

# Study of the effective filtration method applicability for the control of composite materials stress-strain state

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**Abstract.** The paper presents the results of experimental studies on the possibility of applying the effective filtration principle in the developing non-destructive testing methods. The presented results make it possible to conclude that the optimal filtration principle can be applied in the further development of methods for determining the absolute values of the stress-strain state of similar objects. It is necessary for its implementation to have impulse responses of similar objects for given stress-strain state values.

## 1. Introduction

The development of a method based on the mechanoelectric transformations (MET) phenomenon for controlling structural disturbances in dielectric composites first began at the Tomsk Polytechnic Institute [1]. The essence of the method is as follows [2]. A pulsed mechanical method excites in a dielectric sample an acoustic wave, propagating in the sample and experiencing multiple reflections. The acoustic wave, interacting with the centers of MET, induces an alternating electromagnetic field whose time realizations are recorded as a response signal by means of capacitive or inductive receivers.

Studies were conducted aimed at elucidating the possible use of the MET phenomenon to create methods for nondestructive testing and evaluation of the stress-strain state (SSS) of composite materials and their strength.

The method sensitivity to the size of the filler in concrete was analyzed in the paper [2]. The dependence of the time response amplitude-frequency characteristics on the geometry of the location of inclusions in concrete and their dimensions was established in the paper [3], in concretes under shock excitation. In the paper [4], under uniaxial compression, the effect of contact between rock samples of different mineralogical composition on the response parameters was investigated. The presence of such a contact has a significant effect on the spectral characteristics of the response. In work [5] acoustic sounding of crystalline quartz and rocks samples, represented by quartzites, was carried out. The study showed a significant change in the amplitude-frequency response characteristics from the distance between the capacitive sensor and the sample surface. The connection between the frequency characteristics of electromagnetic signals and the characteristics of the acting pulse is also established. Works [6–10] show the efficiency of using the MET phenomenon and the high sensitivity in the responses variations on changes in the SSS and on the degree of samples defectiveness for pulsed acoustic probing.



The revealed dependencies and high sensitivity of the response parameters to the change in the stress-strain state are prerequisites for using the effective filtering method in determining the absolute values of the control object's SSS by the set of time realizations obtained at the given SSS values.

The optimal filtering method [11] is as follows.

If a short pulse (in the limit of infinitesimal duration) is applied to the input of a linear system (a system in which the superposition principle is satisfied), then it will have a response, which is called the impulse response  $h(t)$ .

If now the signal of the given form  $s(t)$  is fed to the input of the same system, then the output  $u(t)$  is received. There is a mathematical expression relating  $h(t)$ ,  $s(t)$  and  $u(t)$ , which is the convolution of the signal  $s(t)$  with  $h(t)$ :

$$u(t) = \int s(\tau) \cdot h(t - \tau) \cdot d\tau$$

An input signal matched with a system and having this impulse response is a signal of the form

$$s^*(t) = h(t - T) \quad (1)$$

on condition  $0 < t < T$ , where  $T$  – is the observation interval.

As follows from (1), the matched input signal is a mirror image of the impulse response of the system. In this case, the response will have the maximum signal-to-noise ratio at time  $T$  and, in addition, in the time interval from 0 to  $T$  will be the autocorrelation function  $h(t)$ .

In our case, the system to be monitored is the sample itself, whose input is fed by an acoustic excitation pulse, and an electrical response arises at the output. The impulse response of this system should depend on the degree of the sample SSS, so if you have a set of impulse characteristics at different levels of the sample's SSS, it becomes possible to estimate the absolute value of the sample's SSS under an unknown load. It is possible to do this by submitting mirror images of these impulse responses to the input and to evaluate according to the responses at which of the impulse characteristics the optimality conditions will be best satisfied. The problem is that a piezoelectric transducer is used as the excitation device, by means of which it is impossible to form a short, and therefore broadband, pulse, because of its selectivity in frequency.

Therefore, it is necessary to consider the impulse response of a system including the characteristics of the excitation device. In such a "composite" system, under the influence of external influences, only the characteristics associated with the sample will change.

If a short electrical impulse is applied to the input of the piezoelectric transducer, then the response can be written in the form

$$u(t) = \int h_0(\tau) \cdot h(t - \tau) \cdot d\tau$$

where  $h_0(t)$  – is the impulse response of the piezoelectric transducer.

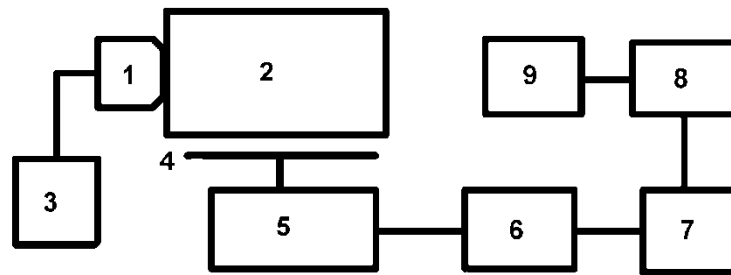
It is necessary to evaluate the effect of the spectral characteristics of the excitation device on the response parameters when using the optimal filtering.

If an inverse impulse response of duration  $T$  is chosen as the input signal, the output signal will have a maximum value at time  $T$ . The time dependence of the response is the autocorrelation function of the input signal when it is fully matched to the impulse response.

## 2. Materials and experimental procedure

A description of the measurement procedure is given in [8, 9]. A block diagram of the measurements is shown in Figure 1.

We used in the experiments samples from epoxy resin with a size  $(6 \times 7.8 \times 9.2)$  cm<sup>3</sup>. Quartz sand was used as a filler. The propagation velocity of longitudinal waves in these samples was 2440 m/s. The piezoelectric source was located on the edge of the sample with a size  $(6 \times 9.2)$  cm<sup>2</sup>. Parallel to the face of the sample measuring  $9.2 \times 7.8$  cm<sup>2</sup> at a distance of 0.1 cm from the surface, a capacitive sensor was fixed.

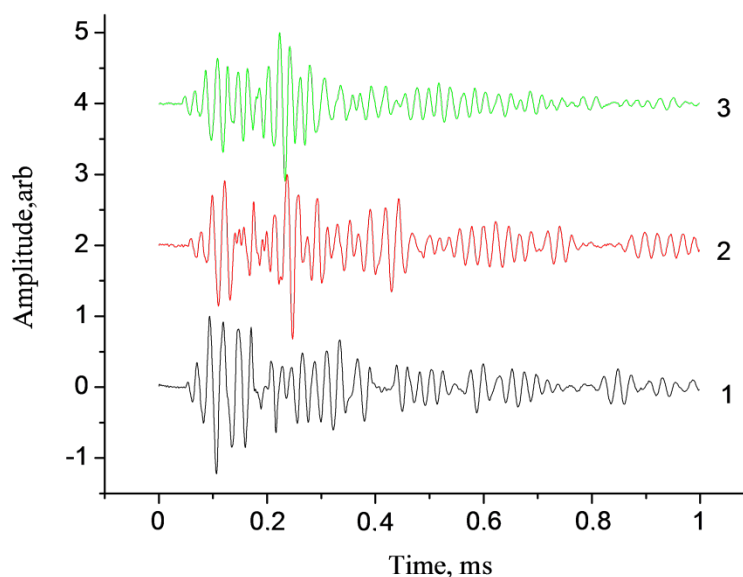


**Figure 1.** Block diagram of the experiments: 1 – source of acoustic oscillations on the piezoelectric ceramics of ZTS19; 2 – test sample; 3 – master generator of sinus-like voltages; 4 – capacitive sensor; 5 – input amplifier; 6 – bandpass filter; 7 – low-frequency amplifier; 8 – emitter repeater; 9 – data input/output board.

The measuring cell with the samples was located on a fixed punch of the MIS-500K test machine. The samples were subjected to uniaxial compression from the side of the sample face with the size  $(6 \times 8) \text{ cm}^2$ . The load stepwise in increments of 20 kN increased from 0 kN to the samples destruction. In the experiments, time realizations of the responses were recorded for each fixed load value using the NI PCI – 6133 data acquisition board. Time realizations, averaged over 140 responses, were analyzed. Sounding acoustic pulses followed with a period of 7 ms. The frequencies of the acoustic pulse spectrum range from 40 kHz to 125 kHz. Dispersion in the experiments did not exceed 5%.

### 3. The experimental results

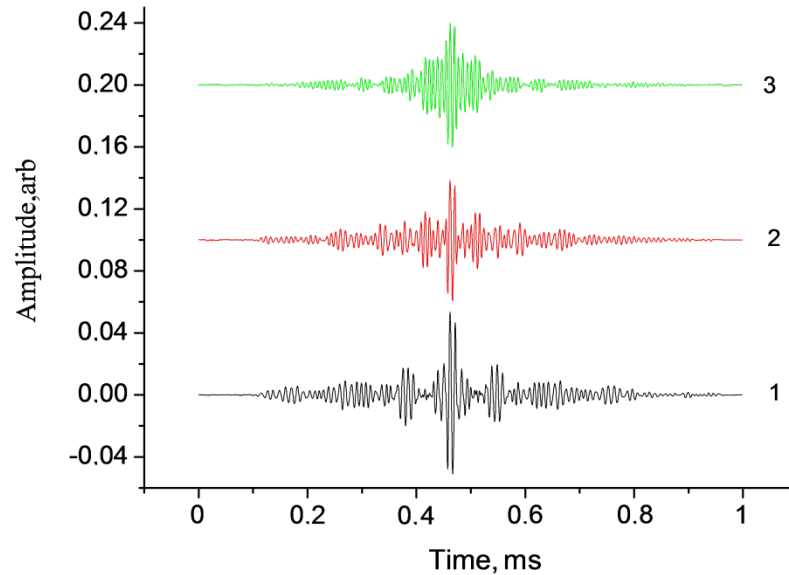
The measurements results are shown in Figures 2 – 4. Figure 2 shows the pulse characteristics for the samples under uniaxial compression at a pressure of 0 MPa, 3.2 MPa and 8 MPa.



**Figure 2.** Time realizations of responses at a pressure of 1–0 MPa; 2–3.2 MPa, 3–8 MPa. Excitation pulse duration – 45  $\mu\text{s}$ , frequency – 44 kHz.

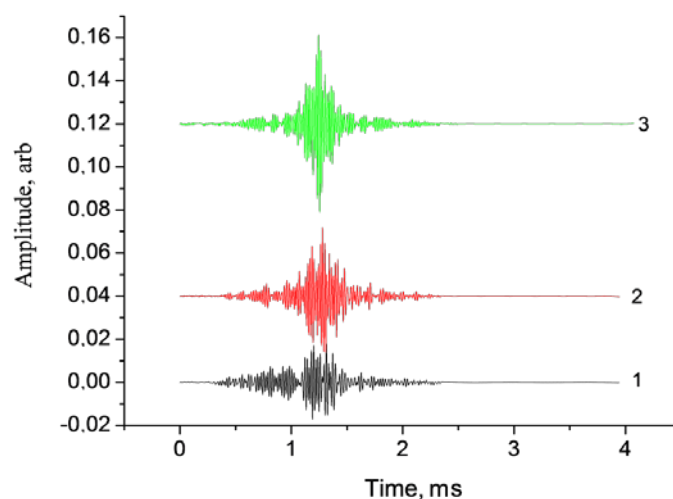
The inverted values of the impulse responses were converted into electrical signals, which were fed to the piezoelectric transducer to form an acoustic probe pulse. The corresponding responses are shown in Figure 3. For this, the objects of investigation were at the same pressure at which impulse

responses were recorded. It is evident that the form of the responses has a symmetrical form with respect to the maximum value.



**Figure 3.** Probe results from inverse impulse responses at a pressure of 1–0 MPa; 2–3.2 MPa; 3–8MPa.

Figure 4 shows the response from the sample, which is under uniaxial compression with a pressure of 8 MPa. The probe acoustic pulses were formed by inverted impulse characteristics, measured at 0MPa, 3.2 MPa and 8 MPa. It can be seen that the non-coincidence of the pressure, at which electrical response is measured, with the pressure, at which the impulse response is recorded, leads to a decrease in the amplitude of the response and to the breaking and disappearance of the symmetry in the form of a response.



**Figure 4.** Responses from the samples at a pressure of 8 MPa from the inverse impulse characteristics, measured at loads of 1–0MPa; 2–3.2 MPa; 3–8MPa.

#### 4. Conclusions

The data obtained in the experiments make it possible to conclude that the principle of optimal filtration can be applied to the further development of methods for determining the absolute values of the similar objects SSS. For its implementation, it is necessary to have impulse responses of similar objects for the given SSS values.

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