Journal of Engineering Science *Vol. XXX, no. 3 (2023), pp. 16 - 25*
Fascicle *Industrial Engineering* *ISSN 2587-3474*
Topic *Mechanical Engineering and Technologies* *eISSN 2587-3482*

https://doi.org/10.52326/jes.utm.2023.30(3).02
UDC 621.833.6:534

PROCESSING OF VIBRO - ACOUSTIC SIGNALS OF PRECESSIONAL PLANETARY TRANSMISSIONS

Stanislav Slobodeaniuc*, ORCID 0009-0002-0865-6701

Technical University of Moldova, 168, Ștefan cel Mare, Chișinău, 2004, Republic of Moldova
*Corresponding author: *Stanislav Slobodeaniuc*, *stanislav.slobodeaniuc@tran.utm.md*

Received: 09. 02. 2023
Accepted: 09. 28. 2023

Abstract. The operation of working machines is accompanied by the constant occurrence of vibrations and shocks, generated by various constructive, kinematic and dynamic factors. The study of the vibro-acoustic aspect of mechanical transmissions and, in particular, of precessional planetary ones is a primary concern for engineers in the field of machine building technologies. The paper presents the research of precessional planetary transmissions under the vibro-acoustic aspect in the anechoic chamber, which is a room, insulated with sound-absorbing material against external noises and isolated anti-vibration. To process the vibro-acoustic signals received as a result of the measurements, the Fourier harmonic series will be applied, a mathematical function that can be used to find the basic frequencies that make up a wave. The final result is the detection of vibration and noise generating sources, the decoding of signals by means of Fourier series and the advancement of constructive-technological solutions to minimize the vibro-acoustic level.

Keywords: *precessional planetary transmission, vibroacoustic signal, transducer, anechoic chamber, harmonic series.*

Rezumat. Funcționarea mașinilor de lucru este însoțită de apariţia în permanență a vibraţiilor şi şocurilor, generate de diverși factori constructivi, cinematici și dinamici. Studiul aspectului vibro-acustic al transmisiilor mecanice şi, în deosebi, al celor planetare precesionale este o preocupare primordială pentru inginerii din domeniul tehnologiilor constructoare de maşini. În lucrare se prezintă cercetarea transmisiilor planetare precesionale sub aspect vibro-acustic în camera anecoică, care reprezintă o încăpere, izolată cu material fonoabsorbant împotriva zgomotelor externe şi izolată antivibratoriu. Pentru procesarea semnalelor vibro-acustice primite în urma măsurărilor vor fi aplicate seriile armonice Fourier, funcție matematică ce poate fi folosită pentru a găsi frecvențele de bază, din care este alcătuită o undă. Rezultatul final este depistarea surselor generatoare de vibraţii şi zgomot, descifrarea semnalelor prin intermediul seriilor Fourier şi înaintarea soluţiilor constructiv-tehnologice pentru minimizarea nivelului vibro-acustic.

Cuvinte cheie: *transmisie planetară precesională, semnal vibro-acustic, traductor, cameră anecoidă, serii armonice.*

1. Sources of noise in planetary precessional transmissions

The operation of working machines is accompanied by the constant occurrence of vibrations and shocks, generated by various constructive, kinematic and dynamic factors. These vibrations and noises create a level of noise pollution, which negatively affects people's health. In the Republic of Moldova, the admissible norms of vibro-acoustic pollution are regulated by HG 589-2016. The shocks and vibrations, to which working machines are subjected, are determined by external and internal causes [1]. Most of the time these causes manifest simultaneously and also generate high dynamic loads, which additionally influence the functionality of the working machines [2].

The dynamic performances of mechanical systems, during operation, can be improved by the appropriate choice of working regimes, by adopting an optimal construction, from the point of view of the stability reserve or by applying some constructive or active control measures. In recent years, there is a tendency to increase the quality and reliability of aggregates, through the use of complex sensory systems, which have monitoring, diagnostic and active control functions.

A common element of most mechanical systems is the mechanical transmission, in most cases geared, which generates vibration and noise. The vibroactivity of reducers depends, in particular, on the exciting forces in the gear. It should be noted that the forces in the gear are generated by execution and assembly errors, as well as by their elastic deformations. In the geometric precessional gear, up to 100% pairs of teeth can be simultaneously in the gear, therefore the determination of the exciting forces is particularly difficult. Therefore, experimental researches are the most appropriate and effective methods for determining the level of vibrations and noise emitted by precessional planetary transmissions. But in this case, the most efficient processing of vibroacoustic spectrograms is particularly important [3].

Each type of mechanical transmission is a medium for generating vibro-acoustic signals, the basic problem of their occurrence usually being:

- incorrect gearing, for example, unevenness in the gearing between the wheels in a transmission can generate vibration and noise. These can be caused by manufacturing errors, damage or wear of the gear teeth;
- wear of bearing bearings, often defective bearings can cause vibration and noise during operation, especially when subjected to excessive loads or when worn;
- an imbalance in transmission components such as flywheels, crankshafts, gears or belts can have an imbalance in their mass, resulting in
of vibration and noise during rotation;
- the occurrence of wear and play of the components or the presence of excessive play can cause uneven movements and fluctuations of the components, generating vibrations and noises;
- overloads and uneven stresses for example incorrect or uneven loads on the transmission can create excessive stresses and vibrations in the transmission components;
- erosion and corrosion as an example damage caused by erosion or corrosion can affect component surfaces and contribute to noise and vibration;
- the occurrence of fluctuations in the engine torque, suppose that the engine torque is not constant or there are significant fluctuations in the transmitted power, this can generate vibrations and noises in the transmission;

- faulty mounting or incorrect assembly such as improper mounting of components or incorrect assembly of the transmission can lead to the generation of vibrations and noises;
- lubrication problems, improper lubrication of components or the lack of it can lead to excessive friction and vibration in the transmission;
- the occurrence of magnetic resonances may cause vibration frequencies that can lead to resonance in transmission components, amplifying vibrations and noise [4].

Magnetic resonance in mechanical transmissions refers to the phenomenon where a variable magnetic field or magnetic source generates vibrations or oscillations in the mechanical components or assemblies around it [5]. There are two main aspects where magnetic resonance can impact mechanical transmissions [6]:

- magnetic torque in gears: In mechanical transmissions involving gears with magnetic components, such as permanent magnets, there is the possibility of magnetic resonance. When two components with varying magnetic fields approach or move relative to each other, a magnetic force of attraction or repulsion between them can occur. If these magnetic forces coincide with the natural frequency of the components, a magnetic resonance can be set up. This phenomenon can lead to unwanted vibrations, which can affect the performance and durability of the gears;
- sub-optimal operating conditions for example a mechanical transmission is used in sub-optimal operating conditions, such as extreme temperatures or contaminated environment, this can lead to the appearance of noises;
- magnetic generators or motors in transmissions: Some mechanical transmissions may contain magnetic generators or electric motors that can generate variable magnetic fields during operation. If the operating frequency of these components coincides with the natural frequency of other mechanical elements in the system, a magnetic resonance can be set up. This can lead to vibrations, noises or even damage to the affected mechanical components.

To avoid or minimize magnetic resonance in mechanical transmissions, it is important to carry out a proper system design, taking into account the magnetic and mechanical interactions between the components involved [7]. Choosing the right materials, balancing components, and careful monitoring of operating frequencies can help reduce or eliminate unwanted vibrations caused by magnetic resonance [8]. Also, the application of techniques to isolate the magnetic components from the mechanical ones and the use of appropriate damping systems can help prevent this phenomenon [9].

Precessional planetary transmissions are a class of mechanical transmissions used to transmit power and torque between different shafts [10]. They are characterized by the use of several planetary gears that rotate around a sun gear and are meshed with a crown wheel. Precessional planetary transmissions have a number of important general aspects:

- *Compact configuration:* Planetary drives have a compact internal configuration, which makes them suitable for applications where space is limited;
- *Variable Gear Ratios:* By adjusting the ratios between the planetary and sun or crown gears, different gear ratios can be obtained, allowing torque and output speed to be adjusted as needed;
- *Torque Splitting Capability:* Planetary transmissions can split torque between multiple planetary gears, making them ideal for applications that require even distribution of power;
- *High efficiency:* Planetary transmissions are known for their high power transmission efficiency, due to their optimized design and the use of quality bearings;

- *Stability under variable loads:* Planetary gears are able to withstand variable loads and shocks, making them suitable for applications with precision requirements under dynamic operating conditions;
- *Durability and reliability:* Due to the fact that the internal components are properly sealed and lubricated, planetary gears have a long life and require less maintenance;
- *Versatility:* Planetary gears can be used in a variety of applications, including robotics, aeronautics, aerospace, medical, machine tools and more;
- *Bidirectional transmission*: Planetary transmissions allow torque to be transmitted in both directions, making them suitable for applications that require reversibility, such as motors and generators;
- *Reduction of vibration and noise:* By proper design and use of suitable materials, planetary gears can reduce vibration and noise during operation [11].

It can be concluded that the sources generating vibrations and noises are to a large extent identical for all types of transmissions, but in the case of precessional transmissions, due to the specific constructive reason, the appearance of the vibro-acoustic sources is longer [12].

2. Recording of vibro-acoustic signals in planetary precessional transmissions

Anechoic chambers are useful in a wide range of applications, including electronic equipment testing, acoustic research, performance testing of telecommunications systems, the study of sounds and vibrations produced by various objects or machines, and many other fields. It is important to note that no anechoic chamber is completely isolated from all acoustic reflections or vibrations, and chamber performance may vary depending on the quality of materials and construction. However, anechoic chambers provide a controlled and isolated environment, essential when recording and analyzing sensitive vibroacoustic signals [13].

The main features of an anechoic chamber include:

Acoustic absorption: The walls, ceiling and floor of the anechoic chamber are covered with acoustic absorbing materials, such as special boards or sound-absorbing material. These materials absorb sound frequencies and minimize reflections and echoes, ensuring that the recorded signal is as pure as possible.

Vibration absorption: In addition to acoustic absorption, an anechoic chamber can also have mechanical isolation systems to prevent the transfer of vibrations from the outside. This ensures that the recorded vibro-acoustic signals are not influenced by unwanted vibrations.

Electromagnetic Isolation: Sometimes anechoic chambers may also have electromagnetic isolation features to protect sensitive signals from external electromagnetic interference.

The anechoic room (Figure 1) from the *„Mechanical and Mechatronic Engineering" Department, „Gheorghe Asachi"* Technical University in Iași is a room, insulated with sound-absorbing material against external noises and anti-vibration isolation, in which sounds are absorbed almost entirely (99%) when incident on adjacent surfaces. The room was built in 1982, with useful dimensions of 10 x 10 x 8 m3 and a wide access door (2 x 1.5 m). The room is wallpapered with clay-based mineral wool prisms, the irregular shape canceling out the reflected acoustic waves. The anti-vibration isolation is almost perfect, the prisms are fixed on a rubber mat, and the foundation of the camera has nothing to do with the foundation of the building. Measurements can be made with great accuracy using Bruel&Kjaer measuring equipment and National Instruments processing

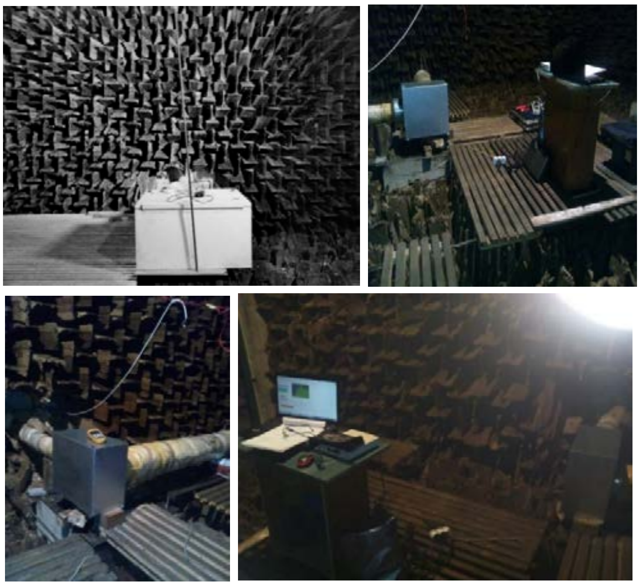

Figure 1. Anechoic chamber.

equipment. The Vibration Laboratory of the Faculty of Mechanics in Iasi uses the camera for the vibroacoustic diagnosis of bearings, gearboxes, some car components, ventilation systems, noise attenuators, calibration of acoustic speakers, etc.

The anechoic chamber shown in (Figure 1) is a specially designed environment to absorb sound waves and minimize acoustic reflections. It is used in a variety of fields and has some distinctive features and key aspects, including:

- *Wall, ceiling and floor covering:* The walls of the anechoic chamber are covered with acoustic absorbing materials, such as acoustic sponges or porous plates, which absorb the incident sound waves. Also, the ceiling and floor are treated in the same way to ensure even absorption;
- *Wall configuration:* The walls of the anechoic chamber may have a special configuration, such as a jagged shape or unusual geometry, to minimize reflections and disperse sound waves;
- *Absence of reflections:* One of the most distinctive aspects of the anechoic chamber is the fact that it minimizes acoustic reflections. This creates an almost totally anechoic environment, where sound waves are largely absorbed and there are no echoes or reverberations;
- *External acoustic isolation:* Anechoic chambers are designed to be acoustically isolated from the external environment, to prevent the entry of unwanted noises and ensure a quiet environment inside;
- *Use in research and testing:* Anechoic chambers are used in various fields such as acoustic research, development of noise-sensitive equipment, testing and calibration of acoustic equipment and testing of absorbent or insulating materials;
- *Specific features:* Anechoic chambers may have certain specific features, such as acoustic windows or special openings to allow testing and measurement inside the chamber without significantly affecting acoustic absorption;
- *Complex design and construction:* Building an anechoic chamber requires complex design and construction to ensure that acoustic absorption is optimized and adequate attenuation of sound waves is achieved;

- *Use in specific studies and research:* Anechoic chambers can be used to study and research different aspects of acoustics, such as evaluating the performance of audio equipment, characteristics of absorbing materials, noise produced by various sources, etc.

Overall, anechoic chambers are a valuable tool in acoustics research and development, providing a controlled and quiet environment for testing and measuring sound waves, as well as for specific studies related to acoustics.

The qualities of the anechoic chamber can be appreciated by the following characteristics:

- the absorption coefficient of the walls (α) is 99% in the frequency band from 150 Hz to 20 kHz. It depends on the characteristics of the sound-absorbing material, the shape and dimensions of the absorbing prisms.
- the deviation from the 1/R law gives indications regarding the nature of the acoustic field in the anechoic chamber, regarding the differences from the conditions of the free acoustic field;
- for sound insulation from the outside, attenuation of 60 ÷ 75dB is recommended, so that the background noise in the room is below the audibility threshold; the background noise falls within the noise curve Cz 25.
- the anti-vibration isolation, on rubber insulators, ensures a low natural frequency (<10Hz).

In recent years, the following have been realized in this room:

- vibroacoustic diagnosis of HVAC equipment (acoustic pressure measurement, FFT analysis, 1/3 octave analysis)
- vibroacoustic diagnosis of noise attenuators (acoustic pressure measurement, FFT analysis, 1/3 octave analysis, acoustic attenuation)
- the study of the acoustic absorption coefficients of different types of sound-absorbing materials (composite, recyclable materials, etc...)

3. Harmonic Fourier analysis of vibro-acoustic waves in precessional transmissions

Harmonic Fourier analysis is a mathematical method used to decompose a complex wave into a series of sinusoidal components of different frequency. This technique is commonly used in the analysis of vibro-acoustic signals to identify and quantify the various frequencies and amplitudes that make up the complex signal. The application of Fourier series in the deciphering of vibroacoustic signals provides an efficient method of analysis and characterization of these complex signals. Fields of applicability include electrical engineering, wave analysis, acoustics. Fourier series are particularly useful in the analysis and deciphering of vibroacoustic signals. These signals can be recordings of vibrations and sounds from various sources, such as cars, engines, mechanical systems or even ambient sounds. By using Fourier series, the frequency components of these signals can be identified and a representation of them in the frequency spectrum can be obtained [14].

In the case of planetary precessional transmissions, Fourier analysis can be used to investigate the vibro-acoustic phenomena associated with the motion and operation of precessional gears. Planetary precessional transmissions type 2K-H consist of two precessional gears, which are formed as a result of the sphero-spatial movement of the satellite block around the precession center – the point of intersection of the straight and inclined axes of the driving crank shaft and the gear teeth generators, which form conical axoids. This complex motion can generate various vibro-acoustic components, including harmonic and interharmonic frequencies, which reflect tooth interactions, tooth movement, and other mechanical phenomena.

A vibro-acoustic spectrogram of a precessional transmission includes several frequencies:

- the rotation frequency of the output shaft, a periodic sinusoidal curve;
- the frequency of engagement of the teeth of the two gears (overlapping on the periodic sinusoidal curve of the driven shaft.

Superimposed on the periodic sinusoid of the output shaft:

- driving shaft rotation frequency;
- tooth engagement frequencies in the two precessional gears;
- frequencies of the bearing elements of the driving and driven shaft, the node of the satellite.

To perform harmonic Fourier analysis of vibro-acoustic spectrograms in precessional planetary transmissions, the following steps can be taken:

Signal recording: The vibroacoustic signal is recorded using specialized sensors or microphones. The recorded signal can be a complex time-varying function.

Signal preprocessing: The recorded signal may contain noise, irrelevant components or artifacts. By applying pre-processing techniques such as filtering and de-noising, the quality of the signal can be improved and the relevant features can be better highlighted.

Fourier series decomposition: Using Fourier series, the preprocessed signal can be decomposed into a sum of complex sinusoidal or exponential components. This involves the calculation of the Fourier series coefficients by integration or specific calculation algorithms.

Spectral Analysis: Identify and analyze the spectral components of signals, such as main frequencies, harmonics, interharmonics, and corresponding amplitudes. By transforming the Fourier series coefficients in the frequency domain, the frequency spectrum of the signal can be obtained. It shows which frequencies are present in the signal and with what magnitude.

Interpretation of results: Analysis of the frequency spectrum allows the identification of the main components of the signal, such as dominant frequencies, harmonics or other specific characteristics. This can help diagnose problems in precessional transmission or understand the origin of vibroacoustic signals. For example, certain harmonic frequencies may suggest problems with gear teeth or precessional motion timing.

This analysis can be particularly useful in diagnosing faults or improving the performance of precessional planetary drives, allowing engineers to better understand the dynamic behavior of the system and identify potential problems before they become critical.

It is important to note that Fourier analysis can be complex and requires advanced mathematical knowledge and signal analysis techniques. Also, harmonic analysis of vibro-acoustic waves in precessional planetary transmissions can be influenced by factors such as lubrication, wear of parts and mechanical loading of the system.

Fourier series have many practical uses, because manipulating and conceptualizing the harmonic coefficients is often easier than working with the original function. Fields of applicability include engineering, wave analysis, acoustics. Fourier series are particularly useful in the analysis and deciphering of vibroacoustic signals. By using Fourier series, one can identify the frequency components of these signals and obtain a detailed representation of them in the frequency spectrum.

Since the vibro-acoustic function of a precessional transmission is periodic, then the most appropriate method of harmonic analysis is the Fourier series decomposition. The presentation of the vibro-acoustic function of the precessional transmission through the Fourier series is dictated by the following advantages:

- unlimited possibilities of presenting the vibro-acoustic function of any real mechanism;
- the simplicity of establishing the causes of vibration and noise generation due to the fact that the form of expression of this function in the form of a trigonometric series corresponds entirely to the nature of vibro-acoustic effects;
- the possibility of decomposing the summary vibro-acoustic function into a series of harmonic components;
- the possibility of establishing the degree of influence of different geometro-kinematic parameters on the summary vibro-acoustic values of the transmission.

The vibro-acoustic function, expressed by the Fourier series in the limits *0 < x > 2,* has the form [15]:

$$F(n) = A_0 + \sum_{k=1}^{n}(a_k \cos kx + b_k \sin kx), \tag{1}$$

where a_k and b_k are the decay coefficients, which best approximate the periodic components. Such values of the coefficients must be found, which will ensure the maximum approximation of the functions *F(n)* and *f(x)*.

According to Eq. (2) we have:

$$a_k = \frac{1}{\pi}\int_0^{2\pi} f(x)\, cos\, kx\, dx;$$
$$b_k = \frac{1}{\pi}\int_0^{2\pi} f(x)\, sin\, kx\, dx; \tag{2}$$
$$A_0 = \frac{1}{2\pi}\int_0^{2\pi} y_2 \sin kx_2\, dx.$$

Using the method of numerical analysis, the Fourier coefficients are approximately determined from the relations:

$$a_k = \frac{2}{N}\sum_{i=1}^{N} y_i\, cos\, kx_i\,;$$
$$b_k = \frac{2}{N}\sum_{i=1}^{N} y_i\, sin\, kx_i\,. \tag{3}$$

The constant component $A_0 = a_0/2$, where a_0 is determined similarly to a_k for *k=0* . Taking into account the peculiarities of *the cos kx* and *sin kx factors,* the number *N* is often taken as equal to *12* or *24* . In case of need for greater precision, *N* is taken equal to *48* .

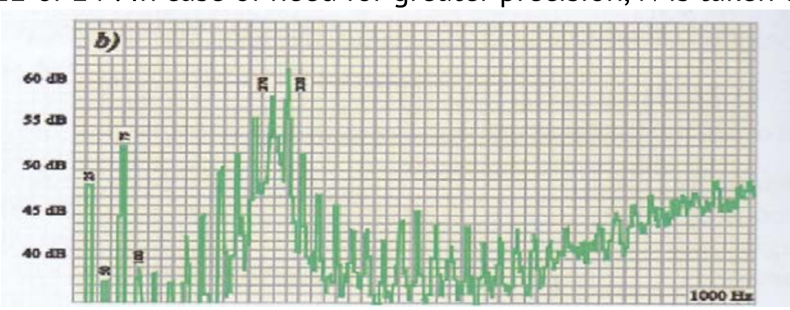

Figure 2. Vibration spectrogram of the 2K-H precessional reducer with the transmission ratio i=-324, n=1500 min^{-1}**.**

Since the research of the vibro-acoustic level of precessional transmissions is obtained graphically (vibro-acoustic spectrograms), then the most convenient method of calculating the Fourier coefficients is the template method.

To obtain the probable values of the Fourier coefficients, a sufficient number of records (spectrograms) (e.g. ten) of the same precessional reducer (e.g. Figure 2), recorded in the same operating regimes, must be analyzed. Each diagram is divided into 12 parts. For different measurements y_i at each point for all diagrams the arithmetic mean y_i is determined.

In order to authentically describe the signal, it is necessary to process it, using various existing methods. Using the method described above, the function for determining the kinematic error was obtained. To obtain the probable values of the *Fourier coefficients,* a sufficient number of records were analyzed – ten diagrams, recorded in the reducer control recorder with the transmission ratio *i = 324* at the same operating regimes.

The arithmetic mean of the *Fourier coefficients* for the 10 measurements:

$$\bar{y}_i = \frac{\sum_{j=1}^{10} y_j}{10}, \quad (4)$$

For arithmetic means ***y,*** we determine the mean squared deviation:

$$\sigma = \sqrt{\sum_{j=1}^{10} \left(y_j - y\right)/9}. \quad (5)$$

The maximum arithmetic and statistical errors will be:

$$\Delta n(y) = \pm 3\sigma;$$
$$\frac{\Delta n(y)}{\bar{y}} = \pm \frac{3\sigma}{\bar{y}}. \quad (6)$$

Based on the obtained values, templates are made, with which the Fourier coefficients are calculated. The result of the performed harmonic analysis is completed with the elaboration of the vibro-acoustic function, which allows the minimization of the detected vibro-acoustic effects.

Fourier transform. The Fourier transform is a mathematical function that can be used to find the fundamental frequencies that make up a wave. Computers use an algorithm called *the Fast Fourier Transform (FFT)* to quickly calculate any but the simplest signal transforms.

4. Conclusion

The basic goal of researchers in the field is to optimize the constructive part by implementing new solutions to reduce the vibro-acoustic factor. The problem of vibrations and noises in the planetary precessional transmissions is a moment that cannot be avoided due to its specific construction.

The study of sources generating oscillations, the recording of signals and their final deciphering, is of major importance at the stage of designing/updating planetary precessional transmissions. The performed harmonic analysis by calculating of the Fourier coefficients ensure the elaboration of the vibro-acoustic function, which allows the minimization of the detected vibro-acoustic effects.

The anechoic chamber was studied for the execution of experimental measurements in order to establish the sources generating vibro-acoustic signals on a prototype of a precessional planetary reducer and the Fourier series were studied in order to decipher the recorded signals with the aim of proposing and implementing constructive solutions to minimize the vibro-acoustic impact.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Katznelson, Y. *An introduction to harmonic analysis. Second corrected edition*. Dover Publications, Inc., New York, 1976, 311 p. ISBN 0-486-63331-4.
2. Cordoneanu, D. Smart monitoring and maintenance of a mechatronic system. PhD thesis. Politehnica University, Bucharest, 2022.
3. Vamsi, I.; Sabareech, G.R.; Vaibhav Sh. Integrated Vibro-Acoustic Analysis and Empirical Mode Decomposition for Fault Diagnosis of Gears in a Wind Turbine. In 2nd International Conference on Structural Integrity and Exhibition 2018, 14, pp. 937-944.
4. Malcoci, Iu. Cercetarea nivelului de vibrații și zgomot în transmisiile planetare precesionale. PhD thesis. Technical University of Moldova, Chișinău, 2015.
5. Fedorenko, I. Ya. *Vibration processes and devices in APK*. Altajskogo GAU, Barnaul, 2016, 245 p.
6. Vibrodiagnostika: Vibrodiagnostika defektov mexanicheskix peredach. Available online: https://vibro-expert.ru/vibrodiagnostika-defektov-mexanicheskix-peredach.html (accessed on 06.08.2023).
7. Malcoci, Iu.; Ciobanu, R.; Ciobanu, O. Dynamic systems – vibro-acoustic analysis laboratory guide: case studies. Tehnica UTM, Chisinau, RM, 2017, 94 p.
8. Vibrations and Noises: Research on the Study of Mechanical Vibrations with Data Acquisition Systems, ©2023 [cited 2023-09-01]. Available online: http://stiintasiinginerie.ro/wp-content/uploads/2014/01/104-CERCET%C4%82RI-PRIVIND-STUDIUL-VIBRA%C5%A2IILOR.pdf (accessed on 06.08.2023).
9. Assessment of Vibration and Noise: Aspects of Assessment of Noise and Vibration in Mechanical Transmissions, ©2023 [cited 2023-09-01]. Available online: https://ibn.idsi.md/sites/default/files/imag_file/190-197_8.pdf (accessed on 06.08.2023).
10. Bostan, I. ; Dulgheru, V. ; Malcoci, Iu. Some aspects regarding planetary precessional transmission dynamics. In CoSME'20 IOP Conf. Series: Materials Science and Engineering, 2021, 1009, 012008.
11. Mechanical transmissions: Signal filters used in vibrodiagnosis of mechanical transmissions, 2023. Available online: https://www.ttonline.ro/revista/transmisii-mecanice/filtre-de-semnal-utilizate-in-vibrodiagnoza-transmisiilor-mecanice (accessed on 16.08.2023).
12. Malcoci, Iu., Bodnariuc I. Vibroacoustical diagnosis of planetary precessional kinematical transmission. In IOP Conference Series Materials Science and Engineering, 2016, 147(1), 012003.
13. Anechoic chamber: Acoustic Laboratory, 2023. Available online: http://www.comoti.ro/ro/laboratoare_experimentari_4_2.htm (accessed on 03.08.2023).
14. Fourier transform: Application of the Fourier transform for deciphering vibro-acoustic signals, 2023. Available online: https://ro.alegsaonline.com/art/35911 (accessed on 16.08.2023).
15. Berman, A.F. Kratkij kurs matematicheskogo analyza. Nauka, Moscow, 1973, 720 p.

Citation: A Slobodeaniuc, S. Processing of vibro - acoustic signals of precessional planetary transmissions. *Journal of Engineering Science* 2023, 30 (3), pp. 16-25. https://doi.org/10.52326/jes.utm.2023.30(3).02

Submission of manuscripts: jes@meridian.utm.md