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THE ACOUSTIC EMISSION TRANSDUCER CALIBRATION USING SPARK METHOD

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The present paper deals with the problem of frequency characteristics and of the sensitivity of acoustic emission (AE) transducers. Basing on a theoretical analysis of possible calibration methods of AE transducers, the method of random noise was chosen using the spark impact as the exciting signal source. The theoretical fundaments of the spark calibration method given in the present work were verified experimentally. On these results, the experimental device was designed and built in the Institute of Physical Metallurgy, Czechoslovak Academy of Sciences in Brno. It is presented in this paper. Estimated by this device characteristics of AE transducers made by META, Prague, Czechoslovakia and by UNIPAN, Warsaw, Poland, are presented.

W pracy omówiono problematykę częstotliwościowych charakterystyk czułości przetworników emisji akustycznej (EA). Opierając się na teoretycznej analizie możliwych metod kalibracji przetworników EA, zastosowano metodę szumu przypadkowego, w której używane jest wyładowanie iskrowe jako źródło sygnału wzbudzającego. Naświetlone teoretyczne zasady iskrowej metody kalibrowania przetworników zostały następnie zweryfikowane eksperymentalnie i na tej podstawie w Instytucie Fizycznej Metalurgii Czechosłowackiej Akademii Nauk w Brnie zaprojektowano i zbudowano urządzenie pomiarowe. W pracy opisano to urządzenie oraz ustalone przy jego pomocy charakterystyki niektórych przetworników EA produkowanych przez META w Pradze i przez UNIPAN w Warszawie.

1. Introduction

In the acoustic emission (AE) instrument technology, a serious problem is connected with the detection of AE signals. The acoustic emission (stress wave) rises due to sudden energy release inside of a material (Fig. 1) by the effect of an external

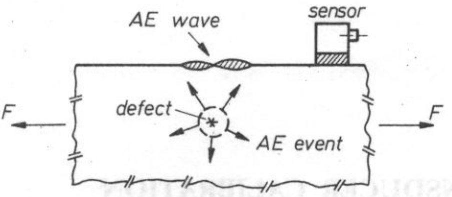

FIG. 1. Acoustic emission rising and propagation

stimulus (mechanical stress, temperature, corrosion etc.). Microphysical conceptions of possible AE sources in metals and metallic systems are demonstrated in Fig. 2. The AE source is here the movement of lattice defects and/or cracking of hard particles as well; the same mechanisms cause the crack nucleation [1,2]. During the

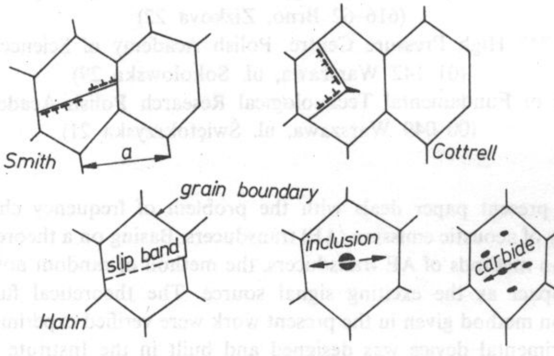

FIG. 2. AE sources in metals

proper crack propagation, the plastic zone is forming ahead the crack front (not the crack itself), thus, the dislocation mechanism again is the source of AE signals.

From this reasoning it is evident that primary signals of the given dynamic effects of moving defects will have the form of very short impulses, the direct registration of which is, under contemporary conditions of measuring technique, impossible. E.g., at the failure propagation over grain of size $a = 10^{-4}$ m, the impulse time $\tau = \frac{a}{c} \approx 2 \cdot 10^{-8}$ s (c is the dislocation velocity). By means of real AE transducers the secondary Rayleigh waves on the free surface of the object are read.

Typical representants of AE transducers are the transducers using the piezoelectric effects. The fundamental dependence between the applied stress and the output signal is linear. At dynamic loading, a strong frequency dependence of the sensitivity of transducers manifests itself. These transducers represent a relatively complicate electromechanical system definable only with difficulties. The analytical solution methods do not give a full characteristic of the transducer (its dependence of sensitivity versus frequency) and it is necessary to complete them by an individual calibration process. Without solving the reliable calibration of transducers, both the objective estimation of the measurement results (e.g., localization of defects) and their physical interpretation, and the comparison of results obtained from various apparatus in particular laboratories, as well, are practically impossible.

The calibration of transducers and the possibility of comparison and transfer of results are then the main problems of AE technology. The development aims to the worldwide standardization by means of unifying standards and recommendations [3].

2. The choice of calibration method

The calibration method was chosen based on the theoretical analysis of possible calibration methods of AE transducers making use of various physical principles.

2.1. The vibration method

It performs the service of calibrating accelerometers. The vibrator excited by means of an electronic oscillator can cover the frequency range 1 ... 10^5 Hz, practical upper limit being, due to mechanical resonances of the vibrator, ca $2 \cdot 10^4$ Hz. The output signal of the calibrated transducer is compared to the output of an identically loaded standard. The sensitivity is given directly in pC/g, and mV/g, respectively.

2.2. The impact method

This method makes use of the stress wave excited by a little ball falling from a definable height on an anvil on which the transducer is placed. Taking into account that the wave course can be mathematically well described, see, e.g. [4], even standard transducers can be placed on the anvil. This method enables even the absolute sensitivity calibration.

2.3. The hydrophone method

In this case, the calibration is being carried out in a big water reservoir in which on the one side a standard transmitter, and on the other – a standard transducer are placed. After taking measurements of the transmission, the tested transducer is placed in the whole frequency range instead of the standard one. The calibration curve is obtained by comparison of both test. For the given method, it is necessary the identical geometry to be constant. A normal frequency range is from 1 kHz to 1 MHz.

2.4. The ultrasound method

This method represents a modification of the foregoing one, the transmitter being connected acoustically directly with the transducer by means of viscous medium. The transmitter is excited by a sinusoidal wave generator, over-tuned in the test frequency range. This method is relatively quick and thus is often used.

2.5. The method of random noise

This method tries to model an AE signal, and real conditions for its propagation and scanning. The transducer is placed on the surface of a large block of material on which a flux of fine, hard particles impinges. Their impingement causes the rise of stress waves propagating through the material and reaching the transducer. The signal has the character of noise with a wide frequency spectrum. A frequency analyser is connected to the transducer output. The amplitude dependence on frequency is then registered by an appropriate method. The way of obtaining impulses is in good agreement with the real situation at AE. The individual particle character imitates the point source of a narrow transit impulse quite well. The general continual process has then a wholly random character. This method is being often used for the selection of AE signals from the signals arising due to external sources [5].

When estimating the suitability of mentioned in Sections 2.1...2.5 particular methods for calibrating the transducers, considering their use for scanning the AE signals it is evident that their application is specialized. The acceleration measuring instruments and the conventional ultrasound exciters are, at the present time, calibrated by the verified methods. As mentioned above, these methods do not, however, correlate with the real AE.

In discussions of theoretical and practical results, with regard to the utilizability, the following requirements of calibration process have been respected.

a) The input calibration signal must have the form of stress impulses with a small amplitude and short time.

b) The propagation of impulses in the calibration device must be similar to real propagation conditions of AE signals.

c) The surface contact conditions of the transducer in the apparatus must be near to those in the case of practical application.

d) Tests (calibration) must be reproducible and exact, having adequate permanent tolerance.

With regard to these requirements, it is evident that for the calibration of AE transducers the method of random noise will be the most convenient. The newest spark calibration method is also based on this principle, using as a source the exciting signal of spark discharge [6,7].

3. Theoretical basis for the spark calibration method

The application of the spark calibration method is conditioned by the validity of the presumption that the sequences of impulses with a certain length can be adjoined the frequency range in which all components have the congruent amplitude. To estimate this presumption, let us consider the sequence of rectangular impulses $u(t)$ with length δ, amplitude E_0 and period T, according to Fig. 3

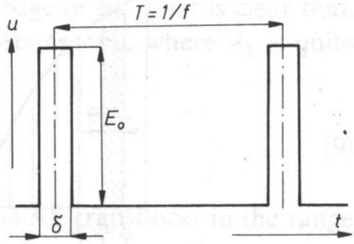

FIG. 3. A rectangular impulse

$$u(t) = 0 \qquad t < -\frac{\delta}{2};$$

$$u(t) = E_0 \quad -\frac{\delta}{2} < t < \frac{\delta}{2}, \tag{1}$$

$$u(t) = 0 \qquad \frac{\delta}{2} < t < T - \frac{\delta}{2},$$

For the Fourier development of this sequence it is valid, see, e.g., [8]

$$u(t) = \frac{A_0}{2} + \sum_{k=1}^{\infty} A_k \cos \omega_k t, \tag{2}$$

where A_0 and A_k are the amplitudes of harmonic components, respectively, $\omega_k = 2\pi k f_1$, and $f_1 = \frac{1}{T}$ is the repeating frequency. For A_0 and A_k we get

$$A_0 = \frac{2\delta}{T} E_0, \tag{3}$$

$$A_k = \frac{2\delta}{T} E_0 \frac{\sin \frac{\omega_k \delta}{2}}{\frac{\omega_k \delta}{2}}. \tag{4}$$

From Eq. (4) it follows that A_k changes periodically with increasing k, proportionally to $\sin \frac{\omega_k \delta}{2}$ and their courses are damped being hyperbolically proportional to the coefficient $\frac{1}{k}$ (Fig. 4). The dependence $A_k(\omega)$ contains the zero points $\left(\omega_{ok} = \frac{2k\pi}{\delta}\right)$,

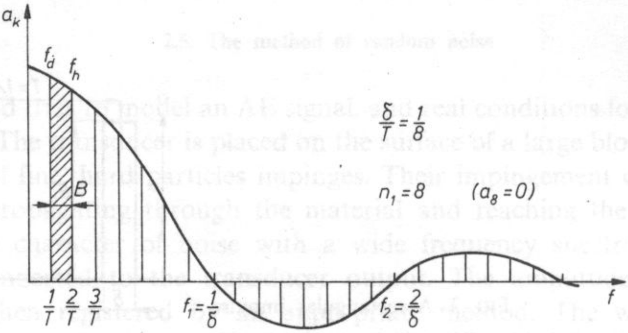

FIG. 4. The spectrum of an unrepeated impulse

separating individual spectrum loops. The number of spectrum components in one loop can be expressed by the relation

$$n = \frac{T}{\delta}. \tag{5}$$

To get the maximum number of components, it is necessary that the impulse is substantially shorter than the period of the given sequence. For $T \to \infty$, we get a solitary impulse $u(t)$, the spectrum of which is continuous. For the amplitude of spectral function $S(\omega)$, it holds then

$$S(\omega) = E_0 \delta \frac{\sin \frac{\omega_k \delta}{2}}{\frac{\omega_k \delta}{2}}. \tag{6}$$

Comparing Eqs. (4) and (6) we see that it holds

$$A_k = \frac{2}{T} S(\omega). \tag{7}$$

As T is constant, the frequency dependence A_k has the same course as $S(\omega)$.

When considering a general impulse $u(t)$, it is suitable, for the estimation of the

$S(\omega)$ course, to introduce the effective impulse time t_m

$$t_m = \frac{1}{E_0} \int_{-\infty}^{\infty} u(t)dt. \tag{8}$$

For the rectangular impulse, $t_m = \delta$.

When applying now the non-dimensional frequency $\Omega = \frac{\omega}{2\pi} \Big/ t_m$ it can be demonstrated, see, e.g. [9], that for $\Omega < \frac{1}{2}$ a value of $S(\omega)$ is approximately constant for the majority of impulses. With regard to the knowledge of Eq. (7) it is clear that, for the sequence (1), the interval of frequencies Δf exists as well, where A_k is quite constant, if it holds

$$\Delta f \ll \frac{1}{\delta}. \tag{9}$$

When we want to find the frequency characteristic of the AE transducer in the range 0...2 MHz, the condition

$$\delta < \frac{1}{f_h} = 5 \cdot 10^{-7} \text{ s}$$

must be fulfilled.

From the information obtained it follows that the presumption necessary to apply the spark calibration method can be fulfilled by means of the condition (9), taking into account the relation (5) being necessary to obtain sufficient number of data measured.

4. The experimental verification of validity of theoretical considerations of the spark calibration method

The model connection according to Fig. 5 was used to verify theoretical considerations and clarification of some technical problems. As the source of narrow impulses with very steep fronts ($\delta = 3 \cdot 10^{-8}$ s) the impulse generator TR 0361 was applied. The position of the first spectral function nodal point (as the case may be, of

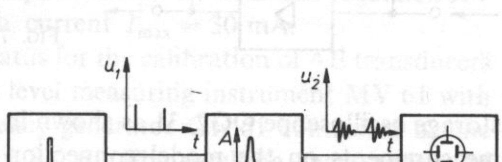

FIG. 5. The model connection

the first spectrum loop) was

$$f_1 = \frac{1}{\delta} = 33 \text{ MHz},$$

When we have chosen the repeating frequency $f_r = 1$ kHz, the first spectrum loop contains then

$$n_1 = f_1/f_2 = 3.3 \cdot 10^4$$

of components distant 1 kHz from each other. By the choice of the repeated frequency, it is possible to change the separation of components arbitrarily, i.e. to reduce or magnify it. For finding the characteristics, only frequencies lower than the limit of the zone considered ($f_{max} = 2$ MHz $\ll 33$ MHz, which represents the course of our spectral function – see Fig. 6) are needed. From Fig. 6 it is evident that in the

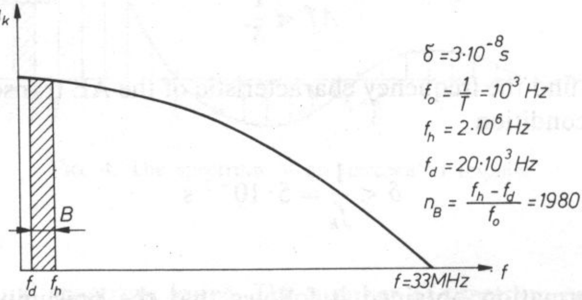

FIG. 6. The spectral curve of impulse $0 = 3 \cdot 10^{-8}$ s

zone $B = 0 \ldots 2$ MHz the amplitude of all the components of spectrum can be considered to be practically identical.

The frequency selection was carried out by an active filter having the double T-network in the feedback branch (Fig.7). The registration was performed by the

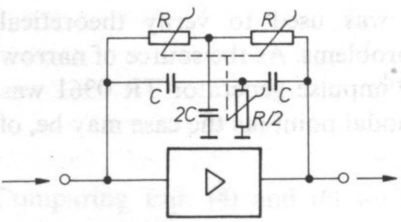

FIG. 7. Block diagram of an active filter

storage oscilloscope OG2–31 as shown in the block diagram on Fig. 5. The results of measurements on the model connection corroborated the rightness of theoretical considerations and checked the applicability of the testing apparatus.

5. The construction proposal and description of the spark calibration apparatus

Basing on a theoretical analysis and obtained practical information and experiences, a calibration device was proposed and built in its final form.

The block diagram of the device is demonstrated in Fig. 8. The AE signal

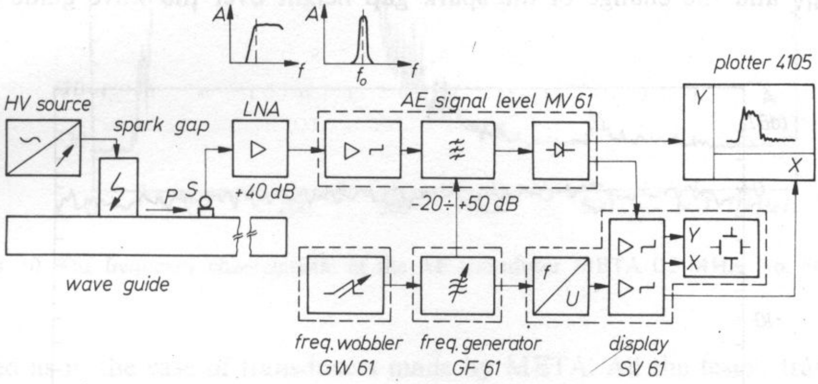

FIG. 8. The block diagram of apparatus for the calibration of AE transducer; S — the probe, LNA — low-noise amplifier: $A = 40$ dB, frequency range 30 kHz...2 MHz

simulator consists of a regulated high voltage HV source, and a spark gap with double electrostatic screening. As the milieu enabling the signal transfer from the source to the transducer a large ARMCO block (wave guide) with dimensions $80 \times 45 \times 800$ [mm^3] was used. The dimensions of that block were chosen so big to eliminate uncheckable reflections in longitudinal direction: on behalf of big thickness of the bar, the propagation of stress waves from their source in form of the dispersion Rayleigh waves was reached.

The spark source for exciting the impact waves has the discharge capacity $c_n = 250$ pF and its charging constant is $t_n = 5 \cdot 10^{-4}$ s. From the approached calculations, and from the practical measurements it follows that the excited impulse time is $\delta = n \cdot 10^{-8}$ s which satisfies all the requirements very well. The regulated HV source supplies the voltage 0...5 kV with current $I_{max} = 30$ mA.

In Fig. 8 the block diagram of the apparatus for the calibration of AE transducers is shown. The apparatus has the AE signal level measuring instrument MV 61 with automatically retuning filters by the frequency generator GF 61 controlled by the frequency wobbler GW 61, and the display SV 61. The resulting characteristic of transducer is presented graphically on the plotter 4105.

6. Experimental results of estimation of particular AE transducers

When practically estimating the frequency characteristics and sensitivity of the transducers, the influences of setting the high voltage value (U_{HV}) and of the spark gap axis distance from the block (wave guide) surface were studied. When searching for the character of response to the parameter changes of the generator of impact waves it was found that the jump distance change (and/or change of U_{HV}), current change I_{HV} and the change of the spark gap height over the wave guide (block)

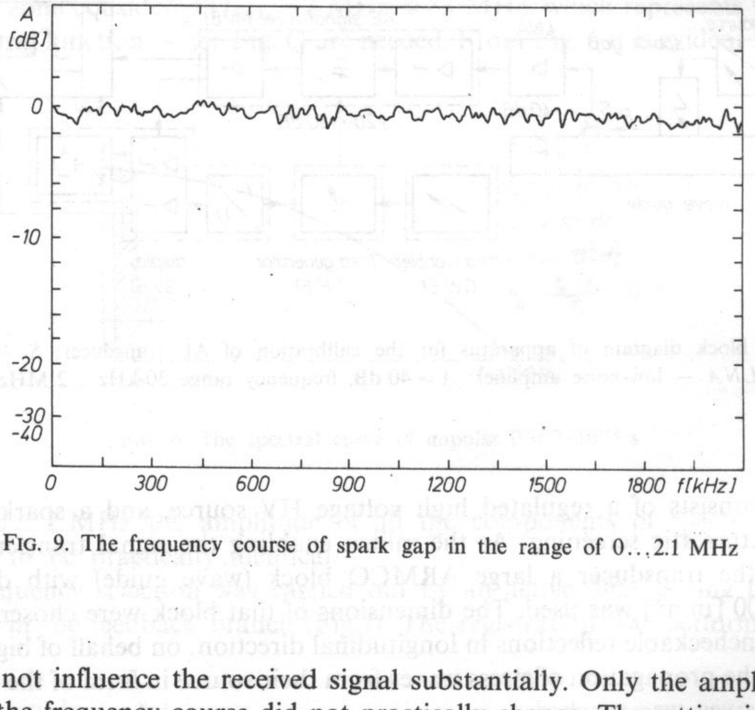

FIG. 9. The frequency course of spark gap in the range of 0...2.1 MHz

surface do not influence the received signal substantially. Only the amplitude was estimated, the frequency course did not practically change. The setting is thus not critical. The frequency course of spark gap in the range of 0...2.1 MHz is given in Fig. 9.

In Figs. 10 and 11 the estimated characteristics of the AE transducers META – 0.5 MHz made in Czechoslovakia are presented (the axis x shows the frequency, y – the amplitude of signal generated by transducer). From the figure it is evident that the tested transducers can work well in the range of 100...300 kHz, where their frequency characteristics and sensitivity are very good.

In the Figs. 12...16, frequency characteristics of transducers UNIPAN made in Poland are shown. It is true that the transducers UNIPAN give larger desired signals but, except for the transducers 0.5 MHz, the frequency characteristics are not so

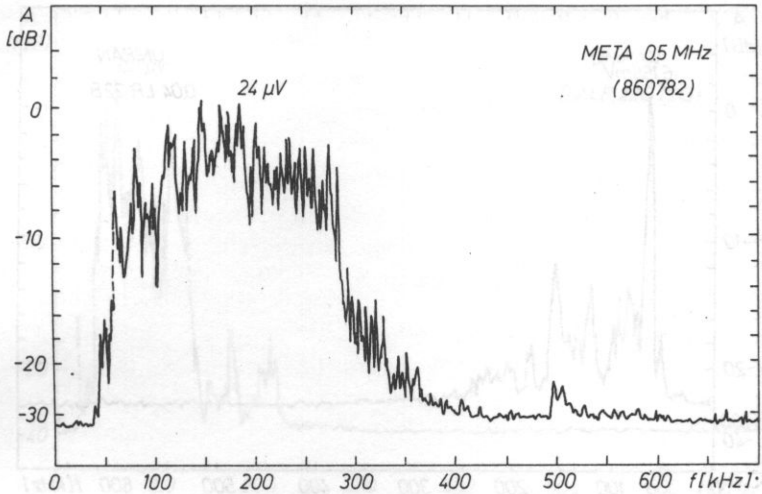

FIG. 10. The frequency characteristic of the AE transducer META 0.5 MHz, No. 860782

balanced as in the case of transducers made by META. All the tested transducers, however, are suitable for measuring the AE signals and they can be recomended; for particular measurements, namely in the frames of basic research, we recommend the transducers META 0.5 MHz, and the transducers UNIPAN 0.5 MHz.

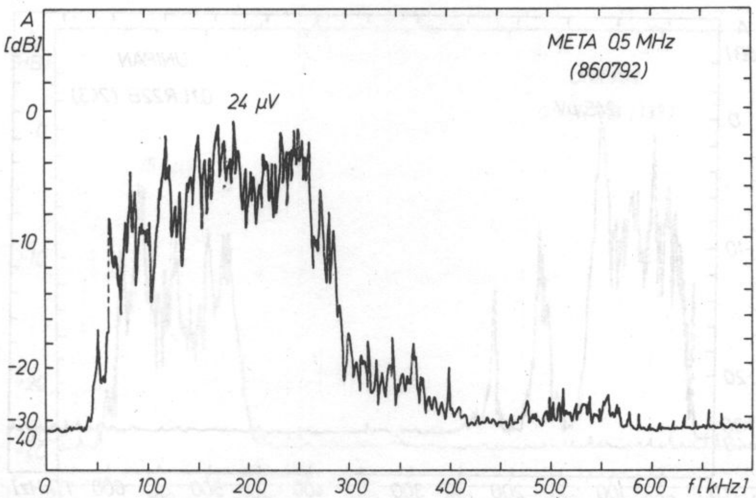

FIG. 11. The frequency characteristic of the AE transducer META 0.5 MHz, No. 8600792

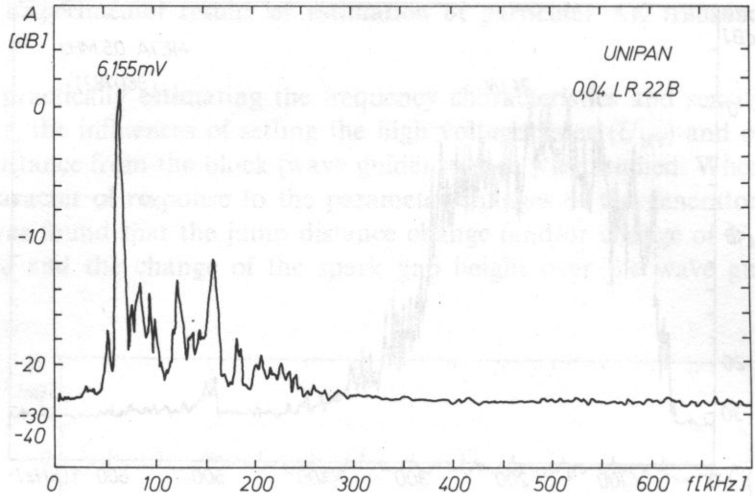

FIG. 12. The frequency characteristic of the AE transducer UNIPAN 0.04LR22B

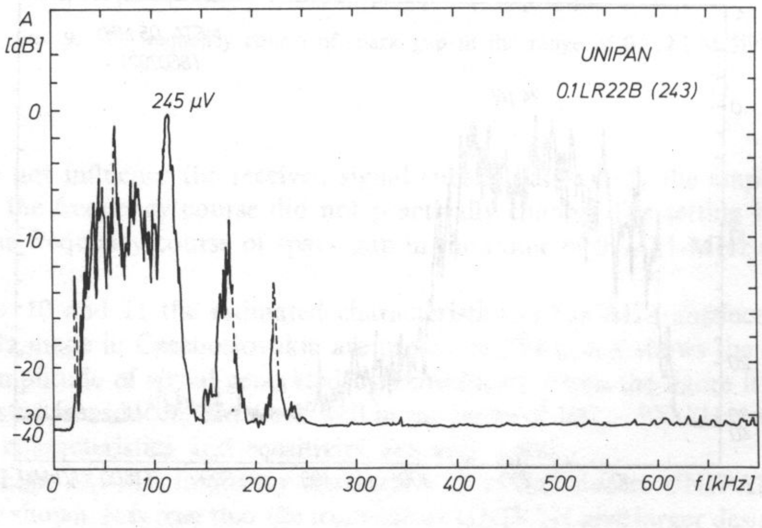

FIG. 13. The frequency characteristic of the AE transducer UNIPAN 0.1LR22B No. 243

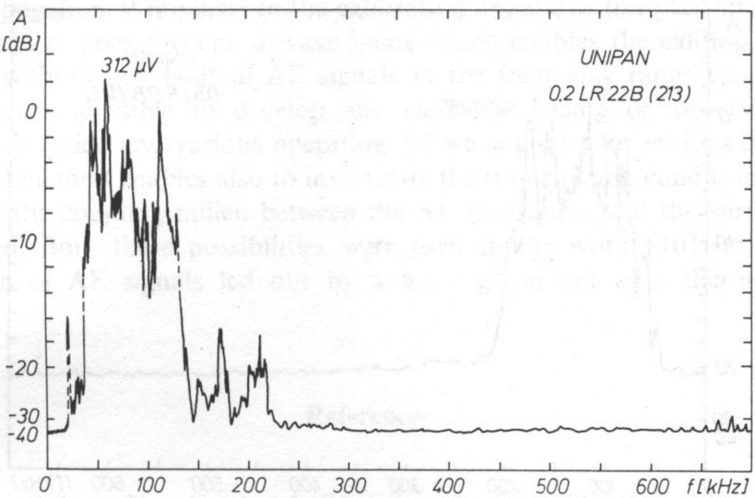

FIG. 14. The frequency characteristic of the AE transducer UNIPAN 0.2LR22B No. 213

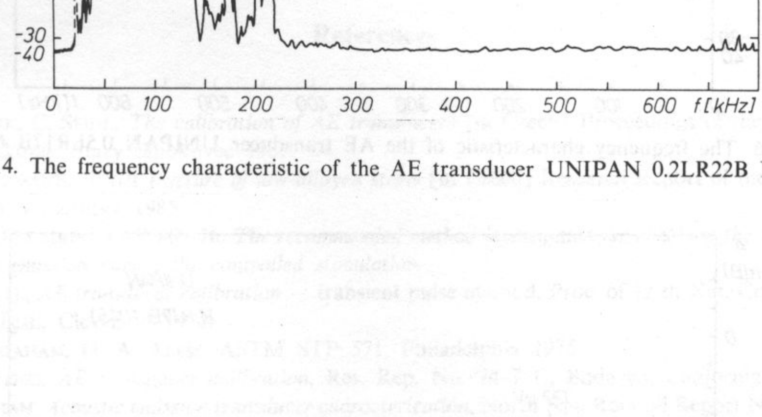

FIG. 15. The frequency characteristic of the AE transducer UNIPAN 0.5LR17B No. 133

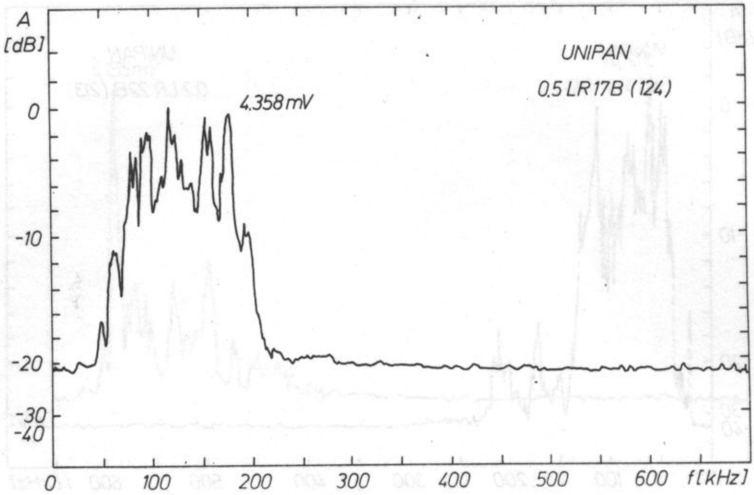

FIG. 16. The frequency characteristic of the AE transducer UNIPAN 0.5LR17B No. 124

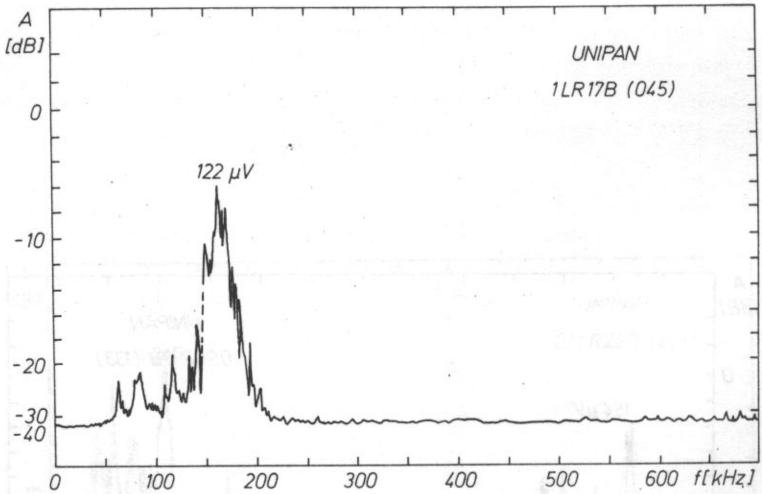

FIG. 17. The frequency characteristic of the AE transducer UNIPAN 1LR17B No. 045

7. Discussion and conclusion

In the present paper, the realization of the AE transducer calibration method has been described, by means of which both the real AE signal and real conditions of its propagation and scanning are shaped. The signal has the character of a noise with a broad frequency spectrum, see Fig. 9. The way of transitive surface wave generated by a spark point source is in good agreement with the real situation at AE.

The propagation of impulses in the calibration apparatus from the source to the tested transducer goes through a wave guide which enables the calibration of the transducer without any fault of AE signals in the frequency range required. The device makes it possible to develop and calibrate, basing on observations on standard wave guide and various operating AE wave guides for various conditions.

The used method enables also to investigate the transmission conditions, and the influence of the coupling milieu between the AE transducer and the surface of the object tested. Both these possibilities were used in the work [10] in which the transmission of AE signals led out by a wave guide out of a thermostat was concerned.

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