ADMITTANCE METHOD FOR MEASURING THE ELECTROPHYSICAL PARAMETERS OF CONCRETE

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https://doi.org/10.23939/istcmtm2025.02.038

Abstract. The paper analyzes methods for controlling the quality of concrete using both non-electrical and electrical techniques, particularly by means of specific resistance. Based on this analysis, it was determined that the practical implementation of the electrical method, which uses electrical resistance as an informative parameter, is relatively rare. Dielectric permittivity, as an informative parameter of concrete, is typically applied only for monitoring concrete moisture with dielectric moisture meters. The authors propose the simultaneous use of specific conductivity and dielectric permittivity as informative parameters for monitoring concrete quality indicators. Their application is possible over a prolonged period of concrete identification – from the production stage to the point of maturity. To measure these parameters, an admittance method is proposed, which involves measuring the reactive and active components of concrete admittance, both of which linearly depend on dielectric permittivity and specific conductivity. In this case, the informative electrical parameters are the obtained measurement results of these admittance components. An electrical measurement circuit for the implementation of such measurements is presented, along with an algorithm for identifying concrete of different quality levels based on these results.

Key words: specific resistance, specific conductivity, admittance, active component, reactive component, concrete, identification, quality.

1. Introduction

For controlling the quality indicators of concrete, predominantly non-electrical methods are used. Regarding the application of electrical methods for monitoring concrete quality parameters, they involve measuring the electrophysical parameters of concrete, particularly specific resistance or dielectric permittivity. Dielectric permittivity, as an informative parameter, is used for measuring the moisture content of mature concrete using dielectric moisture meters. Various methods exist for measuring the specific electrical resistance of concrete. The most common are measurements of volumetric and surface specific resistance, as well as the measurement of the resistance of fresh concrete using electrodes embedded in the concrete. Typically, specific resistance is used to monitor the strength of concrete and can also be applied to control the process of its maturation. That is, changes in specific resistance and dielectric permittivity reflect any alterations in the physicochemical properties of concrete throughout its entire service life – from production to maturity. These parameters are informative, and their variations can be used to assess concrete quality indicators at any stage. However, both theoretical and practical applications of such a method remain rare. Despite the development of modern concrete research methods, current industrial practice still predominantly relies on traditional compressive strength testing to assess concrete quality. Nevertheless, the results of compressive strength tests alone do not fully reflect the quality or durability of concrete. Thus, the development of such a method and its practical implementation remains relevant. The importance of this direction is also driven by the rapid growth of the construction industry, which constantly seeks better and more effective ways of evaluating concrete quality.

2. Literature Review

An analysis of the literature sources on the topic of this work has shown the following. For controlling the strength of concrete on control samples, traditional mechanical and physical non-destructive methods are predominantly used [13, 14]. Mechanical methods are based on correlation relationships between the strength and other mechanical characteristics of concrete (such as hardness, elasticity, plastic deformation capacity, etc.), as well as the force causing its local destruction. When using non-destructive methods, strength is determined based on previously established calibration relationships between the compressive strength of samples and indirect strength characteristics.

In physical methods, correlations are employed between the strength of concrete and the velocity of ultrasonic wave propagation within it, as well as with other physical characteristics (such as vibration frequency, gamma radiation intensity when passing through concrete, etc.). Among physical methods, the ultrasonic method is widely applied in practice, based on the relationship between concrete strength and the propagation speed of ultrasonic vibrations. This method is used for accelerated determination of the compressive strength of monolithic structures and buildings. It is also applied for determining concrete strength during the hardening process in thermal installations or under natural conditions.

There are also known methods for controlling concrete quality indicators based on electrophysical parameters, namely: specific resistance or conductivity [1–9, 12]. Experimental studies of this method have shown its promising application at all stages of concrete maturity. In particular, resistance is used as an informative parameter for controlling the quality parameters of reinforced concrete sleepers in production conditions [1]. As a result of these studies, a State Standard of Ukraine was developed.

The disadvantage of this electrical method lies in the limited functional capability of its application, as well as the fact that the means of implementing the method are not universal. Specific resistance and dielectric permittivity, as the main informative electrical parameters of concrete, are measured using technical means of different purposes. Their simultaneous measurement would improve the reliability level of quality control of concrete and its maturity, as well as enable the identification of falsified concrete at the production stage. This method can be implemented using simple technical means with the ability for operational quality control of concrete both in laboratory and field conditions.

3. Purpose of the Work

The purpose of this work is to develop a method for controlling the quality of concrete based on the parameters of complex conductivity (admittance) using two parameters that are proportional to the dielectric permittivity and specific electrical conductivity of the concrete.

4. Measurement of Electrical Admittance Parameters of Concrete and Its Identification

4.1. Admittance Method for Measuring Specific Conductivity and Dielectric Permittivity

The authors propose a method for the operational quality control of concrete, which involves the indirect measurement of the dielectric permittivity and specific electrical conductivity of concrete. For this purpose, the measurement of these parameters is carried out using an immittance-based quality control method [10].

According to the immittance method, the concrete is represented as a two-terminal network placed in an alternating current electrical circuit with a specified frequency and test signal level. This enables the conversion of the non-electrical parameters of concrete into an electrical complex quantity – an admittance Y of a capacitive nature. In this case, the reactive component of the admittance is proportional to the equivalent capacitance, and the active component corresponds to the equivalent conductance. Therefore, for the identification of such materials, it is most appropriate to use the admittance method as a partial variant of the immittance-based quality control method. The informative parameters in this case are the reactive B_x and active G_x components of the concrete admittance Y_x.

A capacitive primary transducer is used for this, with the controlled object placed in the inter-electrode space of a capacitive multi-element two-terminal network. A simplified electrical model of such a two-terminal network includes a parallel circuit of an equivalent capacitance C_x and resistance R_x. Accordingly, the admittance of such a two-terminal network is determined by the well-known formula:

$$Y_x = \frac{1}{R_x} + j\omega C_x = G_x + jB_x \,. \qquad (1)$$

The active and reactive components of the admittance (1) are described by the following expressions

$$G_x = \sigma_x \frac{d}{S} = A_1 \sigma_x \qquad (2)$$

$$B_x = \omega C_x = \omega \frac{\varepsilon_0 \varepsilon_x S}{d} = A_2 \varepsilon_x \qquad (3)$$

where $A_1 = d/S$– is a constant of the primary transducer (where S is the electrode area and d is the distance between them); ε_0 is the dielectric permittivity of vacuum; $A_2 = A_1 \varepsilon_0$, ε_x and σ_x are the dielectric permittivity and the specific conductivity of the tested concrete, respectively.

Since the electrophysical parameters σ_x and ε_x are linearly dependent on the conductance (2) and capacitance (3), it is reasonable to use the appropriate measurement mode of the device for these measurements – namely, the mode of separate measurement of the admittance parameters according to a parallel scheme with the reactive component ωC and the active component G. Considering this, these admittance components also become informative parameters. In other words, an indirect measurement of the specific conductivity σ_x and dielectric permittivity ε_x of the tested concrete is obtained through the results of measuring the active and reactive components of its admittance. Accordingly, based on these parameters, it is possible to perform concrete identification.

4.2. Concrete Identification Using Electrical Parameters

The basis of identification of such products using admittance parameters is the differential method of assessing product quality. For identifying concrete of different types or varying strength levels, it is necessary to compare the measured parameters with the corresponding components of its standard samples. The comparison indicators in this case will be the active and reactive components of the admittance of the comparison objects at a certain frequency or several frequencies.

That is, in order to perform concrete identification, it is necessary to have a traditional standard sample that meets the boundary norms for its individual indicators, within which the concrete still corresponds to the established quality level. The quality indicators of the concrete are determined by standardized traditional methods. To implement concrete identification using admittance parameters, it is necessary to form an electrical standard (baseline) sample based on the measurement results of the corresponding active and reactive components of its admittance of the traditional standard concrete sample at a fixed frequency (or fixed frequencies) [11]. Thus, we obtain baseline samples with known reactive and active parameters of their admittances at fixed frequencies, which reflect the corresponding quality indicators of the concrete.

Similarly, the same parameters are measured for the controlled concrete. Using the differential method of quality assessment, the measured parameters of the controlled concrete are compared with the corresponding parameters of all groups of baseline samples. An illustration of this for a single baseline sample with electrical parameters at one frequency is shown in Fig. 1.

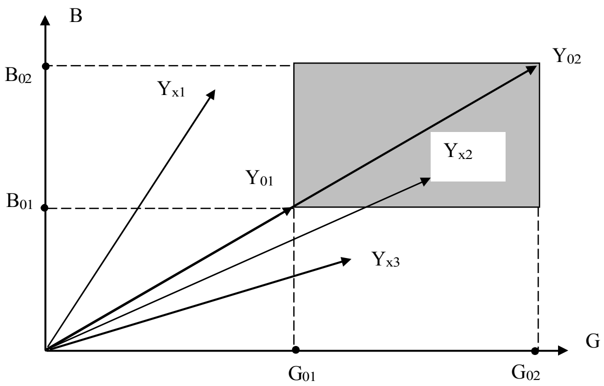

Fig. 1. The range of quality indicator values for the standard sample, limited both from below and from above

On the Fig. 1 the boundaries of the admittance of the base sample are indicated by vectors Y_{01} and Y_{02}. Accordingly, the lower boundaries of the active G_{01} and reactive B_{01} components of the admittance Y_{01}, as well as the upper boundaries of G_{02} and reactive B_{02} components of the admittance Y_{02}, are obtained. If the measured active and reactive components of the admittance of the controlled sample at the chosen fixed frequency lie within the rectangular boundaries, then such concrete is considered to belong to the normalized quality level corresponding to these boundaries (concrete with admittance Y_{x2}). If the obtained admittance values are outside the specified limits (beyond the boundaries), the concrete is identified as not conforming to the accepted level, or as falsified in some way (concretes with admittances Y_{x1} and Y_{x3}).

It should be noted that by identifying the concrete based on two electrical parameters, it is possible to detect concrete that meets the normalized values for only one parameter. That is, although the concrete with admittance Y_{x1} meets the normalized limits for the reactive component (and accordingly the dielectric permeability), and concrete with admittance Y_{x3} meets the normalized limits for the active component (and accordingly the specific conductivity), both are identified as not meeting the normalized quality indicators.

The practical implementation of such identification is ensured by measuring the admittance parameters of the base sample and controlled concrete using the same equipment. Furthermore, measurements must be carried out under the same climatic conditions, as temperature dependence of informative parameters leads to their change. Given the known temperature dependencies of the controlled parameters, any errors due to external influences can be corrected during the measurement process. For this, it is necessary to have results of admittance parameter measurements for base concrete samples under various temperature conditions.

4.3. Implementation of the Admittance Method for Measuring Electrical Parameters of Concrete

The implemented measurements of the mentioned parameters can be performed using simple technical devices of special purpose or serial wide-range impedance or conductivity (admittance) meters. However, these devices may not always be able to ensure the required measurement conditions, as their operating modes are not always suitable. Furthermore, these measuring devices may not always be available to the consumer, or they may be absent. A structural diagram of the measuring device for determining the active and reactive components of admittance for such measurements is proposed (Fig. 2).

The diagram includes a test signal source (TSS), which generates a sinusoidal signal with a specified amplitude U_m and frequency, a capacitive primary transducer "object-impedance" with two non-insulated flat electrodes 1 and 2, between which the concrete sample is placed, and a vector transducer (*VT*) to convert the object's parameters into an electrical parameter–admittance Y_x with parameters C_x and R_x. The vector transducer is built on an operational amplifier (*OA*), with the negative feedback elements consisting of a reference resistor R_0 and the object under control. The connection of the object under control is made using a three-electrode scheme, which eliminates the influence of non-informative parallel impedance Z_x caused by the surface impedance. For this purpose, electrode 3 is used, which shares a common point with the TSS and VT, ensuring the measurement of the bulk impedance parameters of the concrete, as the non-informative impedances Z_1 and Z_2 shunt the output of the TSS (contact 1) and the input of the OA (contact 2).

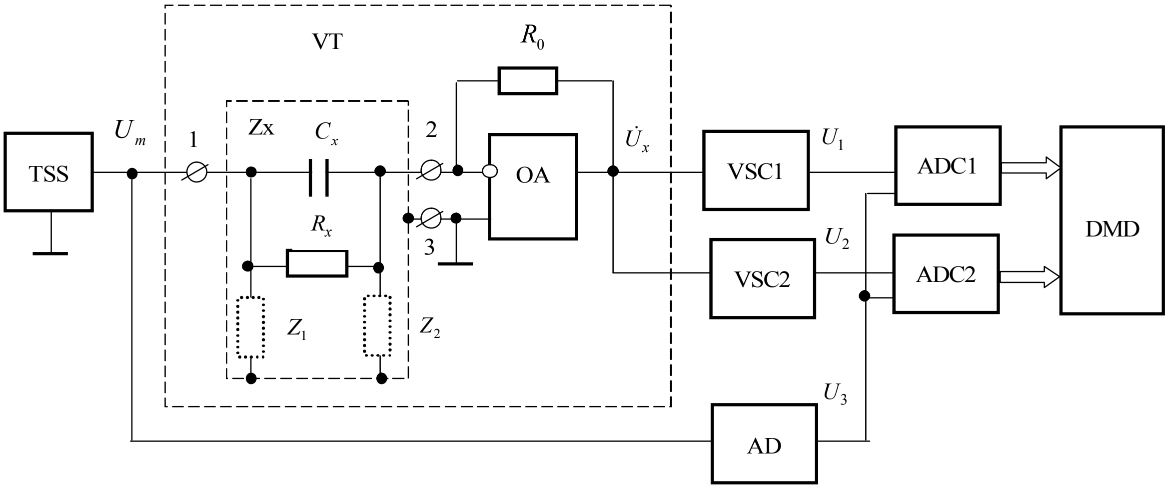

Fig. 2. Structural diagram of the concrete active and reactive admittance component meter

The output complex voltage $\dot{U}_x$ of the vector converter with the transformation coefficient a is described by the expression:

$$\dot{U}_x = U_m \, a \, R_0 \left(G_x + j\omega C_x \right). \tag{4}$$

From this, using the “vector-scalar” converters (VSC1 and VSC2) with transformation coefficients b_1 and b_2, the voltages are formed as:

$$U_2 = U_m b_1 R_0 G_x , \tag{5}$$

$$U_1 = U_m b_2 R_0 \omega C_x . \tag{6}$$

These voltages are fed to the information inputs of the analog-to-digital converters (ADC1 and ADC2), respectively. The reference voltage is supplied to the reference inputs of these converters, which is generated by the amplitude detector (AD) with a transformation coefficient b_3, as:

$$U_3 = U_m b_3 . \tag{7}$$

In this case, the converters ADC1 and ADC2 perform the division of voltages (5) and (6) by the voltage (7), and their outputs give the results N_1 and N_2, respectively:

$$N_1 = \frac{U_m b_1 R_0 G_x}{U_m b_3} = \frac{b_1 R_0 G_x}{b_3} . \tag{8}$$

$$N_2 = \frac{U_m b_2 R_0 \omega C_x}{U_m b_3} = \frac{b_2 R_0 B_x}{b_3} . \tag{9}$$

A simple analysis of expressions (8) and (9) shows that the measurement result does not depend on the DTS voltage and linearly depends on the reactive and active components of the concrete admittance. Taking into account expressions (2) and (3), we get:

$$N_1 = \frac{b_1 R_0}{b_3} A_1 \sigma_x , \tag{10}$$

$$N_2 = \frac{b_2 R_0}{b_3} A_2 \varepsilon_x . \tag{11}$$

The values of the dielectric permeability and specific conductivity can be derived, if necessary, by transforming expressions (10) and (11). Then we have

$$\sigma_x = \frac{A_1 N_1 b_3}{b_1 R_0} \tag{12}$$

$$\varepsilon_x = \frac{A_2 N_2 b_3}{b_2 R_0} \tag{13}$$

Thus, the proposed admittance method for measuring the electrophysical parameters of concrete allows the implementation of the differential method for quality assessment and its identification based on the reactive and active components of its admittance. Moreover, based on the results of these measurements, the same can be done for electrophysical parameters.

5. Conclusions

1. The admittance method for measuring the active and reactive components of concrete admittance allows for its identification based on two parameters simultaneously: specific active conductivity and dielectric permeability. This method enables monitoring the active and reactive components of concrete admittance at different quality levels over a wide frequency range and analyzing their amplitude-frequency characteristics.

2. The proposed method for concrete quality control ensures operational efficiency and can be imple-

mented using measurement tools for both laboratory and field applications. Identification of concrete based on two electrophysical parameters provides a higher level of reliability in quality control compared to using only one parameter.

3. An algorithm for forming an electrical concrete sample based on the measurement results of the admittance parameters of traditional standard concrete samples, which meet the specified regulatory requirements for quality levels, has been proposed.

4. Unlike traditional strength tests, the proposed method is non-destructive, making it ideal for preserving the structural integrity of concrete when assessing its quality. Thanks to advantages such as ease of use, rapid result acquisition, and correlation with the properties of concrete, research is motivated to standardize the method in order to establish requirements for specific electrical conductivity (resistance) and dielectric permeability at all stages of concrete use.

Conflict of interest

The authors declare that there are no financial or other potential conflicts of interest regarding this work.

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