Abstract

Noninvasive monitoring of concrete structure is an important element of building inspection. A new model of inductive sensor and reconstruction algorithm of rebar location is presented. The Measurement and Diagnostics Department in the Electrotechnical Institute performs research and development in that field. A new electromagnetic tomographic method is explored that can be combined with other methods due to fusion of output data at the image reconstruction phase. Reinforcement of concrete structure is made of ferromagnetic material characterized by high conductivity. Concrete cover is featured by low conductivity. The investigated area of concrete construction is stimulated by magnetic field generated by head. The variation in spatial distribution due to conductivity difference is registered simultaneously at a few points for different input frequencies. The resulted data is the reference spatial image for various frequencies. On the basis of the resemblance the most probable image is selected. As a result of digital processing the spatial image of reinforcement is obtained and further estimation of cover thickness, rebar diameter and its location can be done. The paper discusses applied method and shows the experimental setup, head structure and algorithm for signal processing.

Key words: Electromagnetic Tomography, reinforcement of concrete, multifrequency sensor

1. Introduction

The key problem in examination of reinforced concrete is to estimate size and condition of rebars. The first step of testing procedure is determining location and dimensions of individual rebars. That testing can be done by noninvasive methods [3, 4] and is the crucial element of concrete structure inspections. At Department of Measurement and Diagnostic Systems in Electrotechnical Institute in collaboration with Szczecin University of Technology and Building Research Institute [2, 6, 9] the research on developing of methods for localization, estimating dimensions of rebars and their covers were performed. The continuation of the performed research is proposing new, cost effective technique that allows measurements with minimal measurement uncertainty.
The work presents a general concept of that technique and device utilizing imaging of reinforcement structures. The aims of research being performed are to better the measurement precision of reinforcement geometry and detect existing rebar corrosion. In experiment inductive multi-sensor heads of various sizes [8] with multi-frequency current source [1] are used.


The concrete reinforcement is made of ferromagnetic material characterized by high conductivity. The concrete cover is made up of low conductivity material. The inductive head generates magnetic field penetrating tested concrete area. Rebars present in that area change the magnetic field distribution. The field is registered at few points for different frequencies. The excitation is given by the following formula:

\[ X(t) = \sum_{i=1}^{N} x_i \sin(\omega_{xi} t + \phi_{xi}) \]  

where:
- \( x_i \) - amplitude of \( i \)-th sinusoidal excitation,
- \( \omega_{xi} \) - angular frequency of \( i \)-th sinusoidal excitation,
- \( \phi_{xi} \) - phase of \( i \)-th sinusoidal excitation.

The object modifies incoming signals to that registered by coil:

\[ y(t) = K(X(t), P) \]  

where:
- \( K(\cdot) \) - given function,
- \( P \) - vector of parameters characterizing reinforcement.

Assuming that the conversion is linear the following expression is obtained:

\[ y(t) = \sum_{i=1}^{N} k_{xi} x_i \sin(\omega_{yi} t + k_{\omega yi} \phi_{yi}) \]  

Where:
- \( x_i \) - amplitude of \( i \)-th sinusoidal excitation,
- \( k_{xi} \) -coefficient of \( i \)-th sinusoidal excitation,
- \( \omega_{yi} \) - angular frequency of \( i \)-th sinusoidal excitation,
- \( \phi_{yi} \) - phase of \( i \)-th sinusoidal excitation.

The information on reinforcement geometry is contained in \( k_{\omega yi} \) and \( k_{\phi yi} \) coefficients. Using an A/D probe a measurement is taken at time \( m \):

\[ y_m = y(t_m) = \sum_{i=1}^{N} k_{xi} w_i \sin(\omega_{yi} t_m + k_{\omega yi} \phi_{yi}) \]  

The signal \( y_m \) is registered in probe’s memory. The record is accessible by serial interface. Independent on registration the microprocessor follows FFT algorithm.
The values of the amplitudes of the measured signal equal:

$$h_i = k_{ij}x_j$$  \hspace{1cm} (5)

The estimation of the discrete values at a given point in time is carried out according to the measurement model taking into account metrological characteristics of sampling [9]. The above relationships show analog-to-digital conversions of the temporary values and amplitude values of the frequency components. Having those values the algorithm EIT creates an image.


The data base is being built at laboratory site [2] that enables reinforced concrete testing with the use of various scanning probes and identification algorithms.

![Functional schema of microprocessor head](image)

*Fig.1 Functional schema of microprocessor head.*

The experimental setup consists of: scanning manipulator, excitation probe, generator of excitation function, excitation signal amplifier, measured signal amplifiers, data acquisition system, industrial PC and terminal for graphical data.
display device. An important element of the system is a probe based on the integrated sensor consisting of a number of identical elements with excitation and measurement coils [6, 8]. Microprocessor generator combines individual sinusoidal components. The parameters of excitation functions are chosen from outside of the probe by the parallel interface. Digital version of the signal is converted by A/D converter, next, after amplifying; the signal controls excitation coils of the integrated sensor.

4. Signal processing algorithms.

The measurement of the field distribution on the object’s surface is done for versatile excitement coil location. The output data are compared with the template that was created by gathering the data prior to the experiment.

\[ X(t) = \sum_{i=1}^{N} x_i \sin(\omega_i t + \varphi_i) \]

*Fig. 2 Flowchart representing a process of excitement and measured signal processing.*
The data base comprises of image templates produced for different frequencies. As a result of comparison the most analogous image set is chosen. The probability is calculated employing probabilistic methods. The result of digital converting is a spatial image of reinforcement location that allows for estimating the cover thickness; rebar diameters and distances between individual rebars. For given reinforcement configuration the measured signal sent by sensor coil is characterized by temporal variations, registered as changes in signal spectrum. The most important parameters for geometry measurement are, as it has been confirmed by previous experiments, the amplitudes of sinusoidal components. The taken signals are verified for error detection, to eliminate stochastic disturbances and potential sampling failures. [9].

The employed software is capable of multi-frequency synthesis of excitement functions, data acquisition, signal frequency analysis and 3D reconstruction image of reinforcement placed inside the tested area. The experimental setup enables for measurement of multi-frequency signals sent by the probe coils. Considering the complexity of computations during the experimental time, the used PC needs to have big computing power. At every point of scanned area a spectrogram is created for sensors of various geometries being the part of the head. The obtained spectrograms are the input data for the EIT algorithms.

5. Conclusions.

The paper presents the application of multi-frequency method for rebar testing. The reinforcement image is created by measurement signal processing after receiving the outputs to excitation. The variation of coil location on the surface of the examined area causes scanning effect to occur. The EIT algorithms allow for reconstructing an image by comparing output data with prototypes found at the calibration stand. The head with a number of sensors and multi-frequency excitement has been implemented. The proposed method delivers more information that allows for effective identification of model’s structure and precise identification of parameter values. The electromagnetic field penetrates the conducting material in the way that depends of applied frequencies, so that the sensor can detect nonuniformity of the material providing the signal are of different frequencies [5, 7].

In the experiment the sensor of various sizes were used. The reinforcement parameters are obtained based on the comparison procedure of excitements and replies. The different rebar configurations provide various signal images as a response to the same excitation. The applied tomographic method can be combined with other methods due to output data fusion at the reconstruction stage of the experiment. It is possible to optimize measurement sensors, sampling and identification algorithms. The aim is to develop a portable device for 3D imaging of concrete reinforcement. The presented results indicate that the multisensor head construction gives the possibility of outcoming data to differ depending on rebar location and its size. The EIT algorithms application leads to improvement of resolution and high noise tolerance.

6. References.


