Spectral Analysis of EME Signal

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Abstract. The new measuring method for detection fine spectra of small cracks, electromagnetic and acoustic emission (EME and AE) signals, is described. It requires wide band ultra-low noise amplifiers, analogy filters, optimization of signal to noise ratio of sensors and the application of noise elimination methods. The analyses of noise sources in sensors and preamplifiers are given. They are thermal noise, polarization noise and low frequency 1/f noise. Measuring set-up background noise suppression also involving the electromagnetic shielding allows us to detect signals in the range of 1 to 100 nV. This measuring set-up was used to observe the crack creation in the granite samples. AE and EME signals show different behaviour in the first interval of about 20 μs, just after the crack creation. For the first stage of crack creation, the frequency spectrum of EME signal is given by the eigen vibrations of crack walls, by the internal friction and the sample electrical conductivity. We observed that the crack opening and crack wall vibration create the high frequency signal in the frequency band up to 10 MHz. These signals were observed in the first time interval of about 20 μs. After that the frequency spectrum is given by the sample eigen vibration or the sample boundary conditions. We have observed the spectra in the frequency range 100 kHz to 2 MHz.

Introduction

The measuring method for detection fine spectra of small cracks, electromagnetic and acoustic emission (EME and AE) signals, is based on utilization of the wide band ultra-low noise amplifier, the analogy filters and the application of noise elimination methods. The sources of noise in AE sensors are the thermal noise, the polarization noise and the low frequency 1/f noise. The described measuring set-up allows us to detect signals in the range of 1 to 100 nV, using background noise suppression and sample electromagnetic shielding. Some electromagnetic disturbance signals from the high-power radio transmitters is very difficult to shield [1,3]. The measuring set-up was used to measure the fine spectra of AE and EME signals originating in the creation of cracks in granite samples. The electromagnetic sensor plates design and the earthing and screening of the measuring set-up are described in detail in [1 to 3].

1. Noise

The measuring set-up sensitivity and the signal resolution depends on the noise of AE and EME sensors, the preamplifier noise and the electromagnetic compatibility of all the devices. The fluctuation of electrical polarization in the piezoceramic samples is an important source of the current and voltage noise. Electrical dipoles vibrate due to the thermal energy and their motion creates induced electric charges on the electrodes. The value of total charge induced on the electrodes is time-dependent.

The noise spectral density of the polarization noise is proportional to the sample temperature and it depends on the sample electrical parameters and geometry:

$$S_U = 4kTR = \frac{4kTd}{\varepsilon_0 \kappa'' A f}, \quad (1)$$

where k is Boltzman constant, T – absolute temperature and R - equivalent series resistance, ε_0 – permittivity and κ – imaginary part of susceptibility, d – thickness and A - area of piezoelectric slab.
The noise voltage u_N is proportional to the measuring set-up bandwidth:

$$u_N = \sqrt{\int_{f_1}^{f_2} S_U \cdot df}, \quad (2)$$

where f_1 is low and f_2 is high frequency. To optimize the signal to noise ratio, the bandwidth $B = f_2 - f_1$ must be as narrow as possible. We must use the filters to cut the frequency band in the low and high frequency region. Noise sources are the sensors, the preamplifier and the amplifier. The noise spectral density of the piezoceramic sample without and with the polarization is shown in Fig.1. Piezoceramic is noisy on the resonant frequency of the serial equivalent resistances. High signal to noise ratio requires sensors with optimized ratio of sensitivity and equivalent serial resistance.

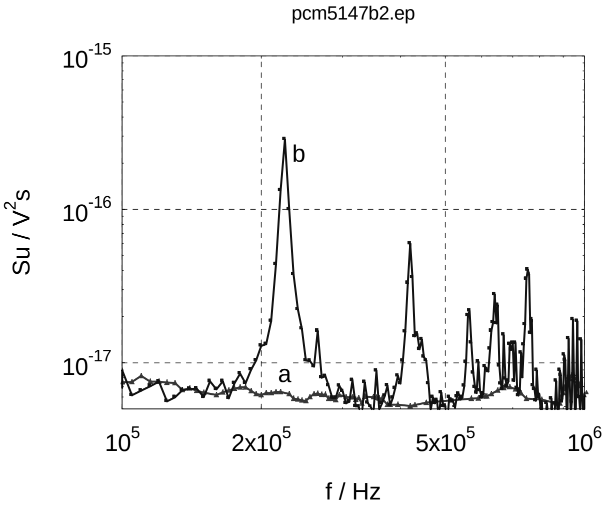

Fig.1. Noise spectral density of piezoceramic sample without (a) and with polarization (b)

2. The Effective Frequency Band

Evaluation of AE and EME signals demands high value of the signal/noise ratio (SNR). This value depends on the noise spectral density of the disturbing signal sources, the transmission way properties and the bandwidth. Output noise voltage u_N depends on the noise spectral density S_U of all the sources, the amplification A and the bandwidth B:

$$u_N = A\sqrt{S_U B}. \quad (3)$$

High value of the SNR is obtained for the minimal value of the preamplifier and amplifier bandwidth. It is very important to know the fundamental limit of the effective signal bandwidth, which is determined by the frequency spectrum on the output of AE and EME sensors.

Nevertheless, the bandwidth is determined not only by the frequency spectrum of AE and EME signals, but also by the transfer properties of the measured mechanical system and sensors. These mechanical transfer properties are variable, and it is convenient to measure them at the beginning of the experiment to optimize the value of signal to noise ratio.

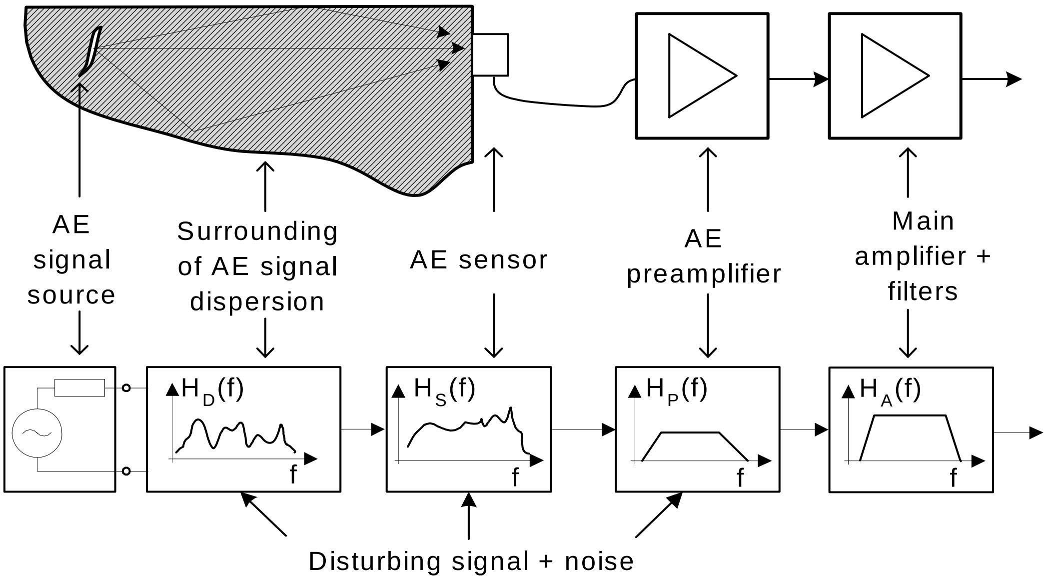

Fig. 2: Simple model of the transmission channel for AE measuring set-up

3. Experimental Set-Up

The measuring set-up was designed in the Czech Noise Research Laboratory and custom-made in the co-operating firm 3S Sedlak. The device is automatic and fully computer controlled. The block diagram of the apparatus is shown in Fig.3. This apparatus for automatic measurement consists of the low noise preamplifier PA15 (PA21, respectively), the low noise amplifier with low and high pass filters (AM22), A/D converter with adjustable sampling frequency (data acquisition card or digital oscilloscope) and computer with an application for computing and process controlling.

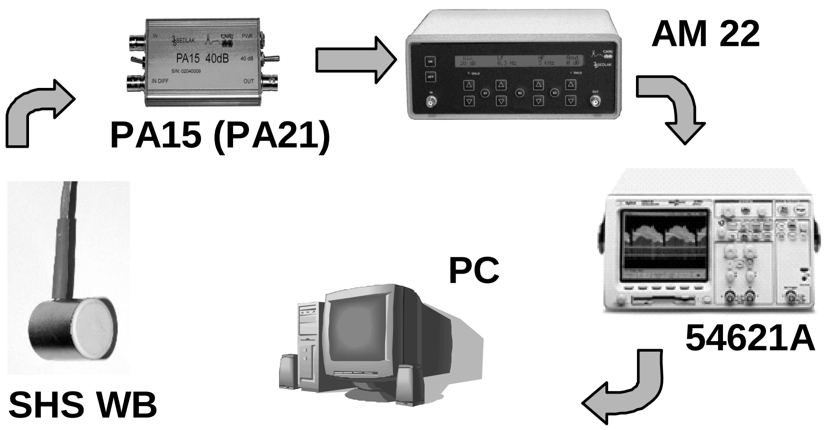

Fig. 3. Schematic view of measuring set-up

The most important parts of the noise measuring apparatus are the low noise preamplifier and the low noise amplifier with filters. Those are the separately powered devices, which are designed for the universal amplifying and filtering of signals from piezoceramic sensors before the subsequent processing in the digitisation circuit. The noise characteristics are shown in Fig. 4.

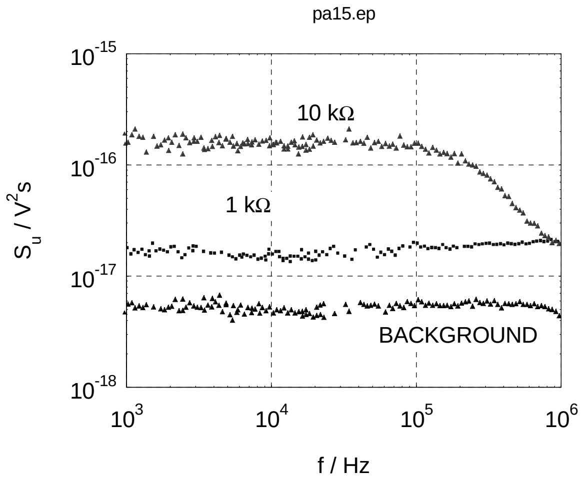

Fig. 4. Noise characteristics of the preamplifier PA15

The preamplifier PA 15 has two-stage control gain 20 and 40 dB with the constant value of the gain in the frequency range 3 Hz - 1 MHz. This preamplifier was used for the amplifying of AE signals. The preamplifier PA21 with the frequency range from 1 kHz to 10MHz was used for the amplifying of EME signals.
The amplifier AM22 consists of the analogue and digital part and the accumulator supply. The analogue part accomplishes the amplifying and filtering of the input signal, the digital part allows us to control the analogue part operation, the communication through RS232 or GPIB bus and the indication of working parameters on the display. The block diagram of AM22 is shown in Fig. 5.

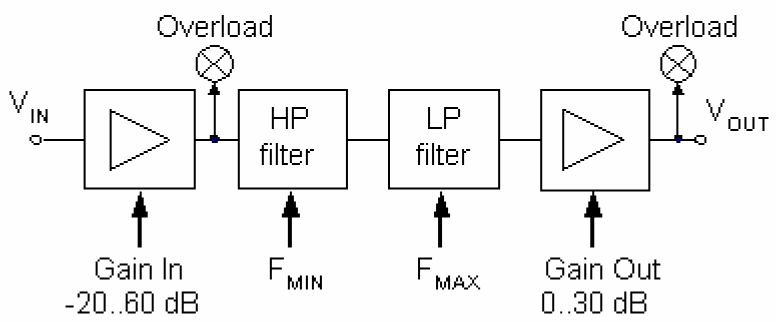

Fig. 5. Block diagram of AM22

4. Fine EME and AE Spectra

The results of the experiment made on the granite sample are shown in Figures 6 to 10. AE and EME signals show different behaviour in the first interval just after the crack creation (see Figs. 6 to 9). EME spectrum in the frequency domain shows that in the first stage of crack creation the spectrum is given by the eigen vibration of the crack walls, the internal friction and the sample electrical conductivity. The voltage on EME sensor is given by [3]:

$$u(t) = u_0 e^{-t/\tau} - \frac{g e^{-\gamma . t}}{\sqrt{{\omega_0}^2 + \omega^2}} \sin(\omega t + \varphi) \qquad (4)$$

Where u_o is an integration constant and $\omega_0 = \gamma - 1/\tau$ is the cut off angular frequency, δ, ω are the damped harmonic motion constants, $\tau = RC$ is the time relaxation constant given by the amplifier input resistance R and the EME sensor capacitance C: for R = 1 MΩ and C = 20 pF we have time constant τ = 20 μs, which is in good agreement with our experiment.

Different orientation of the crack with respect to the EME sensor plates results in the positive or negative voltage step $u_0 e^{-t/\tau}$ at the point when the crack is created.

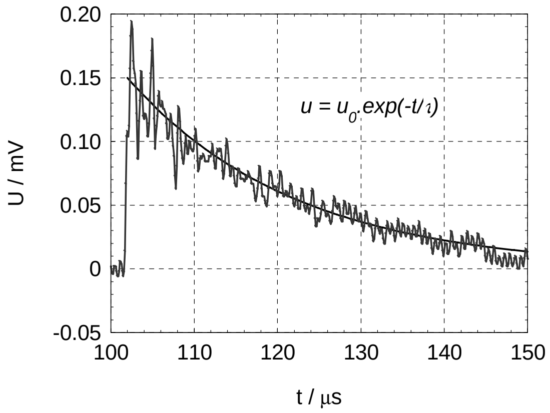

Fig. 6. EME signal time dependence for the brittle samples (u_0 = 0.15 mV, τ = 20 μs)

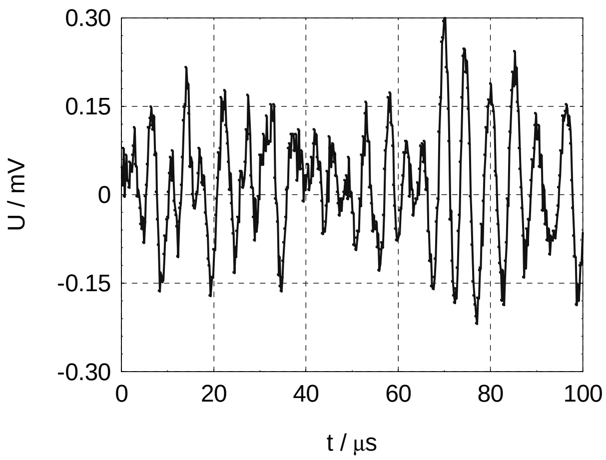

Fig. 7. AE signal in the time domain

We have observed that the crack opening and the crack wall vibration create the high frequency signal in the frequency band up to 10 MHz (see Fig. 10). These signals were observed in the first time interval of about 20 μs. After that the frequency spectrum is given in the first approximation by the sample eigen vibration or the sample boundary conditions. We observed spectra in the frequency range 100 kHz to 2 MHz. In this second period the EME signal amplitude depends on the sample electrical conductivity.

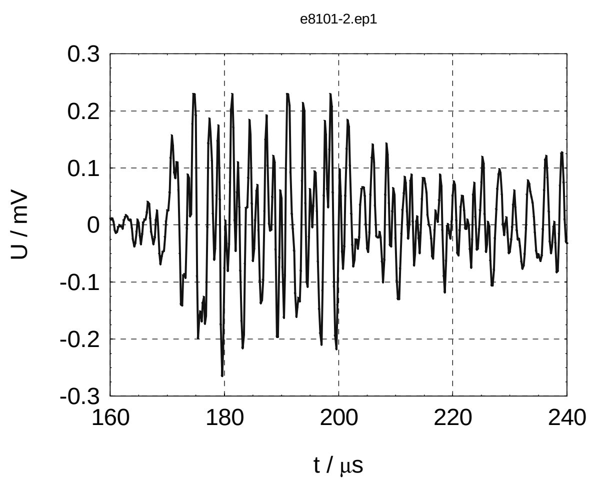

Fig. 8. EME signal time dependence for samples with the slow crack opening

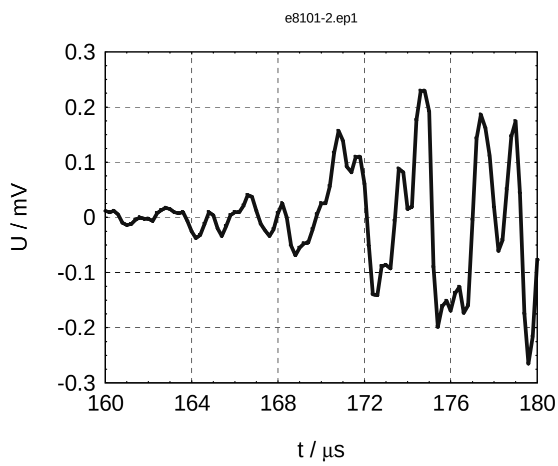

Fig. 9. EME signal time dependence for samples with the slow crack opening (fine structure)

For the samples with slow crack opening no DC component is observed in the time dependence of EME signals (see Figs. 8 and 9). The frequency spectra of EME signals depend on the frequency of crack wall vibrations while AE signals are influenced by the sample geometry.

5. Summary

The measuring method for the detection fine spectra of small cracks, electromagnetic and acoustic emission (EME and AE) signals, is described. It requires utilization of the wide band ultra-low noise amplifiers, analogue filters, optimization of signal to noise ratio of sensors, and application of the noise elimination methods. Measuring set-up background noise suppression involving electromagnetic shielding allows us to detect signals in the range of 1 to 100 nV.

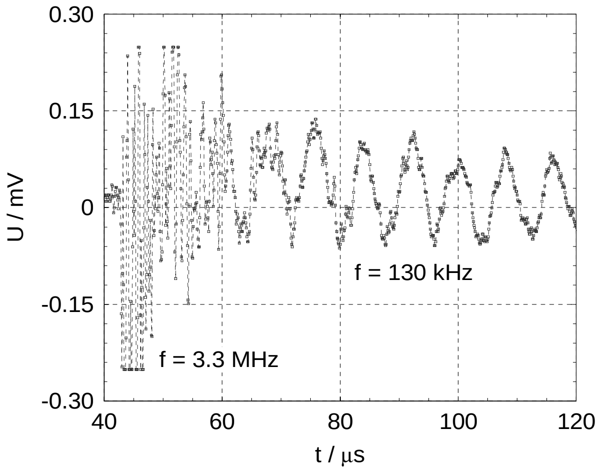

Fig. 10. EME signal time dependence with low electrical conductivity

This measuring set-up was used to observe crack creation in the granite samples. EME frequency spectra show that in the first stage of crack creation the spectrum is given by the crack walls eigen vibrations, the internal friction and the sample electrical conductivity.

Acknowledgement

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