

APPLICATION OF ACOUSTIC EMISSION FOR CONTROLLING TECHNOLOGICAL PROCESSES IN MACHINE PART MANUFACTURE*

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Summary

Prospects of introducing a universal operative diagnostic method of materials, technological processes of machine part manufacture and of their service conditions is discussed. The method is based on the phenomenon of acoustic emission accompanying practically all dynamic processes in materials. The principles of interpreting acoustic emission, utilizing the relationship between the statistic characteristics of the processes and the spectral properties of emission are discussed. An apparatus for receiving and analyzing acoustic emission signals is described. It is based on the separation of spectra components, their transformation into digital shape and further processing by computer. A short survey of experimental studies with acoustic emission is given.

Optimization of technological conditions in service and intensification of technological processes for manufacturing machine parts emphasizes increased requirements to diagnostic methods. The necessity of diagnostic information appears in all stages of material production, part manufacture and part service life.

In the production of materials of construction, control of physico-mechanical properties and structure will allow to ensure optimum relationship between strength and plasticity. In technological processing, methods of control and diagnostics serve to choose optimum conditions and to determine quality parameters of the products. In service, defectoscopy allows to detect defects and to determine the true degree of damage in constructions and parts.

Let us consider the preconditions for introducing a universal method of diagnostics including materials, technological processes and service conditions of machine parts. In latter years, acoustic emission methods for investigating solids have gained importance. These methods are based on the generation of elastic waves by dynamic processes in materials subjected to various effects. Practically all forms of rearrangement of the defective structure are sources of acoustic emission (AE): dislocation reactions; cracks; phase transformations; elastic contact of microinhomogeneities. It has also been found that AE is

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thermoelastic in nature and may be induced by friction, electric current, optical irradiation or ionizing particle flow.

AE signals are received by piezosensors, transforming the acoustic vibrations into electric signals in a range of 10 kHz to 10 MHz. The electric signals are random pulse flows, due to the random character of the sources and to external effects. The signals are then amplified, filtered and processed by methods depending on the actual task.

The advantage of methods utilizing AE over other non-destructive control methods consists in the possibility to obtain information continuously on processes in the material at a great distance between the source and the sensor, without stopping the process and disconnecting joints. Another advantage is the wide frequency range, allowing to eliminate low-frequency technological, testing and service interferences.

Multiple tasks are being solved by AE investigations of elemental dislocation acts and mechanisms of structure rearrangement [1]; development processes of elastic deformation zones [2]; and crack formation [3]; defectoscopy of materials of construction, of welds and of large-volume objects [4]; control of the micro- and macrogeometry of the surface at grinding [5].

Thus, the preconditions exist for developing and introducing an unified acoustic emission method suitable to control the technological processes of manufacturing machine parts and to detect the defects generated in service conditions.

In [6] and [7] it is noted that the most complete information on the type and degree of the emission process is contained in the AE spectrum, the spectral density function reflecting the power distribution of emission over frequencies, and connected with the signal $A(t)$ by the Fourier transformation:

$$G(f) = \left| \int_{-\infty}^{+\infty} A(t) \exp(-i2\pi ft) dt \right|^2 \quad (1)$$

where t and f are time and frequency, resp.

The time function $A(t)$ may correspond to individual pulses or to crossing pulse flows. The pulses, depending on the type of the source and on its power demand, differ in shape, amplitude A and duration τ . Individual pulses accompany rapid growth of cracks, tearing away of particles at wear in the friction zone, individual acts of elastic contacting and thermoelastic incitation. For such emission sources the condition $\tau < 1/F$ is usually satisfied, with F equal to the mean frequency of pulse succession. In this case the integration limits in Eq. (1) are 0, T_a , where T_a is chosen by the condition $\tau < T_a \leq 1/F$.

In [6] and [7] it is demonstrated how the shape and duration of pulses generated jointly by a number of defects changes with the number of defects N and their correlation degree U . Let us cite some examples illustrating the

relationship between the statistic characteristics of sources with AE spectra. At high correlation of the elementary emission sources $U > 0.1$ and $N \simeq 10^5$, the function of optical density is described by a curve continuously dropping in the range between 10 kHz and 1 MHz, with a maximum power drop of 10 dB. With increasing U and N values, coherence of emission will increase. In the limiting case, when all elementary sources emit simultaneously, the pulse shape will be S-like, and the corresponding spectrum will be of the regular type of white noise. Such spectra are recorded at leaps of large cracks, co-operating phase transitions, tears of surface rubbing against one another. Decreasing values of U and N result in a "reddening" of the spectrum, that is, a shift of the main power output towards the region of low frequencies. For example, at $U = 0.01$ and $N = 10^4$, the spectrum will drop by 20 dB from 10 kHz to 1 MHz. Such emission is characteristic for dislocation reactions in far-removed nuclei within the deformed material.

At large numbers of independent emission sources (plastic deformation, multi-point contacting, continuous development of cracks), acoustic emission can be considered as a Poisson-type pulse flow with the activity $m = F$. The spectral density function in this case will have the form

$$G(f) = mS(f) \quad (2)$$

where $S(f)$ is the spectral density of an individual pulse.

Consequently, emission sources of this type can be identified independently of their activity by the shape of the spectrum. Increased activity will result in proportional increase of power over the total frequency range, and the shape of the spectrum will not change.

The discussed features of acoustic emission from different source types indicate that the emission spectrum allows to identify power, extent, duration and statistics of dynamic processes.

However, AE spectra are distorted by the transfer characteristics of the medium, the piezotransformer, and the signal-receiving apparatus. Complex geometry of the part and the presence of junctions will result in a significant transformation of the spectrum.

In [7] the evolution of the spectrum for linear relationship between damping factor and frequency $\delta = A + Bf$ is discussed. A calculation of the propagation of longitudinal waves in large cylindric samples made of steel 20 demonstrated that the spectrum is substantially distorted already at distances of 0.5 m from the source. The distorted spectrum can be described by the product of the true spectrum and the exponent of the damping factor

$$G(f) = G_0(f) \exp(A + Bf) R \quad (3)$$

where R is the distance between the emission source and the piezotransformer.

To eliminate multiplicative interferences and to reduce frequency-depending damping, parameters are formed retaining the characteristics of the spectrum, but stable to distortion.

The ratios of the spectral components J_i in all moments t_k of spectrum processing are such parameters:

$$z_{ij} = J_i/J_j \quad (4)$$

where $i = 1, 2, \dots, n$ is the number of the spectral component, $k = 1, 2, \dots, k$ is the moment of time.

The spectral components are obtained by narrow-band filtration of the acoustic emission and subsequent detection. They have the form

$$J_i = \left| \int_0^t \exp \mu(\tau - t) A(\tau) \exp(-i2\pi f_i \tau) d\tau \right| \cos 2\pi f_i t \quad (5)$$

where μ is a filter parameter, F_i is the central frequency in the filter tuning.

Let us consider the principle of operation of the apparatus used for diagnostics of technological processes and identification of defects (Fig. 1).

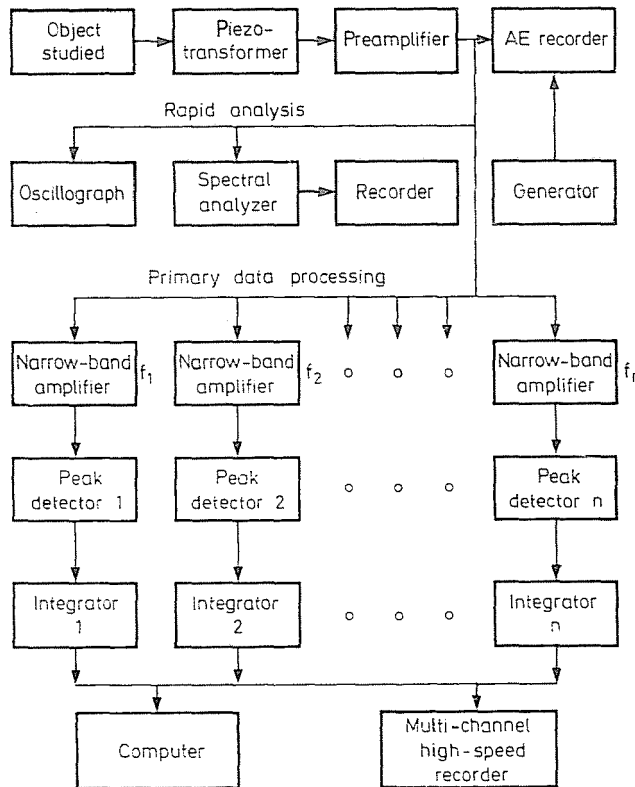


Fig. 1. Schematic diagram of receiving and processing acoustic emission

The acoustic pulses are transformed by means of a piezotransformer in contact with the part through a thin layer of a suitable liquid into electric signals. These signals pass onto a wide-band preamplifier with an adjustable amplifying coefficient from 10 to 60 dB and a sensitivity of $10 \mu\text{V}$ in the frequency range between 40 and 1000 kHz. Narrow-band amplifiers with 40 dB amplifying coefficients and transmission bands $\Delta f = 0.1 f_i$ are connected to the output of the preamplifier. Simultaneously the signals are recorded on magnetic tape using a videotape recorder type Elektronika 501, having a limiting frequency of 3000 kHz. The spectral components are detected, transformed into digital shape and fed into a computer to form the parameters α_{ij} .

The described laboratory apparatus is difficult to use under production and service conditions. Therefore technological processes and structures are usually controlled in the following manner. The output of the preamplifier passes onto two or three narrow-band amplifiers adjusted by frequencies, detected and in the analogue form introduced into a high-speed recorder. Selective microvoltmeters with built-in detectors are used as narrow-band amplifiers. Simultaneously the total wide-band signal is recorded on magnetic tape. For rapid analyses of the recorded emission, a continuous-type panoramic spectroanalyzer and an electronic oscillograph are used. A detailed digital analysis is performed in the laboratory by computer, utilizing the information recorded on the magnetic tape.

Under production and service conditions, simple and small instruments specialized for defined tasks are required. Such instruments should be calibrated directly in values of the informative parameters α_{ij} . The critical values of the parameters must be determined in the research stage.

This approach to interpret AE has been utilized for solving various tasks; control of physico-mechanical characteristics of structural steels; bench tests of parts and structural elements; diagnostics of technological processes and service conditions.

In the followings a short survey of experimental work done by the authors jointly with B. M. Medvedev, N. P. Kukol, A. V. Arsentev and B. G. Ivanov is given.

AE signals accompanying plastic deformation, viscous, brittle and fatigue failure were studied using steel 3, steel 20, steel 45, steel 09GS, steel ShKh15 samples subjected to monotonous and cyclic stress. From the processed experimental data, $\{\alpha_{ij}\}$ parameter sets were formed for each steel, corresponding to micro- and macroplastic deformations, growth of cracks and friction of their borders. The parametrized AE spectrum for each emission mechanism demonstrates significant differences. For instance, the spectral component ratio at frequencies of $f_2 = 100 \text{ kHz}$ and $f_3 = 500 \text{ kHz}$, in tensile tests performed with cylindric samples of steel 3 at deformation rates of $0.21 \cdot 10^3 \text{ s}^{-1}$ to $4.16 \cdot 10^3 \text{ s}^{-1}$ in the development stage of plastic deformation zones

varied between 3.7 to 3.9, whereas at crack formation in samples of the same steel subjected to concentrated flex, $\alpha_{2,5}$ was equal to 1.2 ± 0.2 . Such differences in the values of α confirm the correctness of the theoretical models, in which a spectrum declining towards high frequencies corresponds to non-correlated sources (initial stage of plastic deformation), while a flat spectrum corresponds to correlated sources (growth of brittle crack). An important characteristic of AE in the initial stage of plastic deformation consists in the independence of the parameters in the frequency range of 100 to 500 kHz of the deformation rate; this finding is utilized for early detection of stress concentrations in parts. In tensile tests of railway car brake beams, cracks 1.5 mm long were detected at $\alpha_{2,5} = 3.7 \pm 0.3$ values, which were formed at butt welds of the drawbar.

We investigated the relationship between acoustic emission and surface quality in grinding. Data relative to metal removed obtained by micrometer and by AE energy agreed within 10%. It was found that the character of AE spectral components mirror-wise reflects the wave diagram of the surface measured with a profilometer. The correlation coefficient calculated for various depths of cutting is 0.82 to 0.86. For flat grinding, waviness of the surface is measured by means of high-frequency spectral components ($f \geq 300$ kHz) to eliminate distortion due to interference effects [2].

Sets of α_{ij} values at low (up to 150 kHz) and high (up to 500 kHz) frequencies were utilized successfully in determining roughness and smoothing of the surface in diamond polishing.

Identification of structural changes due to the effect of laser irradiation is another promising direction of acoustic diagnostics. The analysis of the acoustic emission incited in rings of bearings made of steel ShKh15 by laser irradiation from the technological equipment Kvant-16 demonstrated the possibility to separate phase transformations against a background of thermo-elastic emission by the AE spectrum.

Let us consider in more detail the results of applying AE for investigating the running-in kinetics of the aluminium-tin alloy A020-1, utilized in railway bearings.

An analysis of the parameter sets α_{ij} in various stages of running-in demonstrated that the most information for separating AE signals from continuous plastic deformation and from discrete wear pulses is supplied by α values from the frequency pairs 100 and 500 kHz and 150 and 1000 kHz. The first parameter varies at plastic deformation within the range of 2.2 to 3.3, whereas at wear it amounts to 4.6...8.0; the second parameter has values of 7.0...9.3 at plastic deformation and 2.4...3.8 at wear. Complete $[\alpha_{ij}]$ matrices representing the parametrized spectrum, processed by the mask method [7] allow to determine the shares of plastic deformation and wear, resp., at different running-in stages.

Another task for practice where it is of importance of separate signals generated by plastic deformation from galling pulses is AE control of pressing-on railway wheels. The correlation between the load P and pressing-on length L and spectral components of AE was studied. The physical processes in the contact zone corresponding to anomalous portions in the load diagram $P(L)$ were determined, at which wheels are rejected.

Acoustic emission accompanying friction of riveted and bolted joints may be utilized for the diagnostics of metal railway bridges. Model experiments with bolted joints subjected to cyclic loads demonstrated that in the degree that joints loosen the number of pulses per unit time m increases.

This method was approved of by testing on experimental span structures and on one of the Moscow railway bridges. The AE spectra obtained were characteristic for non-damaged sections of the span structure and for loosened joints.

The successful application of AE in various fields allows to conclude that introduction on a large scale of the acoustic emission method is very promising for material diagnostics, for control of technological processes and for machine testing.

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