Development of data optimization methodology for non-destructive testing of concrete strength by the parameters of the electric response to impact excitation

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Abstract. The paper presents the research results by the improvement of the non-destructive testing method of concrete strength by the parameters of the electric response to impact excitation. The electric response parameters from the set of identical concrete samples sized of 100x100x100 mm were studied. It is shown that the use of linear filtering procedure reduces the variance of diagnostic electric parameter for concrete strength determination and is in a good agreement with the elastic characteristics of the material.

1. Introduction

Concrete is widely used in the power structures, therefore the control of its strength is of practical importance. For these purposes, the existing methods for the concrete strength control are improved [1, 2] and new methods are developed [3-7]. Most of these methods has some disadvantages and doesn't find practical application.

The method based on the phenomenon of mechanoelectric transformations is developed [8, 9] to solve the problem of the concrete strength determination. This method is based on the fact that under mechanical impact excitation of the heterogeneous non-metallic materials, an electric response appears. Electric response arises when the elastic wave induced by the impact excitation deforms and displaces the signal sources in a heterogeneous material. Electrical double layer and piezoelectric inclusions on the border of components are the main sources of mechanoelectric transformations in concrete. These inclusions are contained in the concrete in the form of sand or coarse aggregate. Investigations have shown that the piezoelectric inclusions play the main role in the mechanoelectric transformations in concrete [10]. Piezoquartz is contained in sand, which is used for the manufacture of cement-sand samples. X-ray diffraction analysis showed that sand consists of 80-90% quartz. X-ray diffraction analysis showed that in the gravel, which is used for the manufacture of heavy concrete, grains containing no quartz aren't detected, while the proportion of grains, which consist only of quartz is about 20%. The charge is forming on the edge of piezoelectric quartz under the influence of mechanical stresses caused by acoustic waves due to the direct piezoelectric effect. The consequence of this is the emergence of an external electric field, which is recorded by signal receiver located near the object of investigation. Thus, the parameters of the electric response relate with characteristics of elastic waves within the material and can be used for their contactless measurement.

The algorithm for determination of the concrete samples strength sized of 50x50x100 mm, based on the use of the generalized parameter of the electric response is developed [11]. Generalized parameter (P) defined by:

$$P = \frac{S}{r_{max}} \quad (1)$$

where, r_{max} is the maximum correlation coefficient of the spectrum of the electrical signal from the test sample with the spectrum of the standard, S is a frequency offset value of the spectrum of the electrical signal from the test sample relative to a reference spectrum in which there is a maximum cross-correlation coefficient, s^{-1}.

As a mathematical standard of electrical signal from the defect-free sample of this form a spectrum of freely damped harmonic oscillations that occur under the law is used:

$$y(t) = Ae^{-\beta t}(\sin 2\pi f t) \quad (2)$$

where, A is the oscillation amplitude, β is the damping coefficient; f is the frequency of oscillations.

The concrete sample with size 50x50x100 mm has the bar shape. Therefore, when the impact excitation occurs along the length of concrete sample the longitudinal acoustic oscillations are formed along the length way of the sample.

In this paper investigated adaptation of proposed algorithm of non-destructive testing on standard cube samples, which are used in manufacturing for evaluation of strength characteristics of concrete products.

2. Methods of investigations

Investigations were performed using the hardware-software complex allowing to produce impact excitations on concrete sample and record electric responses. The figure 1 shows the image of the measuring system:

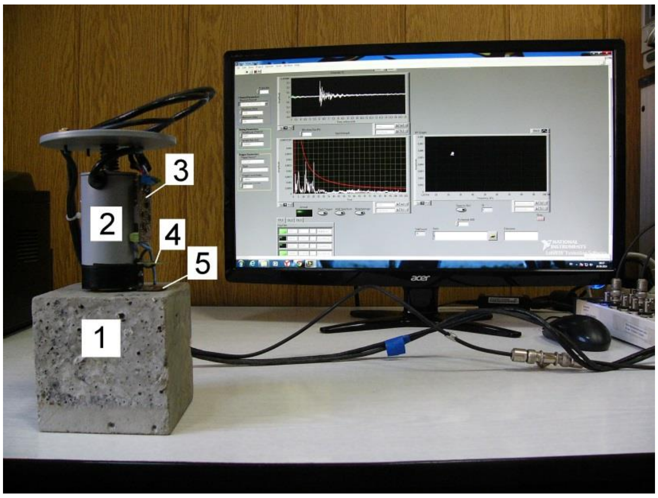

Figure 1. Measuring system: 1 – sample, 2 – electromechanical impact device, 3 – differential amplifier, 4 – compensating electrode, 5 – measuring electrode.

Pulse mechanical excitation of the samples is performed using electromechanical impactor with normalized force of the impact. Impact excitation is performed using device based on electromagnet. Differential electric sensor is used for recording electric response. The receiver of the electric sensor consists of two metal plates size 20x20 mm. One plate is measuring receiver, and the second plate is compensating receiver. The electric measuring receiver is located at a distance of 2 mm from the surface, thus creating the conditions for non-contact reception. The compensating receiver is located at a height of 30 mm from the measuring receiver. The measuring receiver treats both a useful signal from the sample and a signal of external noise. The compensating receiver is distant from the source of useful signal and practically only accept external noise. This measurement scheme allows to improve significantly the signal-to-noise ratio. Receivers are fixed on the body of the electromechanical impactor device through the acoustic isolation. As a result, the distance from the electric receiver to the point of impact is always the same (20 mm).

Electric signals from the sensor are recorded using the I/O board "NI PCI-6251", combined with PC. More detailed method of measurement is presented in the article [12].

To measure the speed of sound ultrasonic pulse generator/receiver OLYMPUS PANAMETRICS 5058PR and piezoelectric sensors OLYMPUS PANAMETRICS V1011 VIDEOSCAN were used.

3. Experimental investigations and discussion

In this work a batch of heavyweight concrete samples with size 100x100x100 mm, consisting of 16 samples was investigated. Samples were prepared in accordance with GOST 10180-2012 with the factory metal molds. The weight ratio of cement, sand and coarse aggregate was 1:2:4. Water-cement ratio equals 0.4. The maximum size of coarse aggregate was 20 mm. The river gravel was used as of coarse aggregate.

Figure 2 shows the spectra of the electric responses of the heavy concrete samples of various shapes.

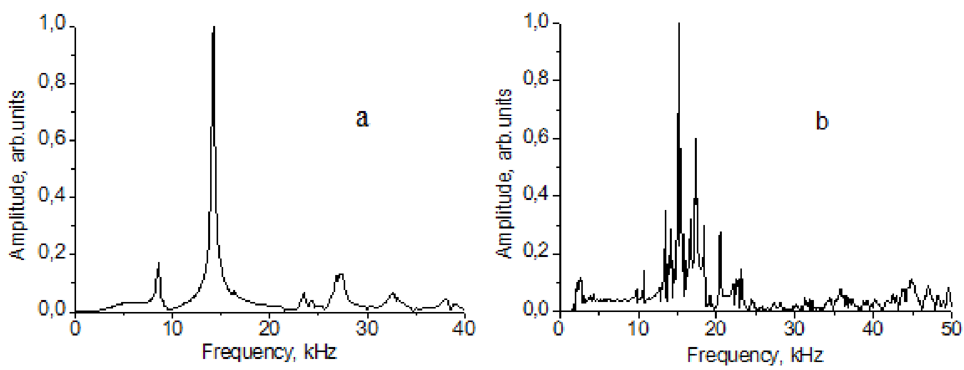

Figure 2. Spectra of electric responses of concrete samples size 50x50x100 mm (a) and 100x100x100 mm (b).

As shown in figure 2 the spectrum of the electric response from the sample in the form of a bar has almost one dominant peak and the spectrum of the signal from the sample of cubic shape are more complicated.

. Along with having a dominant peak a considerable amount of significant spectral peaks located at either side of the main peak is observed. This is due to the formation of more complex wave processes in a cubic sample.

Investigation showed that even in the samples having the same composition and made from the same materials there are significant differences in the ratio of the spectral peaks located near the dominant peak.

Using the program developed in the programming environment LabView, the generalized parameter according to the formula (1) was calculated.

Figure 3 shows the results of the calculation of the generalized parameter and averaging the data of multiple tests.

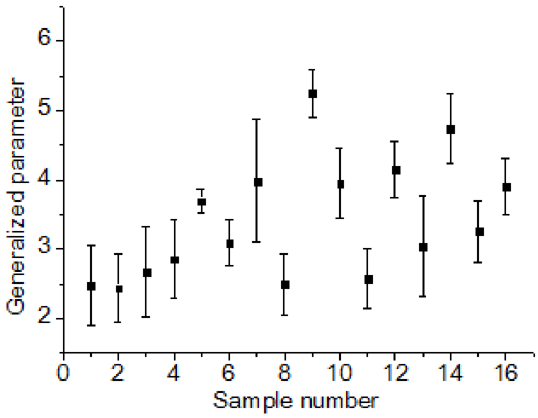

Figure 3. Variation of the generalized parameter when using the algorithm described above.

The figure 3 shows a significant spread of values in multiple tests of the same sample and between samples. To reduce the spread of values, it was proposed to produce linear filtering of spectra in the mode of moving average. The program for the calculation of the generalized parameter was supplemented this procedure. Figure 4 shows a front panel of the program.

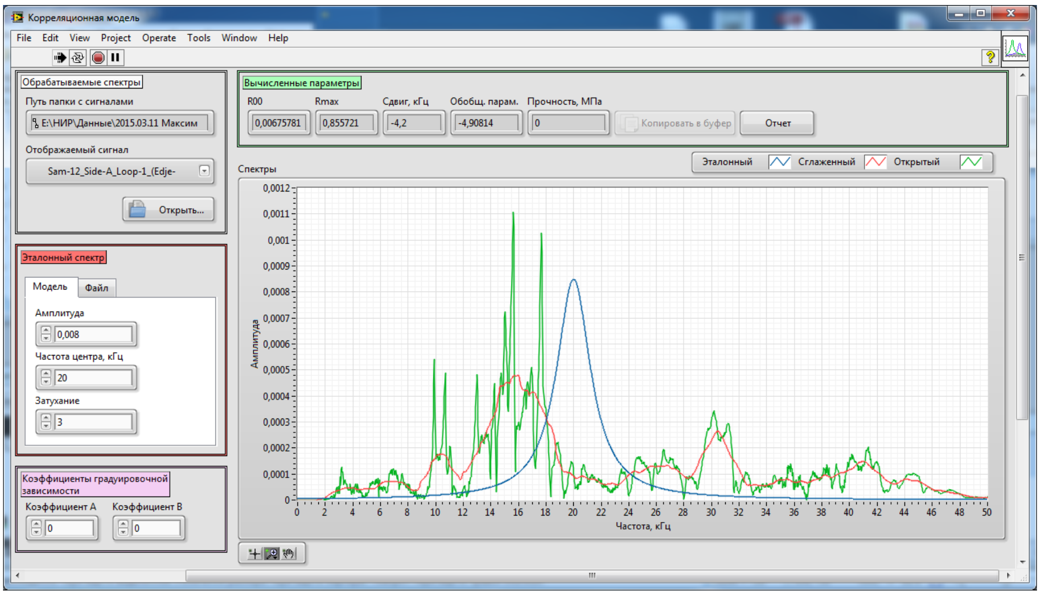

Figure 4. Front panel of program for the calculation of the generalized parameter.

The program allows specifying the necessary filtering options, depending on the specific experimental data, and changing the standard spectrum (amplitude and attenuation coefficient). The results of the calculation are written to files for further processing and analysis.

Figure 5 shows the results of the calculation of the generalized parameter when comparing the standard spectrum with a smoothed spectrum.

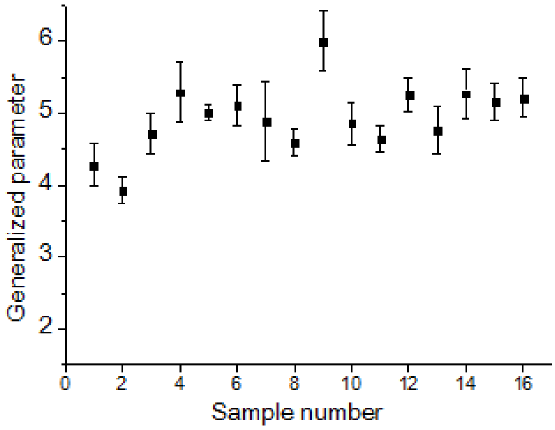

Figure 5. Variation of the generalized parameter when using the linear filtering procedure.

Investigations have shown that the use of linear filtering procedures can significantly reduce the spread of the values of the diagnostic parameter for identical samples.

If there are no defects in the samples, the strength is proportional to the Young's modulus of concrete. To evaluate the modulus of variations in the samples sound velocity and density of the samples were measured. Calculation of Young's modulus was produced by the formula:

$$E = \frac{c_\rho{}^2 * (1 + \vartheta) * (1 - 2\vartheta) * \rho}{1 - \vartheta} \quad (3)$$

where, E is Young's modulus; c_ρ is velocity of longitudinal wave; ϑ is Poisson's ratio.

Table 1 shows the values of sound speed, density and calculated Young's modulus.

Table 1. The calculated Young's modulus.

Sample number	Speed of sound [10^3 m/s]	Density [10^3 kg/m^2]	Young's modulus [GPa]
1	4.13	2.36	36.30
2	4.27	2.31	37.91
3	4.10	2.28	34.48
4	4.17	2.37	37.02
5	4.13	2.33	35.75
6	4.27	2.36	38.83
7	4.17	2.34	36.58
8	4.24	2.31	37.36
9	4.13	2.25	34.55
10	4.07	2.35	34.95
11	4.17	2.27	35.47
12	4.20	2.31	36.69
13	4.10	2.29	34.63
14	4.07	2.29	34.03
15	4.07	2.32	34.52
16	4.13	2.33	35.81

Analysis of the data in the table shows that the Young's modulus in the batch of samples has similar values. The maximum value of the Young's modulus is equal to 38.83 GPa and minimum is equals 34.03 GPa. The average spread of the values is order of 1%. Such close values of Young's modulus of the samples indicate the identity of samples in the batch. Spread of the values of the generalized parameter without the use of linear filtering procedures for these samples is about 6%. Linear filtering procedure leads to the fact that variations in the generalized parameter become equal to 1.7%. Consequently, the use of linear filtering procedure allows normalizing generalized parameter relatively elastic properties of concrete.

4. Conclusions

The purpose of the investigations presented in this paper was the development of methodology to improve reliability of non-destructive testing of concrete strength, based on the phenomenon of mechanoelectric transformations. The paper proposed to produce linear filtering of spectra of electrical responses in the mode of moving average. It is shown that the use of linear filtering procedures can significantly reduce the spread of the diagnostic parameter values for identical concrete samples.

5. Acknowledgements

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