Bulgarian Society for NDT
International Journal "NDT Days"
Volume VI, Issue 1, Year 2023

ISSN: 2603-4018
eISSN: 2603-4646

Acoustic Express Tribotesting Technique

Sergey BUKHAROV[1], Vladimir SERGIENKO[1], Alexander ALEXIEV[2], Vitaliy MERINOV[1]

[1] V. A. Belyi Metal-Polymer Research Institute of National Academy of Sciences of Belarus, Gomel, Belarus
e-mail: sbuharov@tut.by

[2] Institute of Mechanics at the Bulgarian Academy of Sciences, Sofia, Bulgaria,
e-mail: alexiev@imbm.bas.bg

Abstract
Obtaining operational data on the wear parameters during friction is an important scientific and practical problem. These data on the parameters of the friction process, extracted from acoustic emission signals, can provide detailed information about the current state of wear mechanisms and changes in rubbing material properties over time. This article discusses the concept of a method for the quantitative assessment of the wear properties of a given class of tribological materials, based on the experimentally discovered connection between the spectral characteristics of acoustic emission (noise) in the audio frequency range above 8 kHz and the linear wear rate of polymer friction composites for work in stationary friction units.

Keywords: friction, wear, acoustic emission, noise, spectral characteristics, friction composite

1. Introduction

New polymer composite materials with improved technical and environmental characteristics for friction purposes are key factor in the creation of high-tech components for mechanical engineering, ensuring maintenance, and increasing competitiveness [1-3]. When creating new friction materials, a number of problems can be identified, the solution of which is necessary to achieve a certain set of technical and other requirements for friction materials: necessity, ensuring a given value and stability of the friction coefficient, and independence of the nature of sliding friction from operating and meteorological conditions. In addition, friction materials must be well suited to the counterbody, not wear out or adhere to it, have sufficient mechanical strength, high wear resistance, appropriate thermophysical properties, and high frictional heat resistance, meet the requirements for corrosion resistance, non-flammability, low tendency for frictional self-oscillations and noise in the audio frequency range, comfort (smoothness) when braking, environmental friendliness, manufacturability, acceptable cost, and an accessible raw material base. In real conditions, friction materials are exposed to the most unfavorable operational factors – high and alternating temperature and dynamic loads, high sliding speeds, intense wear, often in the presence of various aggressive media (salt solutions, oil products, acids, etc.).

The standard test methods (bench and road) available today make it possible to obtain adequate design and materials science solutions aimed at developing friction materials that are balanced in terms of their main performance characteristics. A significant drawback when using these methods, including life-saving bench and operational tests, due to the duration and complexity of the tests, is the extremely high time and financial cost of developing the material. During the development of friction composite formulations, it is important to have a set of express methods that can reduce the time required to obtain a friction composite that is balanced across the entire range of performance characteristics, from a model composition to a prototype ready for life tests. Based on the results of the research, an acoustic express method for testing friction materials for work in stationary friction units has been proposed, which can significantly reduce the duration of tribological tests in terms of determining wear resistance, as well as provide additional information content of experimental data regarding the generated acoustic emission in the audio frequency range.

2. Materials and methods

Analyzing the results obtained by the authors in a number of experimental studies [4-8], aimed at studying the influence of the component composition of friction materials under various load-speed test conditions on the spectral characteristics of noise during friction, it was established that there is a stable correlation between the high-frequency acoustic emission in the area of the sound frequency range (above 8 kHz) and the linear intensity of the wear process of rubbing materials. This correlation was first discovered when studying the influence of thermally cross-linked oligoimide maleid-F (M-F) and basalt fibers (BV) on the tribotechnical and acoustic characteristics of highly filled friction materials based on polytetrafluoroethylene (PTFE) for stationary friction units in technological machines [4]. This correlation was first discovered when studying the influence of the multi-purpose chemical modifier Maleid-F (M-F), which is a composition of 75% metaphenylenedimaleimide, 20% $C_{17\text{-}20}$ fractions and 5% naphthane plasticizer, on the tribological and acoustic characteristics of highly filled friction materials based on polytetrafluoroethylene (PTFE) for stationary friction units of technological machines [4]. A concentration range of the binary filler (BV+M-F) from 2.5 to 20% of the volume was chosen, with a ratio of BV/M-F components from 1 to 3 as a factor that objectively influences the wear process.

The essence of the proposed method, the applicability of which is discussed in relation to the class of friction materials under study under sliding friction conditions during stochastic interaction of microroughnesses of solid bodies, i.e. outside self-oscillatory states, is based on the assumption that there is a relationship between the spectral density of the acoustic radiation spectrum *G(f)* and the linear wear intensity I_h, expressed through the area *S* (Fig. 1), limited by the curves of two spectral functions – the reference function $G_0(f)$, corresponding to background acoustic radiation with conditionally zero wear intensity, and the curve of the signal function $G_1(f)$ generated during friction of the test sample within the analyzed frequency range from f_1 to f_2, i.e.

$$S = S(I_h) = \int_{f_1}^{f_2} G_1(f)df - \int_{f_1}^{f_2} G_0(f)df \tag{1}$$

It is proposed to use a normalized wear coefficient $\overline{w}$ as a parameter for quantitative assessment of the intensity of the wear process, extracted from acoustic emission signals.

$$\overline{w} = \frac{S}{S_{\max}}, \tag{2}$$

where S_{max} is the upper limit of the range of values of S for the selected class of materials under study, determined by the expression (1).

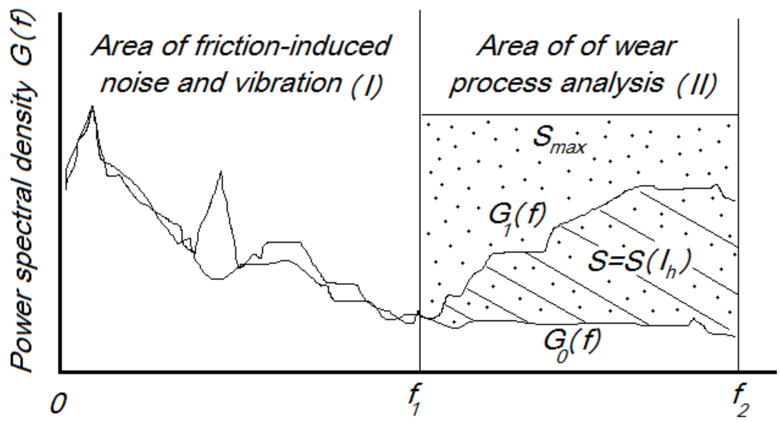


Fig. 1. Relationship between the spectral density of the acoustic radiation spectrum and the linear intensity of wear: the area of noise and vibration as a consequence of frictional self-oscillations (I); area of analysis of wear processes during stochastic interaction of microroughnesses (II)

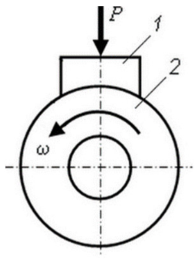
Testing of the proposed acoustic express method was carried out with stationary friction of samples according to the kinematic scheme "shaft–partial liner" using measuring instruments and a vibro-acoustic test setup, the general diagram of which is presented in Fig. 2. The counterbody material was steel grade 45 with a hardness of up to 50 HRC. The initial roughness of the friction surface is R_a = 0.52 µm. The running-in of the friction pair and friction-wear tests were performed at a specific load of P = 1 MPa and a relative sliding speed ϑ = 1 m/s. Running-in was performed until the actual frictional contact area reached at least 90% of the contour area. The ambient temperature during testing was in the range of T = 18–23°C, and the relative humidity was no more than 50%. The kinetic dependence of the friction force was recorded using the chart tape of the recording device. The temperature in the friction contact area was determined by using a DT-8839 pyrometer with an accuracy of ± 2°C. The linear wear rate was determined using the following equation:

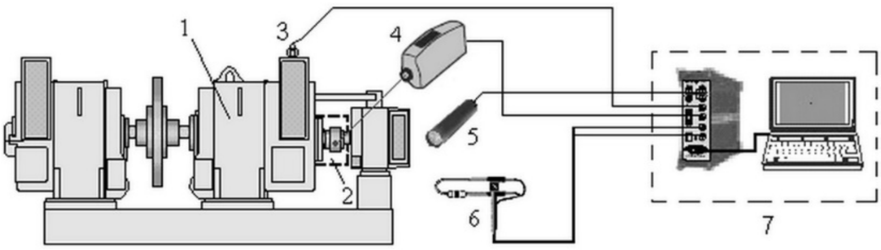
$$I_h = \frac{m_0 - m_k}{\rho \cdot \sigma \cdot L}, \quad (3)$$

where m_0 is the initial mass of the sample, kg; m_k – mass of the sample after testing, kg; ρ – density of the sample material, kg/m^3; σ = 2 cm^2 – contour area of frictional contact; $L = \upsilon \times \tau$ – test run length, m.

The densities of the samples were determined by hydrostatic weighing on an XS 204 DR Mettler Toledo analytical balance. After the running-in and each test, the surface of the metal counterbody was cleared of the transfer film by grinding with an abrasive material (P320). Wear tests were carried out in the stationary friction mode without lubricant. Acoustic emission signals generated by the friction pair were recorded at a specific load of P = 2 MPa and a relative sliding speed ϑ = 1 m/s.

Acoustic emission signals and the corresponding spectral characteristics generated during stationary friction of the test samples were recorded using a multi-channel data collection and analysis system Pulse 3560 B (Bruel & Kjaer), unipolar measuring microphone 4961 (Bruel & Kjaer), acoustic intensimeter 3599 (Bruel & Kjaer), photoelectric tachometer MM0024 (Bruel&Kjaer), and digital signal processing using frequency FFT analysis methods.





(a)
1 – test sample;
2 – counterbody;

(б)
1 – friction testing machine (dynamometer);
2 – friction unit;
3 – three-component accelerometer;
4 – LDV;
5 – photoelectric tachometer;
6 – intensity probe;
7 – multi-channel data collection and analysis system

Fig. 2 – Kinematic (a) and general diagram of the experimental setup for tribotechnical testing of friction materials (b)

3. Results and discussion

The results of standard tribological tests in part of determining the linear wear rate of PTFE-based polymer composites with a test duration of $\tau = 2$ hours, presented in Fig. 3.

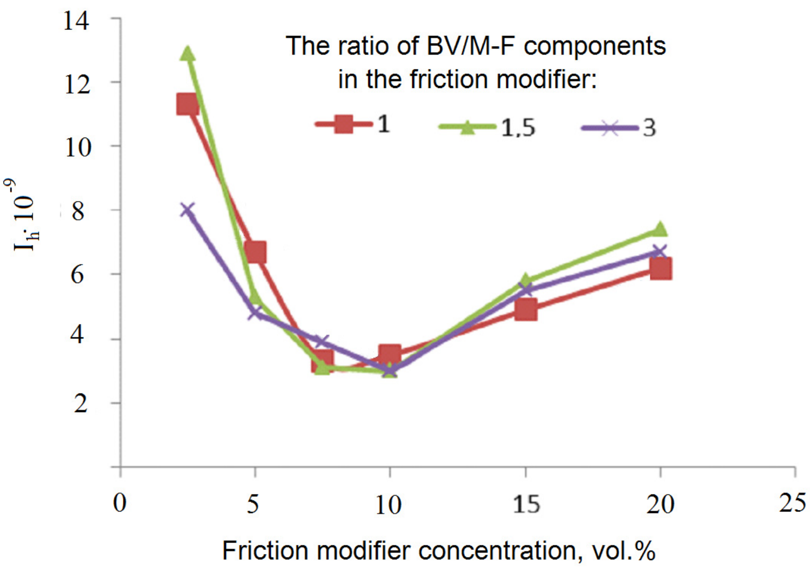


Fig. 3 – Dependence of the linear wear rate I_h on the content of the modifying component (BV+M-F) in the friction composite for different values of the volume ratio of fillers at $P = 2$ MPa, $\vartheta = 1$ m/s, $\tau = 2$ h

It has been shown that the introduction of a combined modifier consisting of Maleid-F (M-F) and crushed basalt fibers (BF) into the base friction composite leads to a rapid decrease in the linear wear rate within a concentration range of up to 7.5-10% vol. A further increase in the content of the combined modifier leads to a monotonous increase in the wear rate (decrease in wear resistance) of the composites. The corresponding characteristics of acoustic emission, reflecting the relationship between the spectral density of noise in the audio frequency range above 8 kHz and the linear wear rate of the composite at a volumetric ratio of BV/M-F components = 1.5, are presented in Fig. 4.

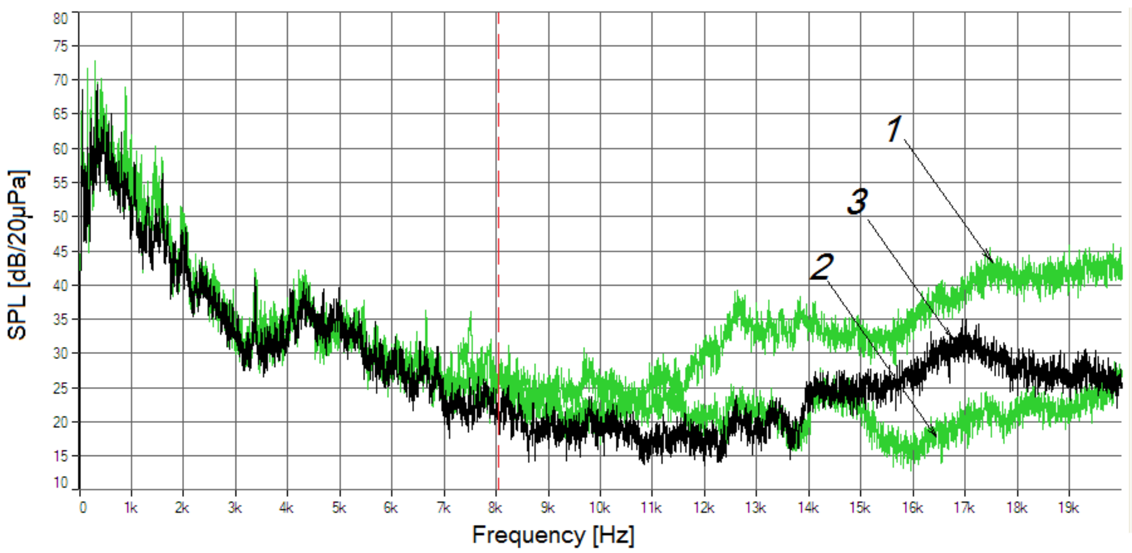


Fig. 4. The results of measuring the spectral characteristics of acoustic radiation during stationary friction of friction composites with different contents of the modifying component (BV+M-F mixture), which determines their wear characteristics (I_h) in accordance with the data in Fig. 3: *1* – 2.5 % vol. ($I_h \cdot 10^{-9}$= *12.5); 2* – 10 % vol. ($I_h \cdot 10^{-9}$= *3.0); 3* – 20 % vol. ($I_h \cdot 10^{-9}$= *7.5)*

4. Conclusion

The results of studies on the tribotechnical and corresponding acoustic characteristics of composites under stationary friction demonstrate the presence of an unambiguous correlation between the wear intensity and spectral density of acoustic emission in the sound frequency range above 8 kHz. The discovered correlation forms the basis of an express acoustic method, which allows one to significantly reduce the duration of tribotechnical tests of friction materials for work in stationary friction units in terms of determining wear resistance as well as providing additional information about the generated acoustic emission in the audio frequency range.

References

1. Sundarkrishnaa K. L. Friction Material Composites: Materials Perspective. Switzerland: Springer, 2-nd edition, 2015. 372 p.
2. Sergienko V.P. Noise and Vibration in Friction Systems /V.P. Sergienko, S.N. Bukharov. Switzerland: Springer, 2015. 251 p.

3. Pleskachevsky Yu.M. Friction materials with a polymer matrix: research prospects, achieved level, market / Yu.M. Pleskachevsky, V.P. Sergienko // Science and Innovation. 2005, No. 5, pp. 47 – 53.
4. Bukharov S.N., Merinov V.K., Sergienko V.P., Grigoriev A.Y. & Negmatov S.S.: Effect of the M-Phenylenediamine on the Tribotechnical and NVH Characteristics of the Frictional Composite Materials Based on PTFE. Lecture Notes in Networks and Systems (LNNS), Vol. 233 (2021), pp. 442–449.
5. Bukharov S.N. Study of the Influence of the Iron Oxide (III) on the Tribotechnical and Vibroacoustic Characteristics of the Frictional Composites for the Stationary Friction Units / S.N. Bukharov, V.K. Merinov, V.P., A.N. Senatrev, V.P. Sergienko // Friction and wear. 2018. T.39, No. 6. pp. 364-370.
6. Bukharov S.N. Triboacoustic Characteristics of Copper-Based Powder Frictional Composites for Operation in Dry and Boundary Friction Conditions / S. N. Bukharov, A. Ph. Ilyushchenko, A. V. Leshok, V. K. Merinov, A. N. Rogovoi, and V.P. Sergienko // Journal of Friction and Wear, 2020, Vol. 41, No. 6, pp. 487–491.
7. Bukharov S.N. Influence of Treatment with Non-Equilibrium Low-Temperature Plasma on Dynamic Mechanical and Tribotechnical Characteristics of Friction Polymer Composites / S. N. Bukharov, A. G. Anisovich, I. I. Filatova, T. A. Akhmetov, V. P. Sergienko, and A. Ya. Grigoriev // Journal of Friction and Wear, 2021, Vol. 42, No. 3, pp. 139–145.
8. Sergienko V.P. Effect of a High-Frequency Electromagnetic Field on Dynamic Mechanical and Tribotechnical Characteristics of Frictional Composites with a Thermosetting Polymer Matrix / V.P. Sergienko, S.N. Bukharov, A.G. Anisovich, N.S. Abed, and A.Ya. Grigoriev // Journal of Friction and Wear, 2021, Vol. 42, No.6, pp. 401-407.