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Sensor Systems for Corrosion Monitoring in Concrete Structures

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Abstract: It is a need of permanently embedded corrosion monitoring devices to monitor the progress of corrosion problems on a new or existing reinforced concrete structures before embarking on repair or rehabilitation of the structures. Numerous devices are available for investigating corrosion problems, because no single technique exists which tells an engineer what he needs to know, namely how much damage there is on a structure now and how rapidly the damage will grow with time. In this investigation we reports the studies on the sensors systems based on the measurements of half cell potential of rebars inside the concrete, resistivity of concrete, corrosion rate of rebars by eddy current measurements and sensing of chloride ions. An integrated system consists of above sensors are fabricated and embedded into concrete. The response from each sensor was acquired and analyzed by NI hardware through LabVIEW software.

Keywords: sensors, corrosion, concrete structures, sensor systems.

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1. Introduction

The implementation of a maintenance strategy together with the adequate monitoring procedures is essential to prevent the premature corrosion of reinforcements and its consequences on the durability of concrete structures. Sensors and associated monitoring systems can provide a realistic assessment of the service life of a structure giving information about both spatial distribution and a temporal change in concrete cover properties and concerning the reinforcement state [1]. Different types of sensors are involved in the corrosion and force monitoring of concrete structures [2-9]. This paper presents a design and its performance of integrated sensor systems comprising of potential sensor, chloride ion sensor, resistivity sensor and eddy current sensor.

2. Experimental

The fabrication of individual sensors are briefly described below:

2.1.Eddy current sensor

This involves measurements of forces in construction steels and the detection of surface stress of strand wires. The transducer type produces an output voltage proportional to the rate of change of flux and inductance of the coil. Variation in inductance of a coil and the eddy current can be achieved by changing the geometry, reluctance of the magnetic path, permeability of the magnetic core material, coupling of two or more elements of a coil, material conductivity and the frequency.

In this approach, the emf variation of inductance of a coil in eddy current sensor based on the geometrical variation was considered. The fabrication of eddy current sensor includes**:**

- Ferromagnetic material is selected with E type core
- 34 gauge inductance coil chosen and 175 winding wound at centre of E core
- Winding was properly made with proper bobbin
- A mild steel specimen of size 6mm dia and 30 mm long was selected and made mirror polished was referred as test specimen.

The experimental set up for effect of eddy current variation on the specimen and the specimen grooving are shown in Fig.1.

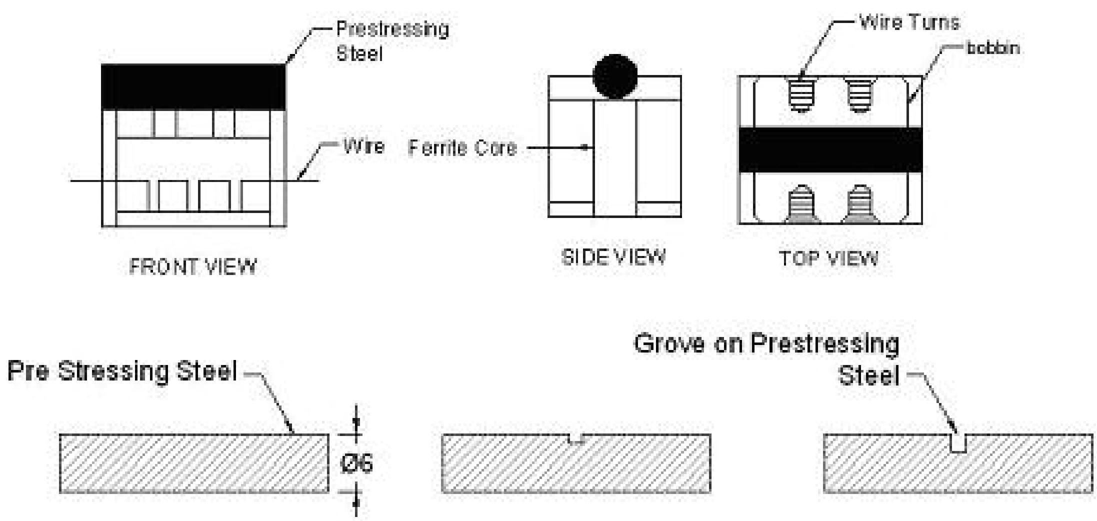

Fig.1. Schematic of eddy current sensor.

2.2.Chloride sensor

Silver wires (99,99% purity), 1 mm in diameter and 30 mm in length, were subjected to the following program:

- They were cleaned for 6 hours in concentrated NH_4OH and immersed in distilled water overnight; a length of 20 mm of each one was anodized in 0.1M HCI for 30 minutes at a current density of 0.4 mA/mm^2 .
- They were immersed in distilled water for 24 hours and finally the non-anodized zones were protected with Teflon tape.
- Electrical lead using shielded coaxial copper wire is connected from Ag/AgCl silver wire.
- A hole was drilled in the PVC rod (or Teflon) and the anodized silver wire was kept in position such that 4 mm of wire is exposed to the environment. Fig.2 shows the schematic of embeddable Ag/AgCl sensor.

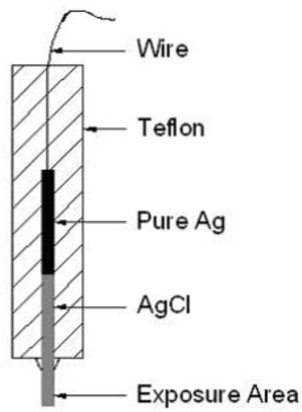

Fig.2. Sketch of embeddable chloride sensor.

2.3.Resistivity sensor

Fig.3. shows the schematic of resistivity sensor. Here 4 stainless steel rod of dimension (length 25mm) and (diameter 1.25 mm) were fixed inside the drilled PVC rod with equal spacing (2.5 mm) and seated. Outer pair of the stainless steel rod was used for excitation of current and inner pair was used to measure the voltage.

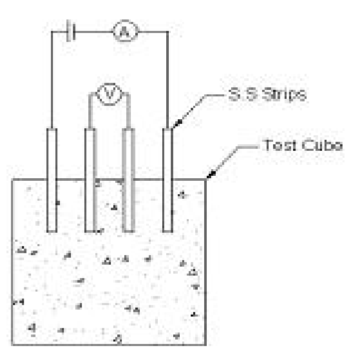

Fig.3. Schematic of resistivity sensor.

2.4. Integrated sensor system for concrete structures

An integrated sensor systems comprising of eddy current sensor, chloride ion sensor, resistivity sensor along with Hg/HgO potential sensor [10] for concrete structures are shown in Fig.4.

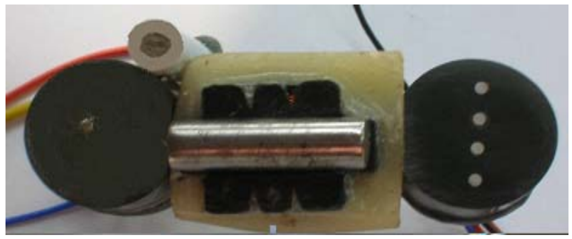

Fig.4. An integrated electrochemical sensor system.

3.Results and Discussion

3.1.Eddy current sensor for corrosion rate measurements

The coil impedance of eddy current sensor positioned close to a test specimen. Normally corrosion-affected material had undergone the micro structural variation in its property. Based on its cross sectional variation on material due to corrosion, voltage variation of the eddy current sensor is observed linearly varying with the dimensions of the specimen and the eddy current response graph is shown in Fig.5.

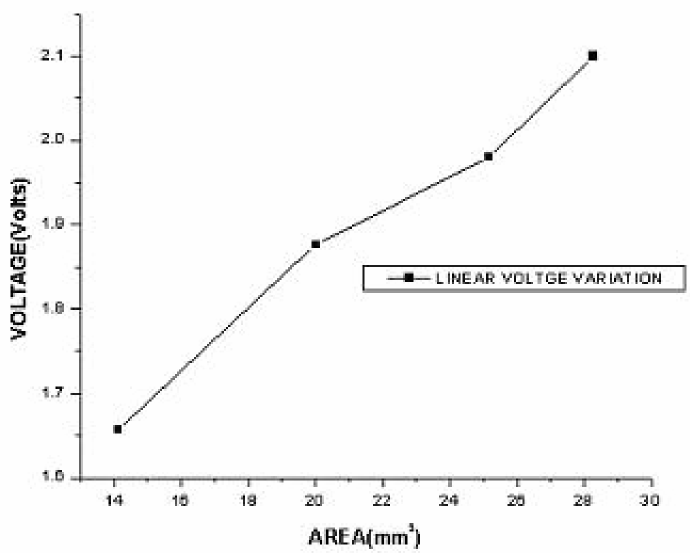

Fig.5. Response from eddy current sensor.

3.2.Chloride ion sensor

Periodically, the chloride was sprayed on the concrete surface and the chloride was measured using Ag/AgCl sensor. The linear relationship was obtained which will give the chloride concentration with respect to potential value as shown in Fig.6.

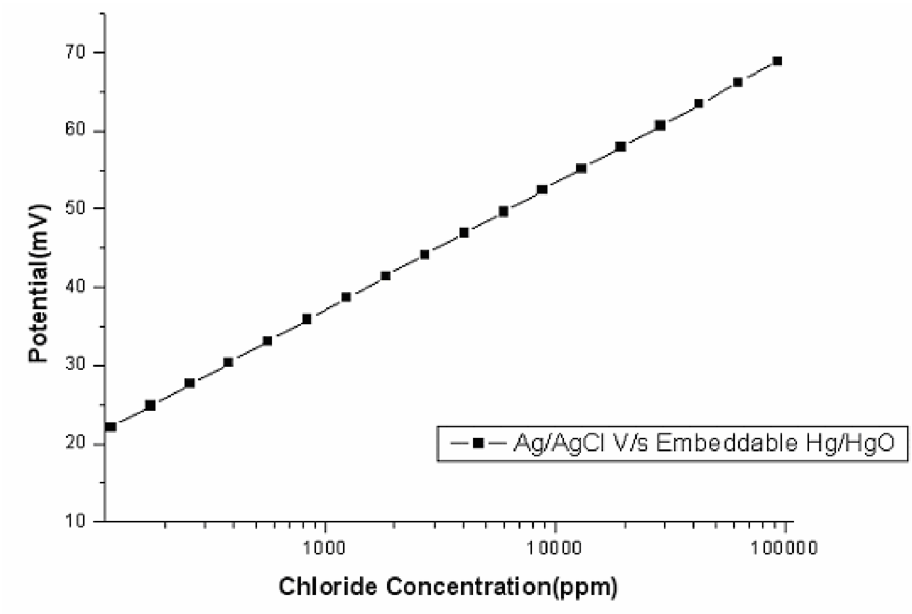

Fig.6.Chloride profile for the Ag/AgCl sensor.

3.3.Resistivity sensor

Concrete resistivity is calculated using the equation $\rho=2 \times \Pi \times a \times R$, where "a" is electrode spacing. Resistivity was measured both in dry and wet conditions. The ratio of resistivity of dry specimen to the wet specimen leads the dryness factor (ρ_{dry}/ρ_{wet}). The resistivity of the specimen was measured for 4 months and the response graph is given in Fig.7.

3.4.Sensor system arrangement

The most important causes of reinforcement corrosion are (i) localized depassivation of the reinforcing steel due to the ingress of chloride ions and (ii) complete depassivation of the reinforcement due to acidification of the interstitial solution in consequences of reactions of the cement matrix with CO_2 present in the atmosphere. Chloride will leads the localized corrosion of steel and consequently shift the potential of rebar to the most cathodic direction. For successful corrosion monitoring parameters such as OCP of steel, corrosion rate of steel, resistivity of concrete and chloride level were to be required. To fulfill the above requirement an integrated sensor system was designed with the following components:

- Potential sensor: Open circuit potential by Hg/HgO sensor
- Corrosion rate sensor: Eddy current sensor
- Resistivity sensor: Resistivity by 4-probe method.
- Chloride ion sensor: Ag/AgCl sensor

The integrated sensor system, which can able to measure the open circuit potential, corrosion rate, concrete resistivity and chloride ion concentration non destructively. The new sensor arrangement was embedding it into the concrete specimen of size 150 mm X 150 mm X 150 mm (mix proportion 1:1.71:2.09). The sensor arrangement was embedded inside the cube specimen at specified location. The response of each sensor from concrete was acquired and analyzed automatically by NI hardware through LABVIEW. The electrical leads coming out from sensor system were properly routed. The algorithm for data acquisition from different sensors through field modules, system configuration, software and hardware procedures are shown below.

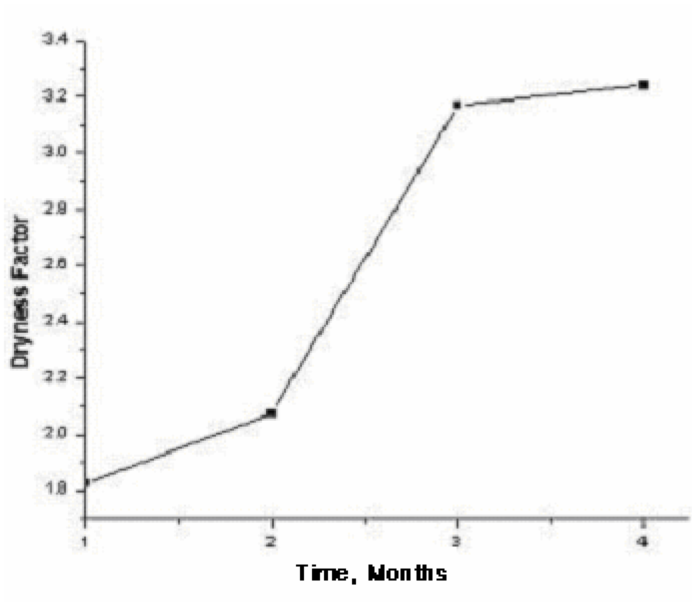

Fig.7. Dryness Factor response.

3.5.Hardware connection

- In our system 4 channels of AI100 (National Instruments - NI), single channel of AO210 and DO410 are required for acquire output from sensor system for corrosion in concrete cube.
- The direct measurement of OCP, chloride potential was directly connected to channel 0and channel 1 of AI100 module.
- The excited input voltage was given to eddy current sensor by frequency generator with fixed frequency 1.5 KHz through Relay circuit, which were controlled by DO210 module.
- The output emf was converted into signal, which was accepted by AI100 through rectifier circuit.
- For resistivity measurement, impress the current through the outer electrodes by AO100 and measure the voltage from inner electrodes by AI100
- Field modules were connected on the field rail and controller modules called FP2000 controlled these modules.
- Connection between field point modules and computer was made by RJ45 using TCP/IP
- During execution process connection should be established properly.

The data collections of each sensor are recorded and graphical representation was done by LABVIEW coding is shown in Fig.8 and Fig.9.

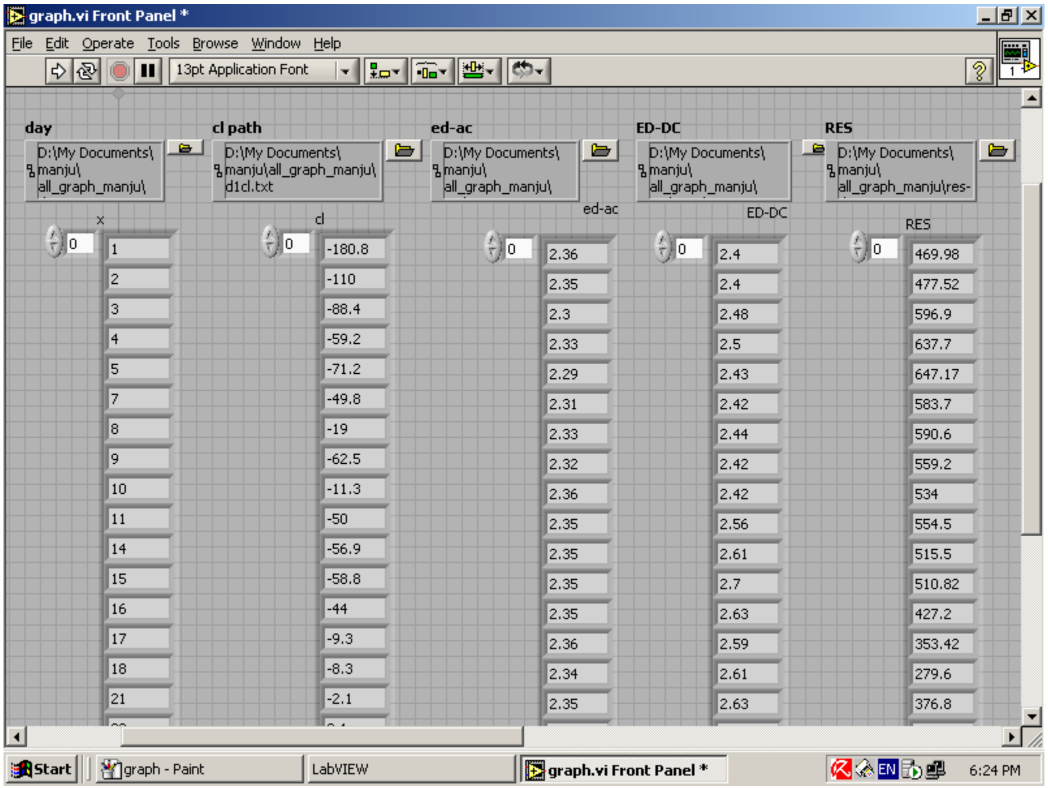

Fig.8. Front panel showing all sensor data.

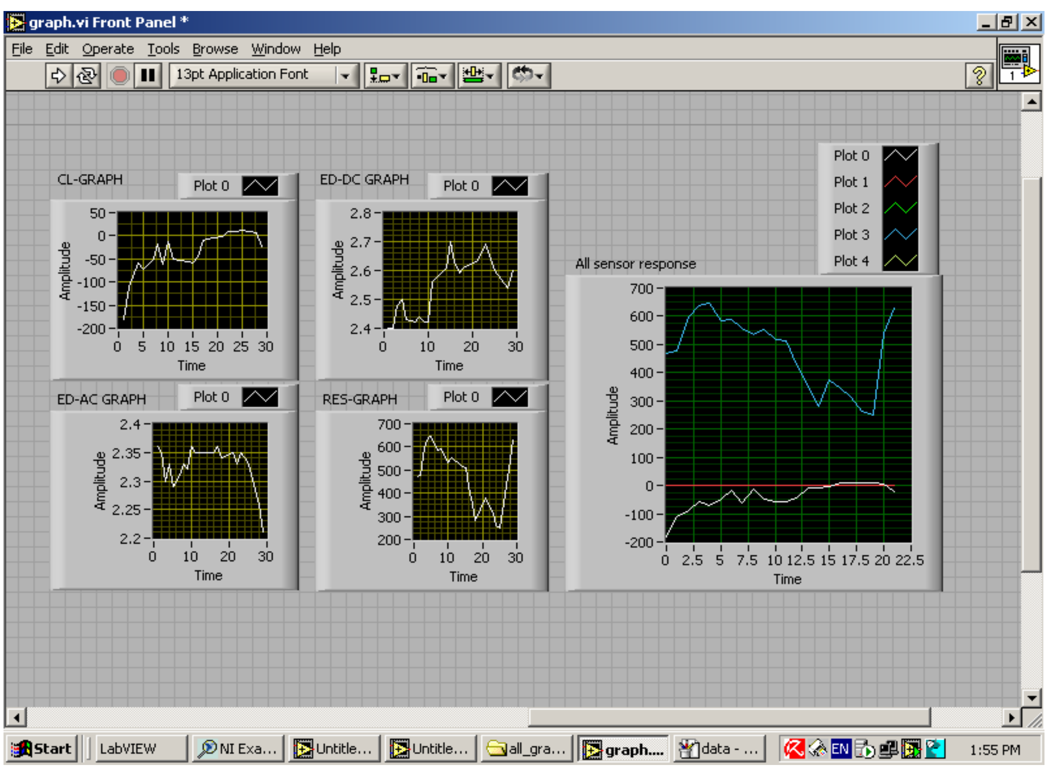

Fig.9. Front panel showing all sensor response.

4. Conclusions

The uses of integrated sensor systems are allowing a rapid development platform for minimization of the design implementation of corrosion measurement system. For effective corrosion assessment, qualitative and quantitative measurements are required. To fulfill the above requirement an integrated sensor system was designed with the following components:

- Open circuit potential by Hg/HgO sensor
- Corrosion rate by new eddy current sensor.
- Resistivity by 4-probe method.
- Chloride ion measurement by Ag/AgCl electrode.

This development process includes physical experiments that are aimed to characterize the main attributes of the sensing device in the corrosion environment. The instrumentation was tested using field point wiring through Lab view coding. This approach provides rapid examination of the effectiveness of the sensing system for corrosion measurement and validation of the algorithms governing the electrochemical process and its control.

Acknowledgements

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