Diagnostics and analysis of noise parameters of supercharger housings by acoustic emission method

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Algorithms and software and hardware for processing informative signals for filtering acoustic emission data in the recorded range of 2–600 kHz are analyzed and optimized. The method of spectral correlation analysis of signals from a broadband pulse source by determining the absorbing properties of the material at a particular sounding site can be used to identify defective sections of supercharger housings. Spectral correlation analysis of elastic wave signals is performed. The analysis of the noise parameters of the supercharger housings was carried out and the possibility of recording acoustic emission signals against a background of noise was established based on the determination of frequency ranges, as well as the values of acoustic emission signals and noise from operating units and the flow of transported gas.

Keywords: elastic waves, diagnostics, frequency, noise signals.

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Acoustic emission diagnostics relies on the recording of elastic energy release at fracture. The use of the acoustic emission (AE) method for these purposes in the kilohertz range is complicated by acoustic noise, which is always present in industrial equipment. The amplitude and frequency parameters of technological noise and „useful" signals are comparable, turning discrimination into a rather difficult task. In the present case, no general solution is apparent, and a thorough analysis of the background acoustic conditions of each specific production facility and piece of equipment is required. This highlights the relevance and importance of finding solutions to common problems. The method for assessing the degree of defect development [1–3] in metal housings of centrifugal superchargers (CSCs), which characterizes the technical condition of the object under study, is based on AE signal recording [4,5]. In the present study, the feasibility of AE signal recording against a noise background is analyzed by determining the frequency ranges and the magnitudes of AE signals and noise from operating units and the flow of transported gas [6,7]. The objectives of the study included AE monitoring (diagnostics) of CSC housings [8–10] and assessment of the technical condition of CSC housings with the determination of the presence or lack of defects (AE sources) that make CSCs unsuitable for further operation and necessitate a repair. EGPA 235-21-3 CSCs manufactured by AO Nevsky Zavod (material — 20GSL steel: working pressure — 67 kgf/cm^2; wave attenuation coefficient — 2.5 dB/m) were used as the test object. The limiting value of permissible amplitude $A_t = 60$ dB was determined in experiments. The standard software of the applied control systems, specialized software (ALine_32D instrumentation system), and the SEIMOST (DMT) programmable interactive set of tools for AE analysis were used in diagnostics.

Elastic waves were converted into electrical signals by P11Z-(0.2-2.0)-2 piezoelectric sensors. These signals were then amplified and recorded by two digital storage (ASU-3106) oscilloscopes and the ALine_32D AE equipment. The primary objectives of the experiment were further development and implementation of AE monitoring of the technical condition of CSCs for identification of regions with an increased AE activity for the purpose of their subsequent examination by alternate non-destructive testing methods [11,12]. Sensors were mounted on the CSC housing. Eight differential R-113 converters with frequency ranges up to 100 kHz and 100–500 kHz (with a resonant frequency of 250 kHz) were used as AE converters. The equipment was standard, the working medium was gas, and the temperature of the object and the environment was 5–17°C. The parameters of the CSC loading mode were measured in two cycles with holding at intermediate and maximum pressures ($P = 67$ kgf/cm^2); the holding time at maximum pressure was 30 min. The operating frequency range was 100–1000 kHz. The sensitivity of AE sensors was no lower than 10 mV/Pa. The dynamic range of the preamplifier was 85 dB at the least, and its noise level referred to input was no higher than 10 mV. The AE system ensured the determination of the following parameters of AE signals and parameters characterizing AE accumulated in the control process: signal amplitude, number of signal oscillations, signal duration, signal rise time, time of detection of this signal, and time difference between the moments of arrival of signals at the converters.

Spectral analysis of AE signals was carried out to examine the relation between the amplitudes of AE signals and noise from the operating unit and gas flow. Figure 1, *a* shows the noise AE signals recorded on the CSC housing in the operating mode.

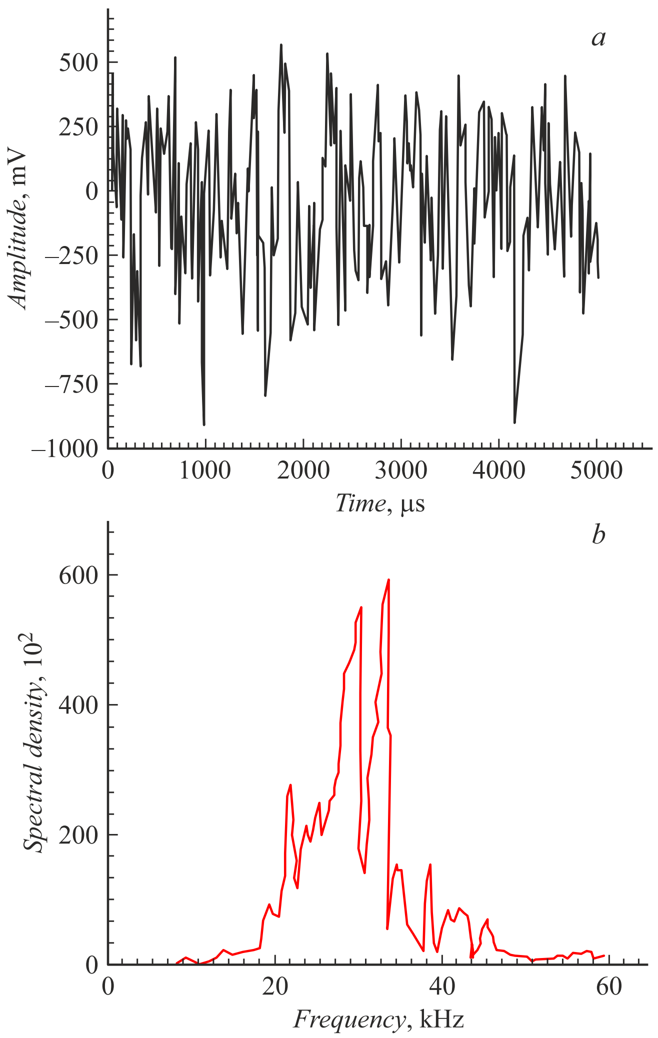

Figure 1. Noise AE signals recorded on the CSC housing. *a* — Amplitudes in the operating mode (from the transported gas); *b* — cross-spectrum of signals obtained via analysis of AE noise of the CSC.

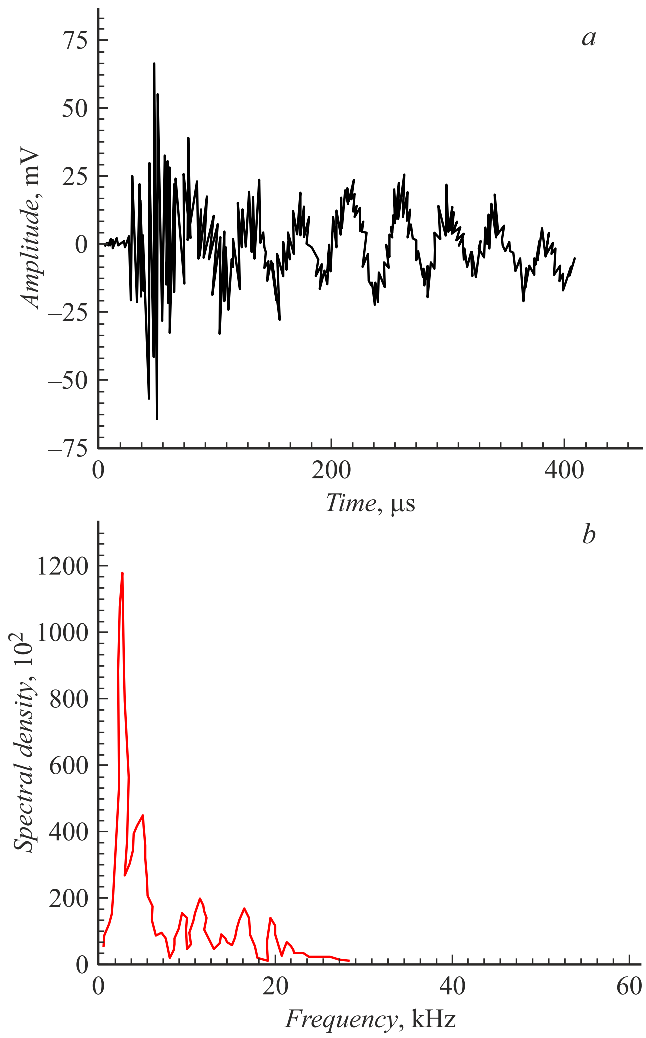

Figure 2. AE signals recorded at a pressure of 19 atm. *a* — Amplitudes in the idle mode; *b* — cross-spectrum of signals obtained via analysis of AE noise of the CSC.

Figures 1, *b* and 2, *b* present the cross-spectra of signals obtained via analysis of noise from transported gas at the branches of the piping of the same supercharger. The spectral density of noise acoustic signals in the operating mode is localized at frequencies below 40 kHz. If the pressure is set to 19 atm in the idle mode (i.e., gas is not transported, but the rotation process continues and the seals are active), the spectral density is localized at frequencies below 20 kHz.

In the operating mode, the maximum spectral density of noise from transported gas at the branches of piping of the same supercharger (Fig. 1, *b*) is found within the 20–40 kHz frequency range. The ratio of amplitudes of AE signals and noise from the oil seal operation was then examined at an increased gas pressure in the CSC housing in the idle mode. The pressure was increased by feeding gas into the supercharger housing through a valve. Piezoelectric film sensors (PFSs) of acoustic emission, which were mounted on the CSC surface, were pre-calibrated [13] prior to signal recording. The obtained data are presented in Fig. 2, *a*, which shows the AE signal recorded at a pressure of 19 atm. It is evident that the amplitudes of AE signals are close to 60 mV. When the pressure approaches zero, gas is not transported, but the rotation process continues and the sealing elements remain active. This is seen clearly in Fig. 3, *a*, which shows the amplitude of the CSC noise AE signal (in the idle mode). This amplitude is approximately equal to 20 mV.

The amplitude of the AE signal recorded at pressure $P = 45$ and 55 atm in the unit was also obtained. The results revealed that the amplitude increases to 300–400 mV and the noise amplitude is also higher (approximately 75–85 mV). Figure 3, *b* shows the characteristic coherence function; it has no significant dips, and individual sections are approximated well. Thus, it will be possible to pre-configure the algorithm for automatic optimization of filter parameters based on the analysis of spectra phase within the

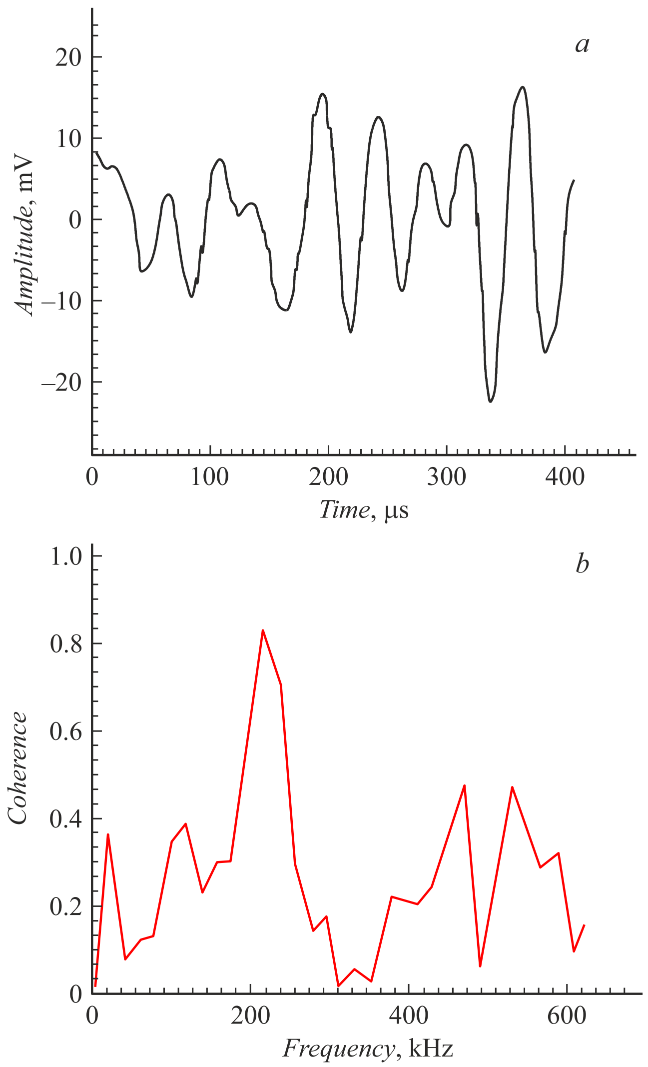

Figure 3. Amplitude of the noise AE signal in the idle mode (*a*) and coherence function (*b*).

frequency range from hertz to kilohertz, which may ensure high noise immunity of AE PFSs in search for leaks under strong noise conditions [9,13]. It is also evident that the coherence function reaches its maximum at the frequency corresponding to the AE signal one (200 kHz).

The same frequency is typical of AE signals from microcracks recorded in laboratory breakdown tests of samples made of 20GSL cast steel, which was used to produce supercharger housings. This implies that AE signals propagate from a single local source against the background of uncorrelated noise.

Supercharger housings were also examined in the scanning mode, and the results suggested that further successful diagnostics is possible. It was established that pulsed ultrasonic scanning may identify clearly the presence of a significant defect (with additional sounding). In the present study, we cannot specify the diagnostic capabilities and evaluate the structural state in accordance with the following criteria: minor defect, passive defect, active defect, and active defect with a high level (according to the classification of sources, classes 1–4, respectively). Further analysis of the coherence function shown in Fig. 3, *b* is another stage of identification of such sources. A class 1 source is a source for which the average pulse amplitude was not calculated (less than three pulses were recorded within the observation interval); a class 2 source is a source with inequality $A_{av} < A_t$ (A_{av} is the average AE signal amplitude) satisfied for three or more recorded pulses; a class 3 source is a source with inequality $A_{av} > A_t$ satisfied for three or more recorded pulses; and a class 4 source is a source that includes at least three series of three or more recorded pulses with inequality $A_{av} > A_t$ satisfied. Taking these results into account, we may work out a classification of AE sources:

$N < 10$ at $S_0 < 2$ — minor defect;
$N \geq 10$ and $N < 100$ at $S_0 < 2$ — passive defect;
$N > 4$ and $N < 100$ at $S_0 \geq 2$ — active defect; and
$N \geq 100$ at $S_0 \geq 2$ — active defect under strong external acoustic noise conditions.

The main characteristics of AE sources in metal (CSC) in the operating mode are number of signals N recorded within the monitoring period, average amplitude $\langle A \rangle$ of these signals, standard deviation S of the amplitude distribution, and parameter S_0 (ratio of S to the threshold AE detection level). $\langle A \rangle$ and S are measured in mV, and quantity S_0 is dimensionless.

An expanded article on spectral analysis (coherence function) of AE signals of CSC scanning will be prepared in the future.

The analysis of AE signals against a background of noise and solving of problems of the initial stage of diagnostics in the study of noise parameters of CSC housings by the acoustic emission method revealed the lack of a common approach in certain parameters. Therefore, when using the AE method, one should keep in mind that each test object has its own unique properties. An important parameter for adjustment of AE PFSs on a specific object is the velocity of wave propagation in it. This velocity depends on the material of the object, its filling, insulation, thickness, AE PFS type, operating frequency band, threshold, distance between PFSs, and, potentially, certain other parameters. Preliminary measurements of the wave propagation velocity are crucial for monitoring and adjustment.

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Conflict of interest

The author declares that he has no conflict of interest.

References

[1] V.I. Ivanov, V.A. Barat, *Akustiko-emissionnaya diagnostika* (Spektr, M., 2017) (in Russian).
[2] A.A. Sidyagin, V.M. Kosyrev, *Raschet i proektirovanie apparatov vozdushnogo okhlazhdeniya* (Nizhegorod. Gos. Tekh. Univ., N. Novgorod, 2009) (in Russian).
[3] V.V. Bardakov, S.V. Elizarov, V.A. Barat, V.G. Kharebov, K.A. Medvedev, D.A. Terent'ev, in *Vserossiiskaya konferentsiya s mezhdunarodnym uchastiem „Aktual'nye problemy metoda akusticheskoi emissii" (APMAE-2021)* (SPb., 2021), p. 27 (in Russian).
[4] O.G. Perveitalov, V.V. Nosov, A.M. Schipachev, A.I. Alehin, Metals, **13** (7), 1272 (2023). DOI: 10.3390/met13071272
[5] V.V. Nosov, A.R. Yamilova, Kontrol. Diagn., No. 6 (276), 30 (2021) (in Russian). DOI: 10.14489/td.2021.06.pp.030-045
[6] K. Makhmudov, V. Saveliev, J. Phys.: Conf. Ser., **1697**, 012066 (2020). DOI: 10.1088/1742-6596/1697/1/012066.
[7] Kh.F. Makhmudov, U. Sultonov, V.N. Savel'ev, K.E. Niginaev, Uch. Zap. Khudzhand. Gos. Univ. Ser. Estestv. Ekon. Nauki, No. 3 (58), 22 (2021) (in Russian). EDN: XHUBZS
[8] S.I. Builo, in *Vserossiiskaya konferentsiya s mezhdunarodnym uchastiem „Aktual'nye problemy metoda akusticheskoi emissii" (APMAE-2018)* (TGU, Tol'yatti, 2018), p. 14 (in Russian). EDN: MKDMSW
[9] Kh.F. Makhmudov, P.I. Afanas'ev, Gorn. Prom-st., No. S1, 142 (2023) (in Russian). DOI: 10.30686/1609-9192-2023-S1-142-149
[10] E. Grigorev, V. Nosov, Appl. Sci., **12** (9), 4549 (2022). DOI: 10.3390/app12094549
[11] A.V. Popov, A.O. Samuilov, I.S. Cherepanov, Adv. Eng. Res. (Rostov-on-Don), **21** (4), 328 (2021). DOI: 10.23947/2687-1653-2021-21-4-328-336
[12] A.V. Popov, D.N. Teslya, A.B. Komlev, Kontrol. Diagn., No. 8 (242), 34 (2018) (in Russian). DOI: 10.14489/td.2018.08.pp.034-039
[13] H.F. Machmoudov, Tech. Phys., **67** (12), 1627 (2022). DOI: 10.21883/TP.2022.12.55198.181-22.

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