
Capacity	0,65 nF
Insulation resistance	1000 mO
Calibration error limit (for inverse elationship): -for oscillation frequencies 50…2000 Hz - for oscillation frequencies 20 ... 4000 Hz	 2% 3%
Maximum acceleration at sinusoidal excitation	3000 m/s^2
Maximum lateral acceleration	1000 m/s^2
Resonant frequency	18 kHz
Mass	28 g

A personal computer sound card converts computer digital information into analog information and vice versa. The system for diagnosing steered axles of wheeled agricultural tractors works as follows. Accelerometers 2, 3 (see Fig. 1, b) are installed on the extension tubes of the controlled axle of the tractor 1 by means of magnetic inserts. Signals from accelerometers are fed to the analog-to-digital converter 5 through the multiplex 4.

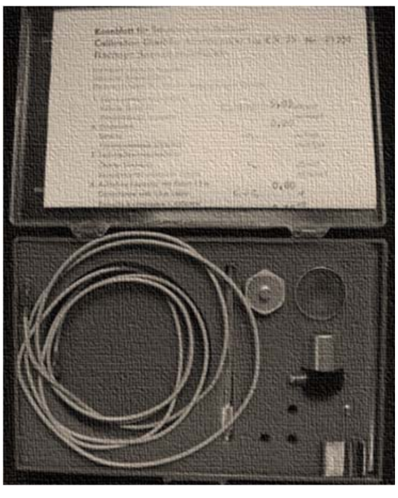


Fig. 2. Accelerometer KD-35

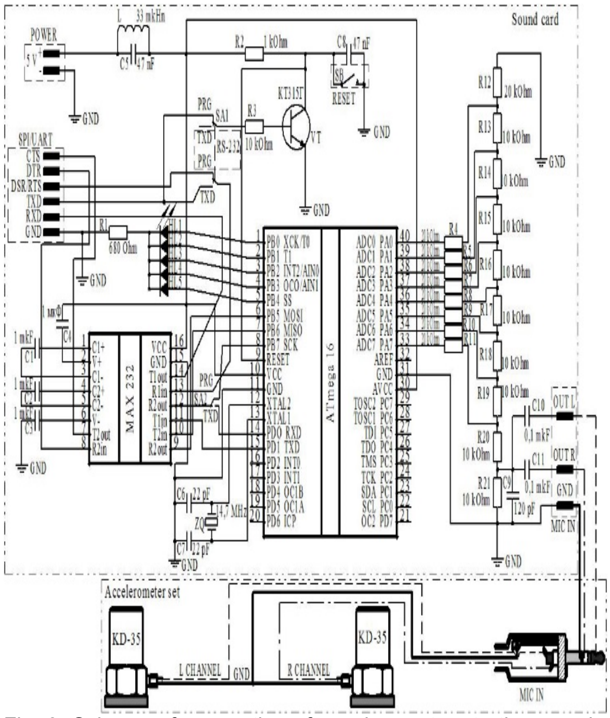


Fig. 3. Scheme of connection of accelerometers to the sound card of the personal computer

The analog-to-digital converter converts the analog signal to digital. Next, the digital signal is fed to the computing device 6, where it is processed. By means of the monitor 7 and the printing device 8 the information on a condition of the controlled axle of the tractor is displayed [3].

As software for recording and analyzing the vibro-acceleration signal, the program SignalExpress 2015 was chosen, which allows not only to display the signal in real time with the possibility of scaling, but also allows digital signal processing with the possibility of further processing the results in various standard applications.

The results of the experimental study

To determine the influence of the location of the accelerometers on the signal registration, install the accelerometers on the beam (Fig. 4), and then on the extension pipes (Fig. 5) of the controlled axle of the MTZ-80 tractor and record the vibration acceleration signal with the tractor engine running. Preliminarily, the ascent of the steered wheels was 5 mm and the track width was 1800 mm.

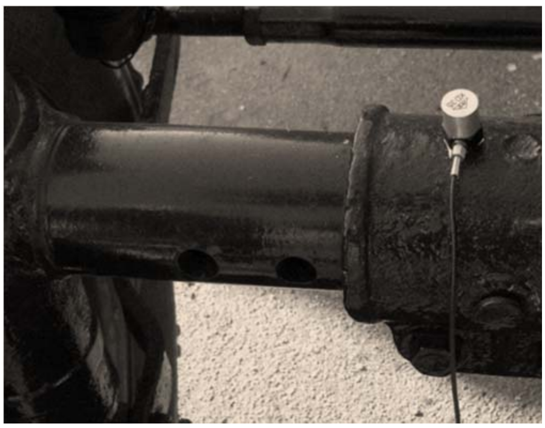


Fig. 4. Installation of the accelerometer on the beam of the axle of the MTZ-80 tractor

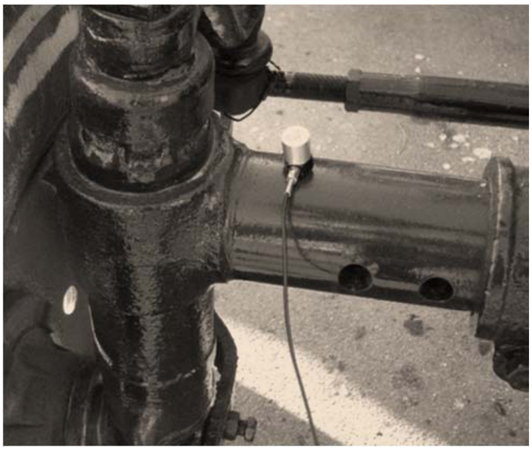


Fig. 5. Installation of the accelerometer on a sliding pipe of the tractor axle MTZ-80

In Fig. 6 it is pointed the oscillogram of the change of vibration acceleration of a serviceable controlled axle of the MTZ-80 tractor at the location of the accelerometer on the bridge beam, and in Fig. 7 - on the retractable pipe of the steered axle of the wheeled tractor.

Fig. 6. Oscillogram of vibration acceleration of the controlled axle of the MTZ-80 tractor at installation of the accelerometer on an axle beam

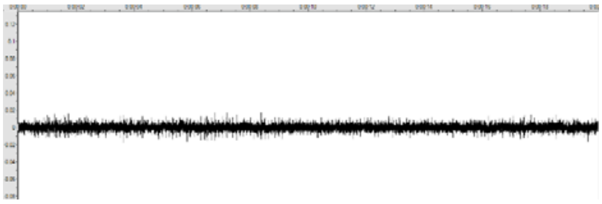


Fig. 7. Oscillogram of vibration acceleration of the controlled axle of the MTZ-80 tractor at installation of the accelerometer on a sliding pipe of the axle

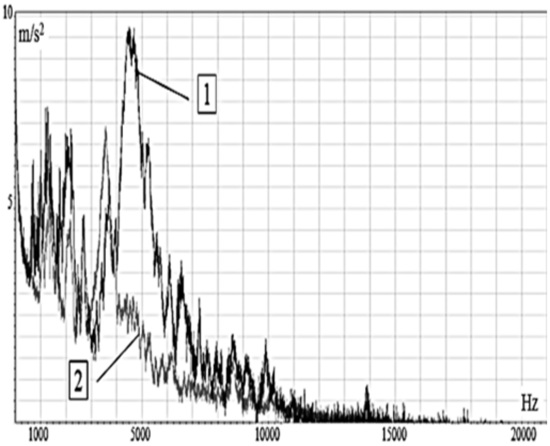


Fig. 8. Spectral analysis of oscillograms of vibration acceleration:
1 - vibration acceleration of the controlled axle of the MTZ-80 tractor at installation of the accelerometer on an axle beam; 2 - vibration acceleration of the controlled axle of the MTZ-80 tractor at installation of the accelerometer on a sliding pipe of the axle

Based on the spectral analysis of oscillograms of the change of vibration acceleration of the nodes of the serviceable axle of the MTZ-80 tractor (Fig. 8) it is established that the vibration acceleration when installing the accelerometer on the axle beam (5.72 m/s²) is greater (approximately 2.6 times) than the vibration acceleration. which is obtained by installing an accelerometer on the extension pipe (2.19 m/s²) of the controlled axle of a wheeled tractor.

This difference is explained by the fact that the accelerometer, which is mounted on the axle beam, is more sensitive to the vibration of the running internal combustion engine of the tractor than the accelerometer, which is mounted on the extension tube of the axle.

Therefore, when diagnosing steered axles of wheeled tractors, accelerometers must be installed on the retractable tube of the steered tractor axle (see Fig. 5).

Conclusion

1. When changing the parameters of the individual elements of the controlled axle will change accordingly the amplitude-frequency characteristic.
2. Determination of frequency characteristics is the basis for diagnosing steered axles of wheeled tractors.
3. Determining the location of accelerometers in vibration diagnostics of steered axles of wheeled tractors is an important component of determining the technical condition, accompanied by a reduction in the measurement error of physical quantities.
4. Experimental studies have confirmed the possibility of using this technique for diagnosing steered axles of wheeled tractors. This technique can be used to diagnose other components and units of tractors, as well as agricultural machinery.

Authors:
BORYSIUK Dmytro – *PhD in Engineering, Assistant, Faculty of Mechanical Engineering and Transport, Vinnytsia National Technical University (21021, 95 Khmel'nyts'ke Highway, Vinnytsia, Ukraine, e-mail: bddv@ukr.net);* SPIRIN Anatoly – *PhD in Engineering, Associate Professor, Faculty of Engineering and Technology, Vinnytsia National Agrarian University (21008, 3 Sonyachna str., Vinnytsia, Ukraine);* KUPCHUK Ihor – *PhD in Engineering, Associate Professor, Deputy Dean for Scientific Research, Faculty of Engineering and Technology, Vinnytsia National Agrarian University (21008, 3 Sonyachna str., Vinnytsia, Ukraine, e-mail: kupchuk.igor@i.ua);* TVERDOKHLIB Ihor – *PhD in Engineering, Associate Professor, Faculty of Engineering and Technology, Vinnytsia National Agrarian University (21008, 3 Sonyachna str., Vinnytsia, Ukraine);* ZELINSKYI Viacheslav – *Assistant, Faculty of Mechanical Engineering and Transport, Vinnytsia National Technical University (21021, 95 Khmel'nyts'ke Highway, Vinnytsia, Ukraine);* SMYRNOV Yevhenii – *PhD in Engineering, Associate Professor, Faculty of Mechanical Engineering and Transport, Vinnytsia National Technical University (21021, 95 Khmel'nyts'ke Highway, Vinnytsia, Ukraine);* OHNEVYI Vitalii – *PhD in Economics, Associate Professor, Faculty of Mechanical Engineering and Transport, Vinnytsia National Technical University (21021, 95 Khmel'nyts'ke Highway, Vinnytsia, Ukraine).*

REFERENCES

[1] Honcharuk, I., Kupchuk, I., Solona, O., Tokarchuk, O., Telekalo, N. “Experimental research of oscillation parameters of vibrating-rotor crusher”, Przeglad Elektrotechniczny, 97(3), pp. 97–100, 2021. https://doi.org/10.15199/48.2021.03.19

[2] Solona, O., Kupchuk, I. “Dynamic synchronization of vibration exciters of the three-mass vibration mill”, Przeglad Elektrotechniczny, 96(3), pp. 161–165, 2020. https://doi.org/10.15199/48.2020.03.35

[3] Kupchuk, I.M., Solona, O.V., Derevenko, I.A., Tverdokhlib, I.V. “Verification of the mathematical model of the energy

consumption drive for vibrating disc crusher”, INMATEH – Agricultural Engineering, 55(2), pp. 113–120.
[4] Opolonik, T. N. "Эффективность диагностирования тракторов" (Efficiency of tractor diagnostics), Rosagropromizdat, Moscow, Russia, 1988. (in Russian)
[5] Kukhtov, V. G. "Долговечность деталей шасси колесных тракторов" (Durability of chassis parts of wheeled tractors), RIO KhNADU, Kharkiv, Ukraine, 2004. (in Russian)
[6] Karasev, V. A., Raitman, A. B. "Доводка эксплуатационных машин. Вибродиагностические методы" (Launching of operational machines. Vibration diagnostics methods), Mashinostroenie, Moscow, Russia, 1986. (in Russian)
[7] Migal, V. D. "Вибродиагностика машин при эксплуатации" (Vibration diagnostics of machines in operation), KhGPU, Kharkiv, Ukraine, 1997. (in Russian)
[8] Gunko, I., Hraniak, V., Yaropud, V., Kupchuk, I., Rutkevych V. “Optical sensor of harmful air impurity concentration”, Przegląd Elektrotechniczny, 97(7), pp. 76-79, 2021. https://doi.org/10.15199/48.2021.07.15
[9] Kuznietsova, I., Bandura, V., Paziuk, V., Tokarchuk, O., Kupchuk, I. “Application of the differential scanning calorimetry method in the study of the tomato fruits drying process”, Agraarteadus, 31(2), pp. 173–180, 2020. https://doi.org/10.15159/jas.20.14
[10] Pavlov, B. V. "Акустическая диагностика механизмов" (Acoustic diagnostics of mechanisms), Mashinostroenie, Moscow, Russia, 1971. [online] Available at: https://xn--c1ajahiit.ws/knigi/nauka-i-texnika/164250-pavlov-bv-akusticheskaya-diagnostika-mehanizmov.html [Accessed: 10 April 2021] (in Russian)
[11] Malkin, V. S. "Техническая диагностика" (Technical diagnostics). Lan, St. Petersburg, Russia, 2013. [online] Available at: https://obuchalka.org/20200719122919/tehnicheskaya-diagnostika-malkin-v-s-2013.html [Accessed: 10 April 2021] (in Russian)
[12] Nosov, V. V. "Диагностика машин и оборудования" (Diagnostics of machines and equipment). Lan, St. Petersburg, Russia, 2012. [online] Available at: https://www.elbooka.com/raznaja-literatura/kniga-uchebnik/41387-nosov-vv-diagnostika-mashin-i-oborudovaniya.html [Accessed: 10 April 2021] (in Russian)
[13] Ram, M., Davim, J. P. "Diagnostic Techniques in Industrial Engineering", Springer International Publishing AG, Cham, Switzerland, 2018. [online] Available at: https://www.springer.com/ jp/book/9783319654966 [Accessed: 10 April 2021]
[14] Borysiuk, D. V., Yatskovsky, V. I. "Системи вимірювання та аналізу вібрації удару і шуму" (Vibration, shock and noise measurement and analysis systems), Vibrations in engineering and technology, 4 (72), pp. 5-12, 2013. [online] Available at: http://www.irbis-nbuv.gov.ua/cgi-bin/irbis_nbuv/cgiirbis_64.exe?I21DBN=LINK&P21DBN=UJRN&Z21ID=&S21REF=10&S21CNR=20&S21STN=1&S21FMT=ASP_meta&C21COM=S&2_S21P03=FILA=&2_S21STR=vvtt_2013_4_3 [Accessed: 10 April 2021] (in Ukrainian)
[15] Borysiuk, D. V., Yatskovsky, V. I. "Методи та засоби діагностування тракторів" (Methods and tools for diagnosing tractors), Collection of scientific works of Vinnytsia National Agrarian University. Series: Technical Sciences, 1 (89), pp. 16-20, 2015. [online] Available at: http://repository.vsau.org/getfile.php/ 9358.pdf [Accessed: 10 April 2021] (in Ukrainian)
[16] Borysiuk, D. V., Yatskovsky, V. I. "Діагностування передніх мостів колісних тракторів" (Diagnosing of front axles of wheeled tractors), Machinery, energy, transport of agro-industrial complex, 2 (90), pp. 43-46, 2015. [online] Available at: http://www.irbis-nbuv.gov.ua/cgi-bin/irbis_nbuv/cgiirbis_64.exe?I21DBN=LINK&P21DBN=UJRN&Z21ID=&S21REF=10&S21CNR=20&S21STN=1&S21FMT=ASP_meta&C21COM=S&2_S21P03=FILA=&2_S21STR=tetapk_2015_2_10 [Accessed: 10 April 2021] (in Ukrainian)
[17] Kline, W. A., Sriram, R., DeVor, R. E., Kapoor, S. G. "Process monitoring for machine tools", *International Journal of COMADEM*, *7*(2), pp. 12-17, 2004. [online] Available at: https://experts.illinois. edu/en/publications/process-monitoring-for-machine-tools-technical-and-business-issue [Accessed: 10 April 2021]
[18] Velychko, O., Gordiyenko, T., Kolomiets, L. "A comparative analysis of results of the group expert assessment of metrological assurance of measurements", Eastern-European Journal of Enterprise Technologies, 9 (90), pp. 30-37, 2017. https://doi.org/10.15587/1729-4061.2017.114468
[19] Borysiuk, D. V., Rutkevich V. S. "Система діагностування керованих мостів колісних сільськогосподарських тракторів" (System for diagnosing of steered axles of wheeled agricultural tractors), Ukraine, Patent UA 108395, 2016. (in Ukrainian) https://base.uipv.org/searchINV/search.php?action=viewdetails&IdClaim=225301&chapter=description
[20] Kollakot, R. A. "Диагностирование механического оборудования" (Diagnosis of mechanical equipment), Shipbuilding, St. Petersburg, Russia, 1980. (in Russian)