ACOUSTIC EMISSION SIGNALS PARAMETERS USE EFFICIENCY CONSIDERATIONS

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Material acoustic emission is the process of producing elastic waves, provoked by local dynamic reconstruction of its structure [1]. Acoustic emission method allows detecting and registering of only developing defects, prompting to classify them not by the size but by the danger level. Besides, it is the most sensible method of NDT. All above mentioned gives acoustic emission method undeniable advantage which unfortunately is hard to always realize.

In early 60s, when the opposition of two great powers inspired the studies of acoustic emission phenomenon, there was no special equipment for that. The peculiarities of acoustic emission signals forming and propagation (complex spectrum, low energy level, wide frequency and dynamic range, etc.) raise the demands to measuring equipment [2]. Acoustic emission equipment should have high sensibility, high amplification coefficient, minimal noise level and introduce minimal distortions. Ionizing emission detecting equipment met all these requirements that time. Besides, the majority of new phenomenon researchers were nuclear physicists. It is reasonable that receiving and measuring devices designed to amplify and measure electrical signals at ionizing signals detector output were used to detect weak elastic vibrations of acoustic emission signals by simple replacement of detector by piezoelectric converter. Geiger-Muller-based devices with their scale marked in impulses per time unit were widely used to measure ionizing emissions. These devices were called intensimeters and the value measured using them – intensity. This was very convenient for detecting the particles with foregone energy characteristics. At that it was meant that to get the actual values of ionizing emissions intensity it is necessary to multiply the result by the correction factor depending on the converter type, as well as registered ionizing emission type and energy. In the process of using this type of electronic equipment to detect acoustic emission such sharpness was lost. As a result, the most common acoustic emission signals parameter is the intensity or the counting rate became deficient of physical content. Contrary to ionizing emissions the number of impulses per time unit here is by no means connected to the intensity of ultrasonic wave propagated on the deformable body.

It cannot be stated that nobody was aware of the situation. As early as in 80s NPO “Dalstandart” in Khabarovsk carried out experiments which have demonstrated that applying acoustic emission parameters based on impulses reading (total acoustic emission, number of AE impulses, AE count rate, and AE activity) for quantitative acoustic emission description principles invariably results in low researches results precision. Such situation in measurements may occur in the presence of not excluded systematic inaccuracies and bear the evidence of incorrectness of such measurements due to improper choice of physical units characterizing acoustic emission properties. If to compare main acoustic emission measurement units with the International System of units [3], it can be seen that generally accepted acoustic units are almost never used for acoustic emission description. The same situation was observed before 70s in the sphere of ionizing radiation measurement just due to wide use of measurement units based on impulses counting. Upon switching to International System of units there was some regulation in values and units usage characterizing ionizing radiation and its field, and that increased measurement results reliability. Unfortunately, that did not happen in the sphere of acoustic emission. All existing normative documents starting from GOST 2763-83 and ending with rather up-to-date RD 03-131-97 and RD 03-299-99 recommend using parameters based on impulses counting.

Experimental studies results inconsistence and huge measuring inaccuracies apply not only to parameters based on impulses counting. Such parameters as AE signal maximum value (amplitude), AE signal average power, AE signal energy, the physical sense of which is beyond exception, are measured by modern acoustic emission systems with abnormally large error. Just receiving converter calibration error is 30%, adding thereto converter unit error and physical quantity measuring error. In the process of metering parameters registration these errors at least double. But this is still not the determining factor. The main error and variability source is the unwillingness of the researches to work in broad band. And we can understand them – in the process of receiving converter pass band spread its sensibility decreases. Up to this day they failed to create broad pass band converter with suitable characteristics. This forces the users to work in narrow band, having measuring error in the above mentioned parameters exceed 100%, thus loosing the meaning of the measurements. Researchers try to solve this problem demonstrating miracles of ingenuity. This results in the variety of parameters, the physical sense of which can be hardly explained.

The author as early as in 1982 during the X International Conference on nondestructive testing in Moscow, based on spectral analysis of the research studies of acoustic emission features of different materials demonstrated the inconsistency of using traditional parameters when analyzing narrow band acoustic emission signals [4], and several times proved that in his further research works. The situation is paradoxical. It turns out that it is simply impossible to measure the majority of acoustic emission parameters. We talk only about detecting an event, the validity of which should be first proved. All that is not beneficial to the method and thwarts its wide application. The situation makes the usual NDT specialist at best having passed the course in the process of qualification, become the experimentalist. Such transformation is hard for some people, and that is the main reason of the non-usage of acoustic emission method. It still used by small number of people and wide sphere for scientific researches. The existent expert NDT reference aids recommend to use twenty six parameters, eighteen of which are primary. The number of secondary parameters used by researchers in their work is kiting with each new thesis and has long ago exceeded reasonable limit.

Another difficulty of AE method realization is associated with the fact that technically we are not able to record every AE act separately. We are bound to analyze only the part of a collective process which appears to be above the equipment sensitivity threshold. This fact gives rise to multiple speculations and scientific fantasies. Mostly we can only see the tip of an iceberg and the rest data is left behind-the-scenes, under sensitivity threshold. As a result, even genuine values of such AE signal physical quantities as pulse height and energy are frequently do not allow to establish any correlations. We need comprehensive knowledge of process physics to evaluate the whole process by available data. It is important to realize that forming of the “tip” is indissolubly related to sensibility and frequency characteristic of a converter, method and accuracy of converter positioning, AE properties of a material and wave characteristics of a survey item, as well as to loading dynamics and structural in homogeneity of the material. We also have to take into consideration that AE formation process is comprised by several simultaneous processes part of which are auxiliary and depend on environmental conditions. I have recited just part of the factors to be considered in AE signal analysis. It is notable that in 70-80s AE was nicknamed as “black magic” in scientific back rooms.

AE research worker challenge can be substantially simplified by excluding doubtful physical parameters. Only unquestionable parameters should be taken. Let’s try to prove the necessity of AE signal analysis in broad band. It is well-known that material AE is the process of producing elastic waves, provoked by local dynamic reconstruction of its structure. It is important to give much attention to cracks formation and development as emergency situations and breakdowns at industrial facilities are commonly stipulated by formation and further development of cracks in material of the survey item.

Solid body is a random set of structural formations. Viewing it in one scale level it can be considered as a set of grains on the surface of failure. The grains can be of a random shape. Crack development process is easy to consider as a process of successive destruction of its separate structural formations (grains). Every coherent destruction of each grain will have its emission of corresponding AE impulse. Each impulse will have individual properties reflecting grain’s individual shape and size. The sequence of mentioned impulses will thus compose AE process.

From what has been said we can conclude that the energy of AE signal of the developing crack will be irregularly distributed along the frequency band. The irregularity will be of a random nature as every AE signal with its spectrum will be unique composition due to it's formation and development features. These facts were many times established and this is the reason why energy and amplitude properties of the signal should be measured in broad band, taking into account all frequency components. Besides, while material destruction acoustic waves (AE signals) undergo serious changes when they spread along the survey item. AE signal in receiver point is a sum of signals from different paths. As a result the wave shape becomes distorted and impulse signals duration increases by hundreds and thousand times.

As is well-known, spectrum of signals sum equals sum of spectra, hence effective width of summarized signal spectrum should not increase. However, its distortion is considerable. Transfer properties of the acoustic tract are described by frequency response function (FRF). Classical method of frequency distortion influence exclusion consists of FRF calculation with subsequent adjustment of received signals spectral characteristics. Plane shape objects FRF can be calculated theoretically. Let us do FRF calculations for a long rod.

Metal or ceramic survey item, as well as other items made of high elasticity material can be calculated with high accuracy by linear systems. In a general way spectral characteristic module of the signal taken from converter output is defined by the following formula:

$$S_{np}(\omega) = S_u(\omega) \cdot K_{mp}(\omega) \cdot K_{np}(\omega) \ , \tag{1}$$

Meanings of the symbols: $S_{ïð}(\omega)$ and $S_{è}(\omega)$ are spectral characteristic module of the converter output signal and AE source respectively; $K_{mp}(\omega)$ and $K_{np}(\omega)$ stand for FRF of acoustic tract (survey unit) and converter respectively.

With the help of distributed parameters system mathematical apparatus it is possible to find complex transfer rating coefficient for the separate type of the wave for survey unit (long rod) FRF structure effect qualitative and quantitative assessment:

$$K_{CT}(j\omega) = \frac{ch[\gamma(j\omega) \cdot (l - x)]}{sh[\gamma(j\omega) \cdot l]}, \tag{2}$$

Meanings of the symbols: $\gamma(j\omega) = \alpha(\omega) + j\beta(\omega)$; $\alpha(\omega)$ - acoustic signal fading coefficient; $\beta(\omega) = 2\pi/\lambda = \omega/v$ - phase coefficient; v - acoustic wave propagation velocity; λ - length of the wave; x - signal source coordinate; l - rod length.

If we place the receiver on the end surface of the rod (x = 0), FRF of the rod will be defined as follows:

$$K_{CT}(\omega) = | \ K_{CT}(j\omega) \ | \tag{3}$$

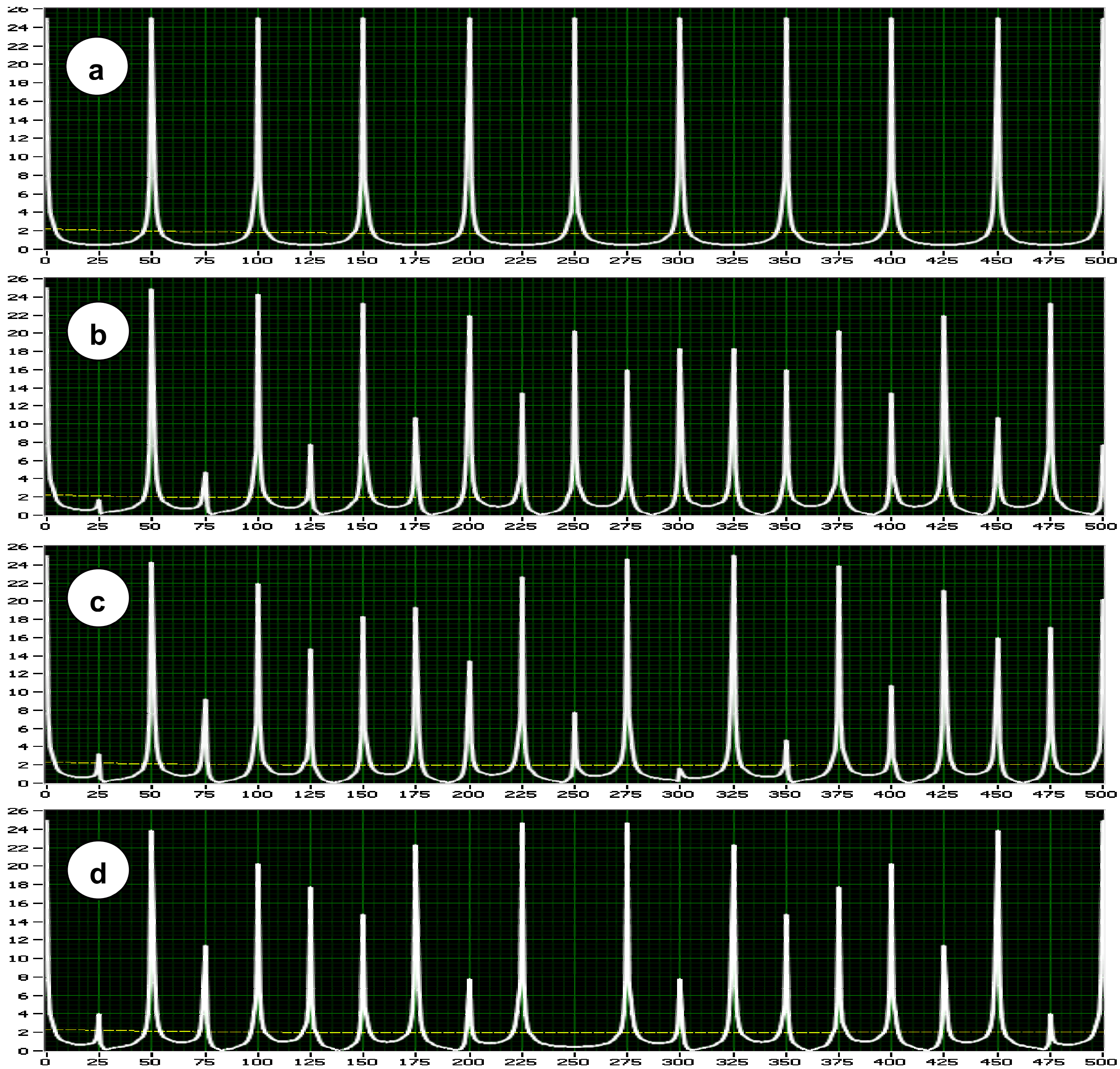

Fig.1. FRF of the rod within 0-500 kHz frequency band with following parameter values:
α=0.4 Np/m, v=5000 mps, l=0.1 m
for signal source coordinate:
a) x=50mm; b) x=52mm; c) x=54mm; d) x=55mm.

Fig.1 represents diagrams of rod FRF relation to geometric center source coordinate. Frequencies beat results in suppression of some frequency components. Owing to above said, Ω_1 frequency halves (Fig. 1, a). Ω_2-type frequencies reveal themselves while source coordinate slight deflection (Fig. 1; b, c) with FRF curve deeply notched (Fig. 1, d). All represented relations are correct if α, l, v values are permanent.

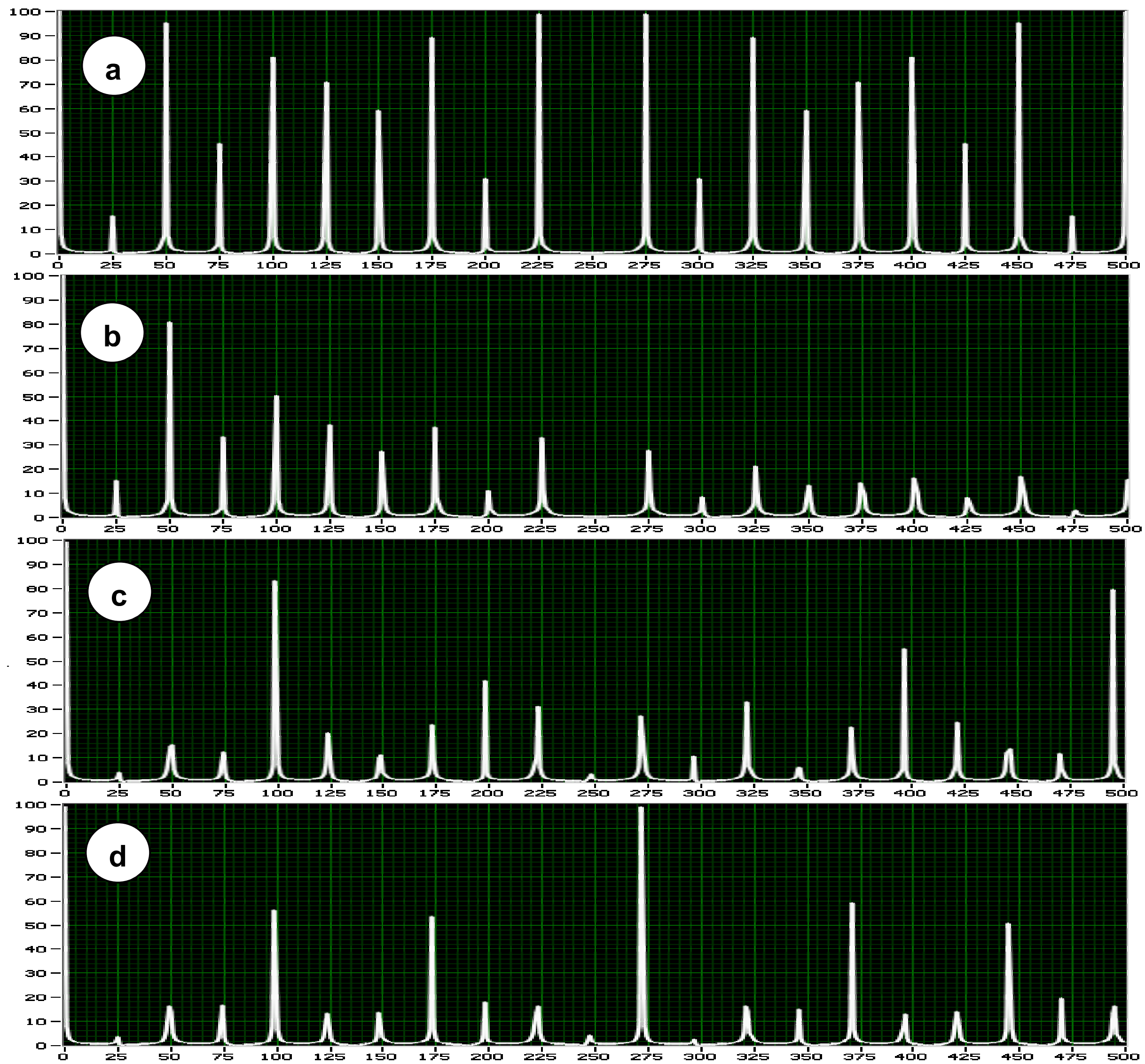

Fig.2. FRF of the rod within 0-500 kHz frequency band with fading parameter α=0.1 Np/m *and parameters: a) v=5000 mps, l=0.1 m; b) v=5005 mps, l=0.1 m; c) v=5000 mps, l=0.101 m; d) v=4995 mps, l=0.101 m.*
Signal source coordinate x=55mm

Unfortunately the statement that alterations of $K_{\tilde{N}\grave{O}}(\omega)$ with frequency change has periodic nature with the following periods $\Omega_1 = \pi \cdot v/l$ and $\Omega_2 = \pi \cdot v/(l-x)$ cannot be called ultimate. Influence of the α, l, v, x parameters on FRF curve distortion is much stronger and complex. Apart from that, we can emphasize Ω_2-type frequencies, which characterize slow FRF altering. These frequencies take place as a result of frequencies beat, leading to the formation of frequency components when α, l, v, x parameters are aliquant. At the same time, these parameters can alter simultaneously resulting in ideal model disintegration (Fig. 2).

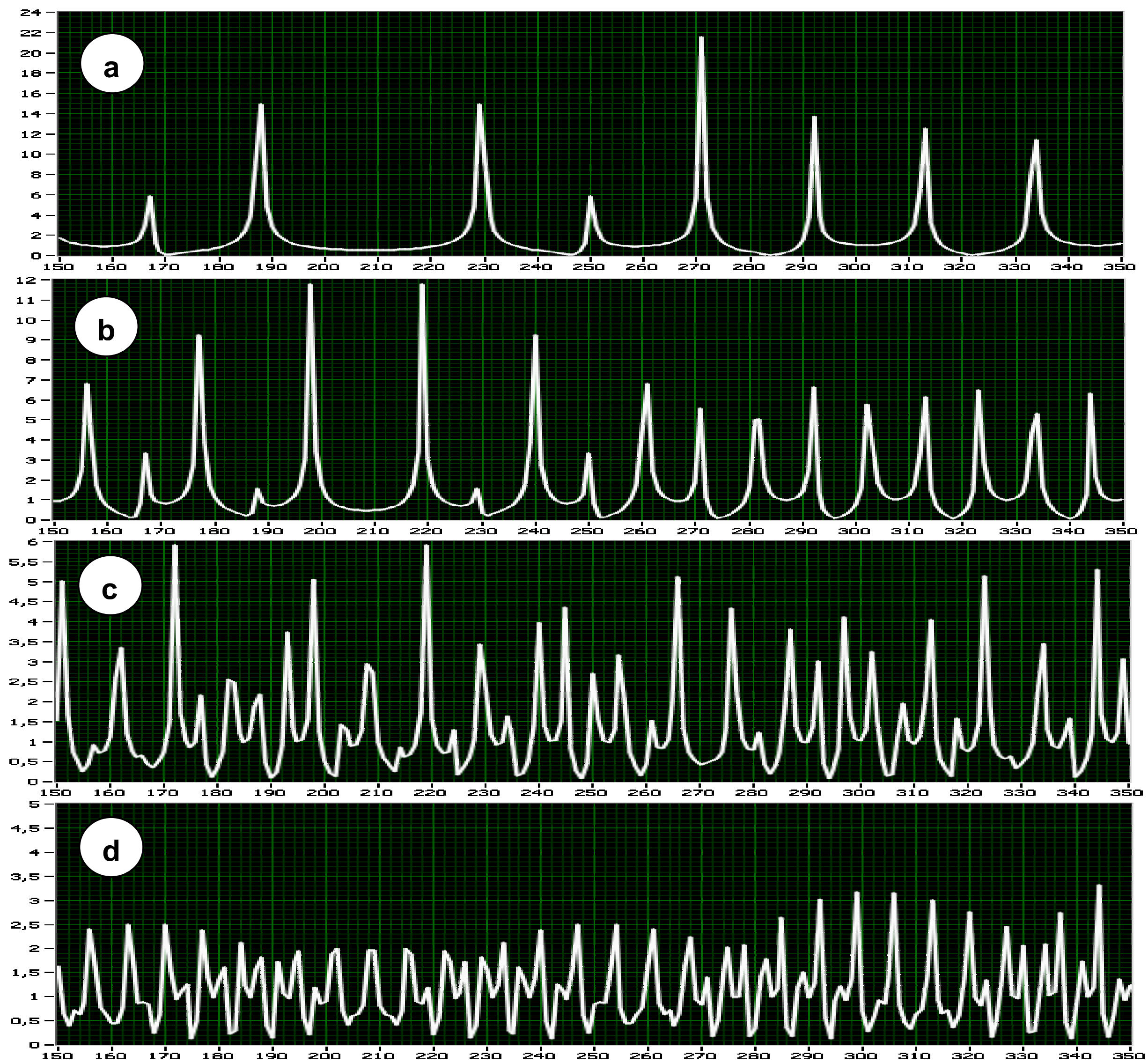

Fig.3. FRF of the rod within 150-350 kHz frequency band with fading parameter α=0.34 Np/m, v=5000 mps, x≈l /2mm and length of the rod: a) l=0.12 m; b) l=0.24 m; c) l=0.48 m; d) l=0.72 m.

Let's take a look at the process in the most preferable 150-350 kHz frequency band.
It is usually used in material and product AE properties analyses as scientists reasonably consider this band to be less influenced by noise and high frequency AE signal components fading is inconsiderable. Fig.3 pictures FRF of the rods. Rods length parameters are as follows: l=0.12 m; l=0.24 m; l=0.48 m и l=0.72 m, source coordinate x equals half of rod length. It is clear, that Ω_1 and Ω_2 frequencies are strongly pronounced only with low l value and constant position of source coordinate ($x=0$, $x=l/2$). Slight deflections of the x coordinate from critical points leads to Ω_1 and Ω_2 frequencies beat and frequency component emerging.

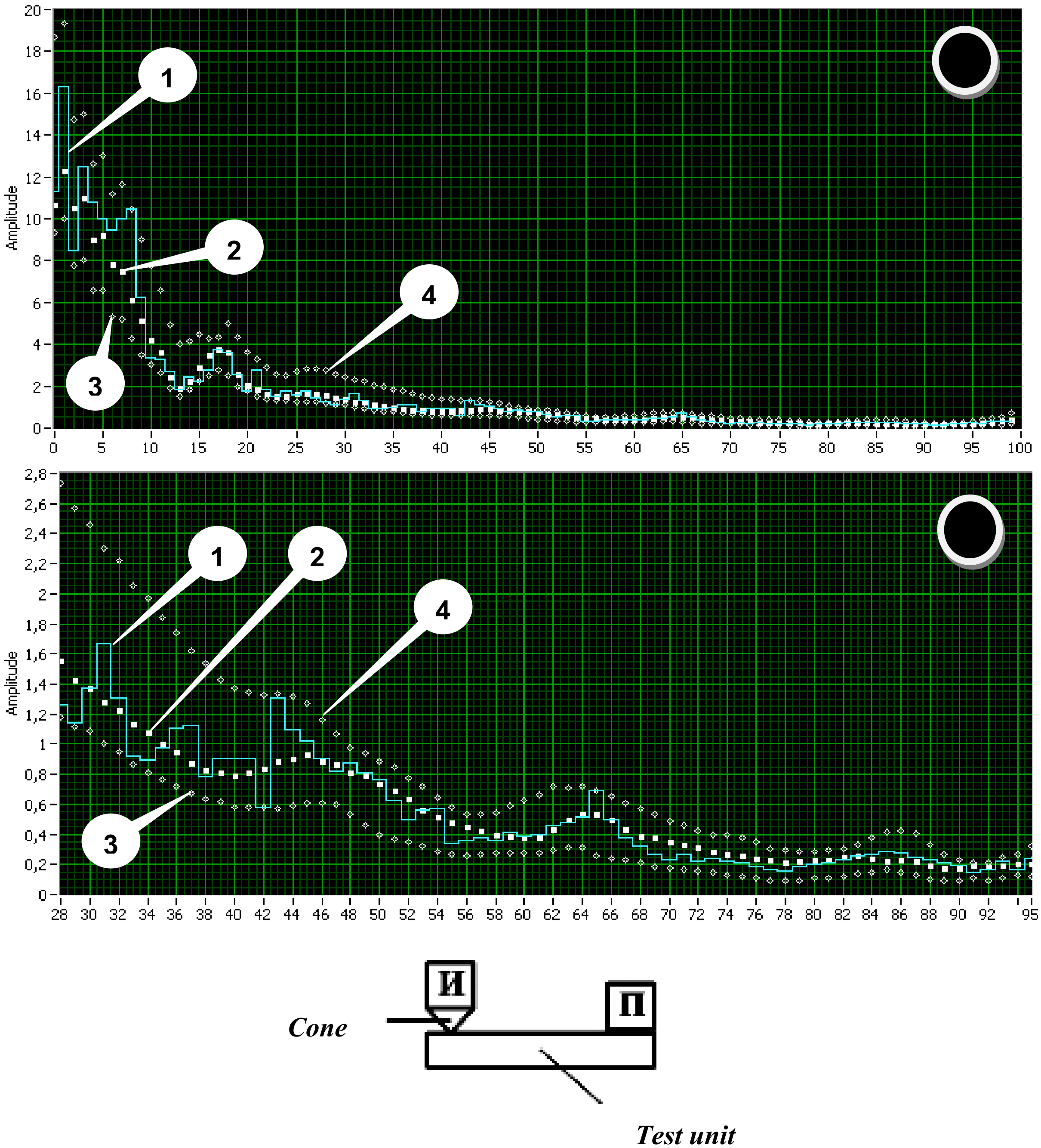

Fig. 4. FRF of the test unit within 20-2000 kHz (a) and 560-1880 kHz(b) frequency bands. Frequency-response curves are smoothed with $\Delta f \cong 10$ kHz (curve 1) and $\Delta f \cong 100$ kHz (curve 2) in acceptable value range (curve 3, 4)

Fig.4 displays experimentally acquired FRF of 0,12m-long square ceramic rods. Acquired curves are definitely of exponential nature, which gives evidence to the fact that the model (2) is not perfect. This model along with other factors makes no allowance for fading frequency dependence. For more precise estimation of fading dependence on frequency the positive verification range is limited to 560-1880 kHz range. This allows to evaluate FRF of the test unit with the 30% max error.

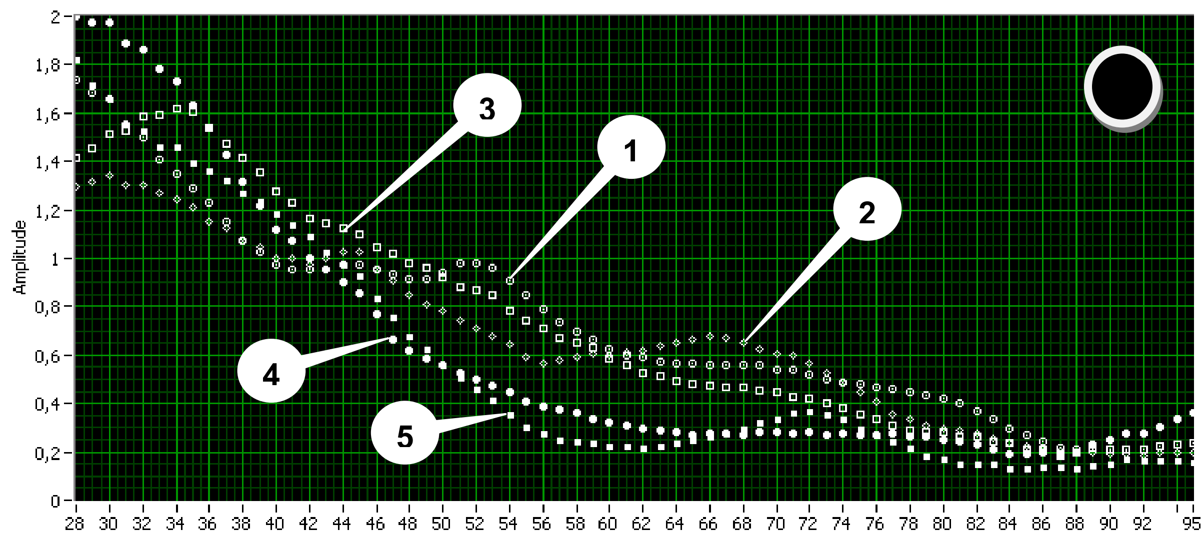

*Fig.5. FRF of S-C-T-R (*signal source-*cone-test unit-receiver) system within 20-2000 kHz (a) range and adjusted FRF of the test unit within 560-1880 kHz range (b).*

Smoothed-out spectrogram represented on Fig. 5 characterize test unit FRF altering in relation to receiving converter positioning. When the receiving converter is positioned on the end surface (curves 1, 2, 3) the FRF has broader band (high frequency components increase) as compared to when receiving converter is positioned on the surface lateral side (curves 4, 5) irrespective of signal source orientation. In the positive verification range (560-1880 kHz) curves can be easily approximated by means of exponent function.

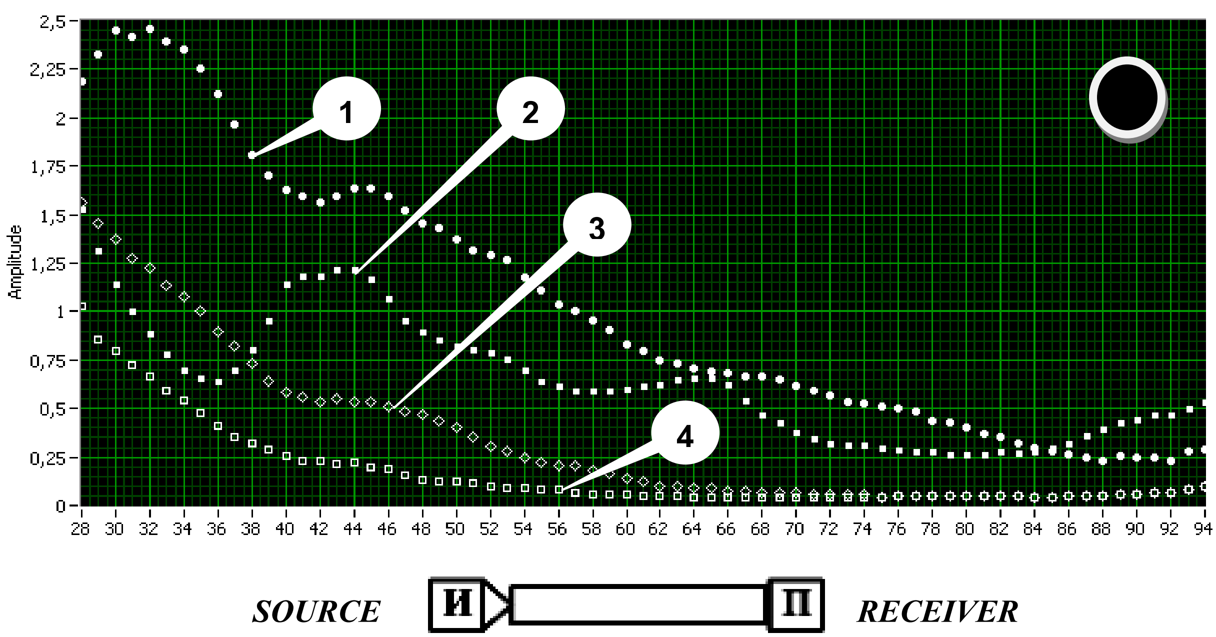

Fig. 6. FRF of the test unit within 560-1880 kHz range
1- electrical insulator porcelain; 2- silicium nitride; 3- alumina refractory; 4- alumina-boron nitride

Fading frequency qualities depend not only on geometry of the sample and converter positioning but also on material properties of the sample. Fig.6 represents adjusted frequency characteristics of the signals passed through different samples made of various materials: curve 1 - electrical insulator porcelain, 2 - alumina-boron nitride, 3 - alumina refractory, 4 - silicium nitride. Frequency characteristics of mentioned materials differ significantly.

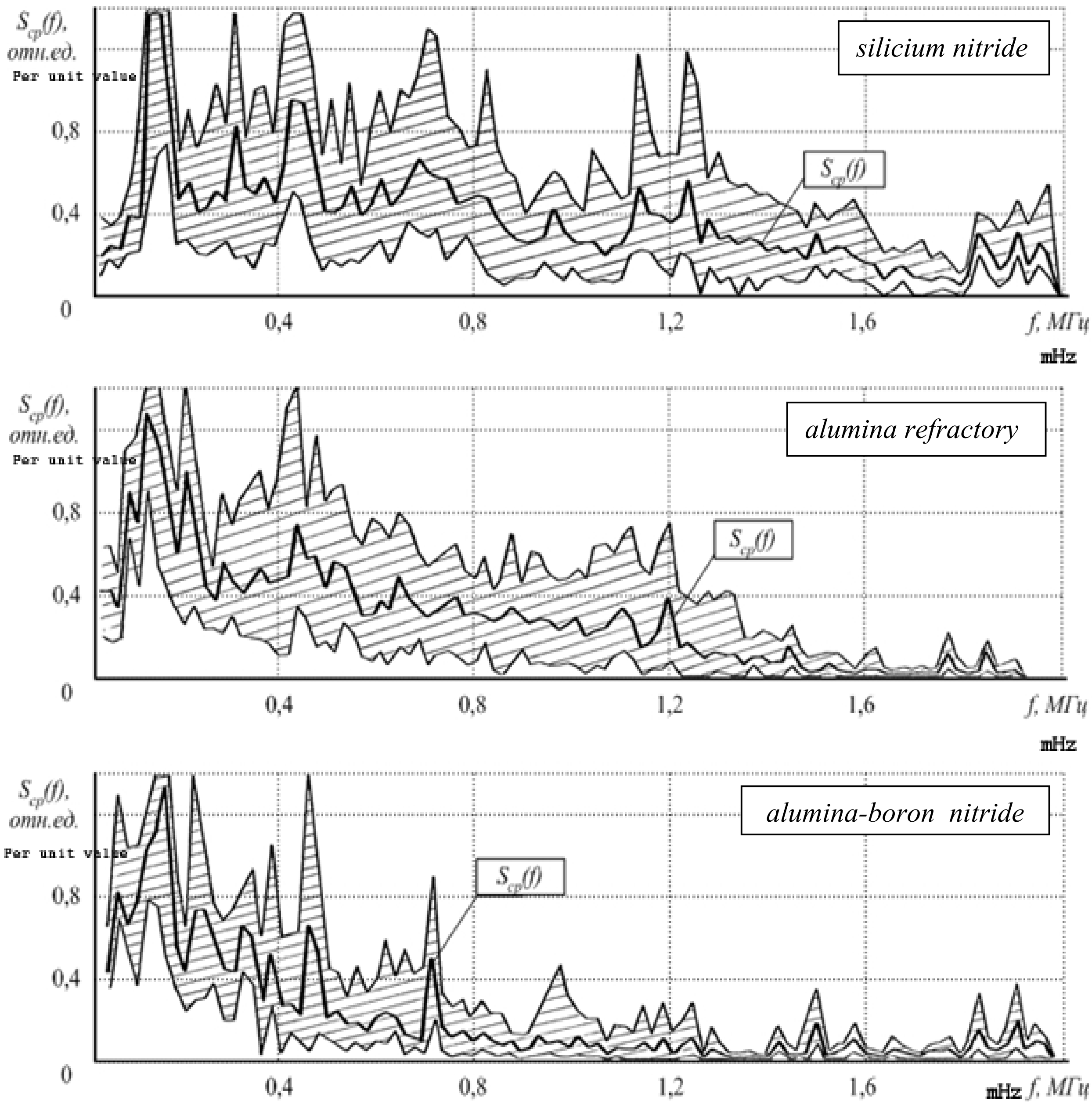

Fig.7. Averaged spectral functions $S_{cp}(f_i)$ *within 20-2000 kHz range*

To evaluate analyzed materials emission ability 4-point bend tests were conducted. AE signals taken were processed by the spectrum analysis device. Spectrum functions were standardized by assigned criterion and adjusted due to FRF. Fig.7 represents $S_{cp}(f_i)$ average number diagrams and ranges of limiting acceptable values of AE signals spectrum functions taken directly before destruction. The obtained results confirm high rate of AE signals emission irregularity and large fluctuations of spectrum components. This conclusion is valid for all ceramic materials under test.

Conclusions made are fortified by performed theoretical and experimental analysis of AE signal spectrum properties and FRF samples. Taking into consideration all above mentioned I think that:

1. It is necessary to separate the detectors which are the majority of modern means of acoustic emission control from the measuring equipment and in new researches make special reference to measuring the limited amount of parameters having physical sense.
2. It is required to bring into sync the acoustic emission measurement units and International systems of units, abandon the parameters based on impulses counting, or use correction factor when detecting each separate impulse.
3. When registering signal amplitude it is required to consider its frequency distribution connecting each amplitude rate with the corresponding vibration rate.
4. It is strictly contraindicated to measure signal energy in narrow band, naming such measures as "energetic parameters". Energetic parameters as the acoustic emission energy itself may be obtained only based on the whole spectrum analysis.
5. With the purpose to reduce the measurement error it is required to perform receiving piezoelectric converters calibration right on the tested unit and in the process of test analysis consider "unit-converter" transfer characteristic.
6. It is required to create the commission with the purpose to draw out general provisions of the normative document that would determine the rules of acoustic emission control organization and performance rules as well as specify main requirements to acoustic emission equipment.

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