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Potential monitoring system for corrosion of steel in concrete

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Abstract

Corrosion of steel in concrete reduces the life and durability of concrete structures. It is a worldwide problem, which causes heavy losses to the economy and industry. The corrosion of steel is inevitable. The durability of concrete structures primarily depends on the condition of the embedded steel in concrete, apart from any deterioration that the concrete may undergo. To determine the condition of the embedded steel, potential surveys are carried out on concrete structures and this is one of the most important monitoring techniques. Most of these measurements in the field are manually carried out and the data obtained are analyzed.

Automation is the best solution where repeated measurements have to be made. This eliminates the human errors in the measurement and improves the accuracy of the data measured from humanly inaccessible regions of a structure. With the advent of computer-based I/O cards and faster chips for data processing, the measurement of data such as voltage, current, etc. from a large number of points simultaneously is possible. In the present work, simultaneous measurement of potential of steel from different points in a concrete slab, using NI-DAQ card (AT-MIO-16E-10), has been made. Suitable software was developed for interpreting the measured data based on ASTM C-876, to assess the condition of the embedded steel. More number of data was acquired in each channel and averaged as the data acquisition device can acquire 100 kS/s. Software was developed using Visual Basic 6.0 and NI-DAQ driver software. Data acquisition system developed is a user-friendly one.

Keywords: Concrete corrosion; Data acquisition; Analysis; Monitoring

1. Introduction

Corrosion of the reinforcement steel used in concrete leads to formation of rust. As the steel corrodes, the volume of the rust also increases and at one stage the force induced by the corrosion products may exceed the tensile strength of the concrete and because of this, cracking of concrete will occur. These corrosion products would exert enormous stress on the surrounding concrete promoting the deterioration of concrete structures [1]. Methods of investigating metal loss are based on the premise that the corrosion of reinforcement steel is an electrochemical process. Among the various electrochemical methods, the increasingly used field technique for detecting corrosion activity in embedded steel is that of potential measurement. To analyze the corrosion behavior of steel in concrete, potential must be measured on the structures at different locations. Manually measuring the potential at different points on a large structure is a cumbersome process [2–5]. To acquire large number of data automatically at specified time intervals, automated measurement system is essential [6–7]. Different types of data acquisition systems available were analyzed [8–24]. Automated simultaneous measurement system is a reliable, more efficient and less time consuming method. To measure the data automatically, simultaneously in multiple locations and to analyze, this measurement system was developed [5].

Computer is a useful tool for such tasks as data acquisition (slow or fast), on-line experiment supervision and evaluation, modeling and sophisticated data treatment. Before computers became common in laboratories, transient recorders, data loggers, etc. were used [25]. Data acquisition in atmospheric corrosion experiments has evolved from hand taking of data to chart recorder to computer acquisition of data [26,27]. Large amount of data can be acquired simultaneously from many measurement points on the system for statistical analysis [3,28–31]. As a result, tremendous advances in the accuracy and speed of experimental data acquisition have emerged [32–36].

With the advent of computer-based I/O cards and faster chips for data processing, the measurement of voltage/current has become automated and direct input to the computer for

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further processing is possible [37]. A range of data acquisition cards, which simply plug into the port of a PC (desktop or laptop) available, enhanced the development of a PC-based on-line data acquisition system. By connecting suitable sensors, they can be used to measure temperature, pressure, humidity, light, resistance, current, power, speed, vibration, etc. These PC-based instruments allow the computer to record the signals from the external phenomenon under study. Using a PC-based data acquisition system, typical current/voltage data from the system under control or test can be acquired from a large number of points, simultaneously.

2. New developments in measurement technology

In computer-based system, the measurement components are defined by the sampling rate and resolution required by the application. Acquisition is performed by these measurement components while the computer performs analysis and presentation. In this way, measurements benefit from the high-performance processing power, available in the computer, but which was not available in earlier stand-alone instruments. In addition to processing speed, the increasing speed of I/O buses such as PCI and PXI/Compact PCI make it possible to create computer-based measurement components that acquire signals at rates that often match or exceed that of stand-alone instruments. At the same time, the speed and resolution of the available analog-to-digital converters allow the data to be acquired with a greater accuracy.

Network technologies such as Ethernet, HTML, wireless communication, and the Internet are facilitating remote and automated measurements and analysis. Another recent enhancement in data acquisition system is that, data is gathered constantly by desktop computers in the laboratory through the use of sensors embedded in the samples at the site. Researchers are able to access test data real time via the Internet. Web camera monitoring at the site can also be implemented. [National Instruments manuals].

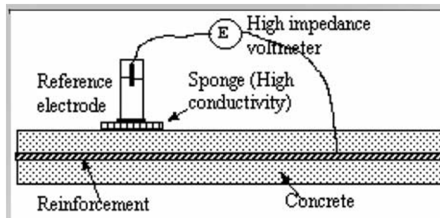
3. Components of a data acquisition system

Interfacing a computer to a real world requires an input/output interface module, which is a bridge between the computer's bus and the transducer of the real world phenomena with which the computer must communicate. The interface must move information accurately and efficiently between the computer bus and the external phenomena. Many applications use plug-in devices to acquire data and transfer it directly to computer memory. Others use data acquisition (DAQ) hardware remote from the PC that is coupled via parallel or serial ports. Obtaining proper results from a PC-based data acquisition (DAQ) system depends on each of the following system elements:

- The PC
- Transducers
- Signal Conditioning
- DAQ Hardware
- Software

3.1. Potential measurement technique

In the potential measurement technique, an electrical contact is made with the reinforcement steel and a voltage reading is obtained with respect to a RE (reference electrode) over the concrete surface using a portable sensing device as established by Stratfull et al. [38]. The principle involved in this method is the appearance of an electrical potential between the reinforcing steel and a reference electrode, named half-cell [39–49].



Principle of the half-cell method

The potential obtained is analyzed to determine whether the steel is corroding or not. Potential survey can be carried out at different nodal points and measurement can be done in more number of points. Correct potential mapping will enable reliable information about the condition of reinforcement beneath to be obtained. This type of survey can primarily indicate whether or not the steel embedded in a structure is corroding and the areas where corrosion activity is greatest, by comparing with the established standards such as ASTM C876-91 [50] or OTR [51].

3.2. Development of a multi-channel data acquisition system

On-line data acquisition system has been developed using a National Instruments data acquisition card (NI-DAQ), AT-MIO-16E-10, which is a plug and play device. It has two modes of operation for measuring the data (1) unipolar (0 to $+10$ V) and (2) Bipolar ($+5$ V). It has 16 analog input channels and two digital to analog output channels, with a resolution of 12 bits. The sampling rate is very high, i.e. of the order of 100,000 samples/s. Automatic gain setting is available in the software itself, which makes the resolution of the measured signal more accurate. Triggering is possible with external circuitry or by software. In this board, everything is software controlled and hence there is no need for the user to be concerned about the system hardware setup. NI-DAQ has an extensive library of functions that can be called from any application-programming environment. These functions include analog input, digital output, and waveform generation, etc.

3.3. System under investigation

For the present study, concrete slabs of size $1\ \text{m} \times 1\ \text{m} \times 0.1\ \text{m}$ were used, namely Slab 1 (without chloride) and Slab 2

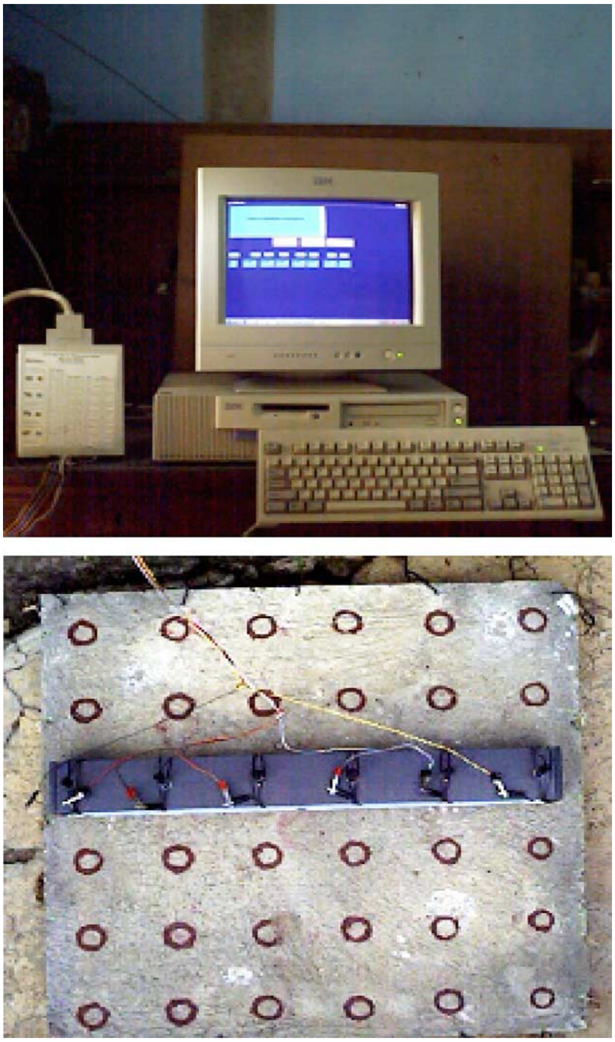


Fig. 1. Test setup for data acquisition in Slab 1 and Slab 2.

(3.5% sodium chloride added by weight of cement) [52–59]. These test slabs were cast with steel embedded in them. All the slabs were left in open air and periodically wetted.

Data acquisition was done on the concrete slabs at the points marked on the structures as shown in Fig. 1. The computer with the data acquisition card was installed in a room. Connections were made from the measurement setup to the slabs. Signals were measured from the structure without signal loss up to a maximum distance of 10 m (using this card). The reinforcement rod was electrically connected to analog input sense (AISense) of the DAQ card. A set of copper–copper sulphate Electrode ($Cu/CuSO_4$) was used as the sensing device (reference electrode), which was moved around the structure, to establish contact on the concrete surface, at the marked locations. The leads of the electrodes were connected to the input channels of the DAQ card. The reference electrode was moved across the concrete surface to be investigated, and the electrode potentials were measured at different locations. In all, the potential of the embedded steel rods were acquired at 36 different marked locations in each slab periodically. The data acquired were stored in a data file for further analysis. When the data were being measured from various points in the slab, the potential at each point was simultaneously measured with a high impedance voltmeter and compared with that acquired by the automated measurement system. Data measured was more accurate when measurement was done using the data acquisition system, as more number of data was measured in each point in microseconds and averaging was done. It was found that the correlation coefficient between all the data points was >0.9, which indicated the accuracy of the developed system.

4. Software development

Fig. 2 shows the block diagram of the measurement setup of the data acquisition system. The data acquisition system developed can be used for measuring data from 16 locations at a time. The software is a menu driven one. Different menus have been developed and options are given for selecting the number of channels to be used for measurement and the settings of the test system for which measurement should be done. If there is any change in parameter settings in any of the menus, it can be done before acquiring the data by just selecting the appropriate menu and incorporating the changes.

Following features have been included in the software:

- To measure the potential (acquire data) from as many channels as required depending upon the requirement of the user.
- To select any channel order for potential measurement (data acquisition).
- To select the gain setting for each channel to improve the accuracy of the measured potential.
- Automatic measurement of data (acquisition of data) at specified intervals.
- Sequential presentation of the acquired potential data as per the selected/desired channel order.
- Presentation of the measured potential (data acquired) as
  - Acquired data with the specifications of the locations from which the potential was measured.
  - A grid pattern illustrating the measured potential at the specified locations and/or a color setting indicating the possibility for corrosion as per ASTM C-876-91 (1999).

This representation will give an idea about the potential distributions on the structure at the specific nodal points.

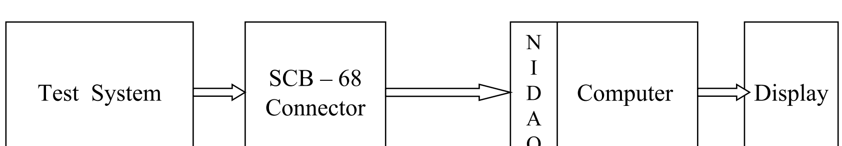


Fig. 2. Measurement setup.

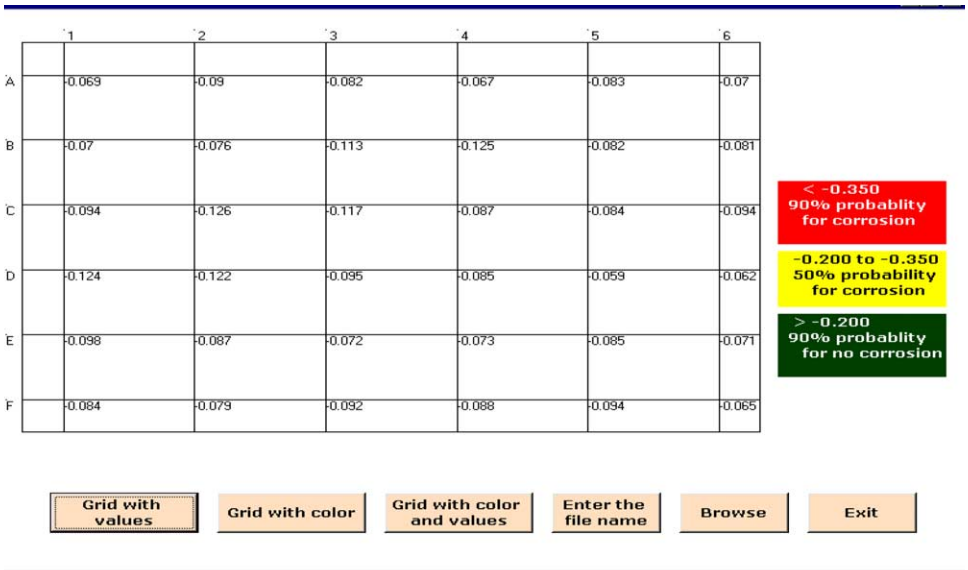


Fig. 3. Potential data display for Slab 1.

Once the potential is acquired, the system can plot the data in MS-EXCEL or any specified software and the required parameters can be evaluated. This data acquisition setup can be used in field applications also, for recording the data. Software developed is a powerful and flexible program for collecting, analyzing and displaying any other data as well.

The measured potential values were compared with ASTM standard C876-91 and suitable color display was presented as given below:

Potential level (V)	Probability for corrosion	Color setting
<-0.350	$>90\%$	Red
-0.200 to -0.350	Uncertain	Yellow
>-0.200	90% no corrosion	Green

Software modules were developed using Visual Basic, MS EXCEL and National Instruments DAQ driver software (available with the card) for data acquisition and analysis.

5. Results and discussion

In the present study, data acquisition system was developed to acquire data and analyze the behavior of the steel embedded in concrete slabs, under different conditions. The conditions imposed were:

(a) Less probability for corrosion (Slab 1: chloride free concrete).

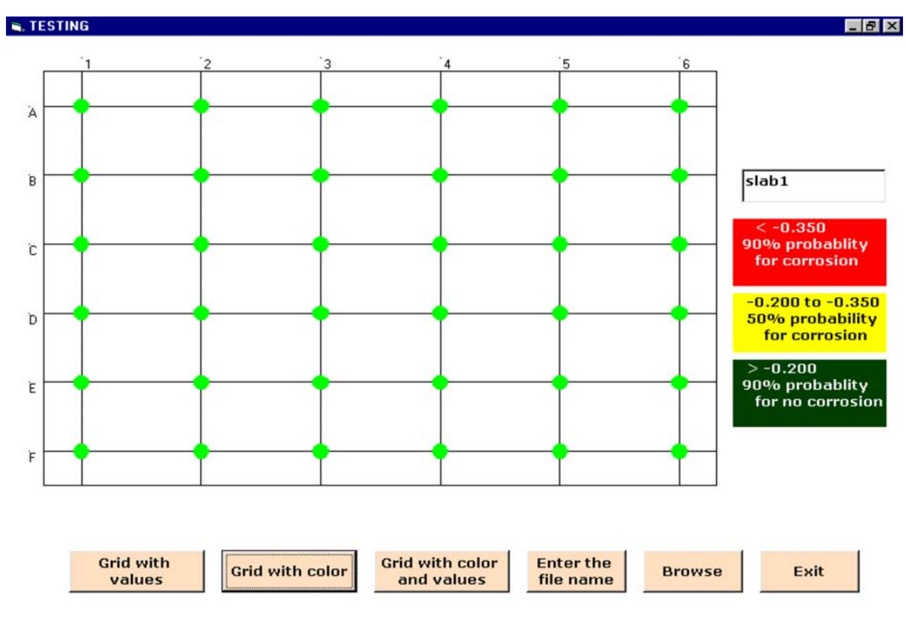


Fig. 4. Potential distribution in Slab 1.

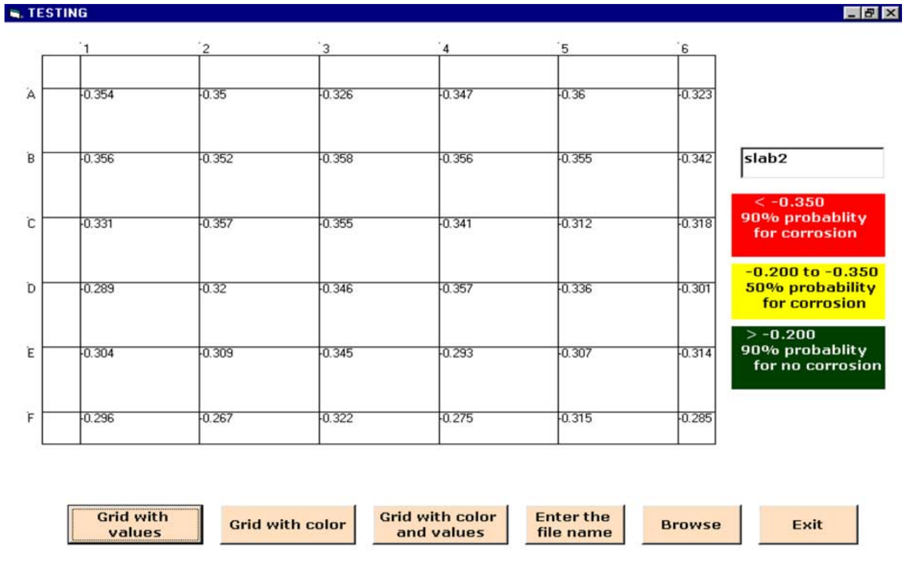


Fig. 5. Potential data display for Slab 2.

(b) More probability for corrosion (Slab 2: concrete containing 3.5% NaCl by weight of cement).

For these systems, the potential data were acquired by using the data acquisition system developed. The stored data was then displayed as shown in Figs. 3 and 4 for Slab 1. Fig. 3 displays the values of the acquired potential with respect to the locations from which the data were acquired while Fig. 4 displays the possibility for corrosion at the monitored locations. In Fig. 4, the color settings were selected in such a way that 'green' represents 90% probability for no corrosion; 'yellow' represents 50% probability for corrosion and 'red' represents 90% probability for corrosion (based on ASTM C-876-91 (1999)), which was specified in the screen itself along with the grid display. Similarly, Figs. 5 and 6 represent a set of data acquired from Slab 2 at specific time intervals of measurement. It can be inferred from Figs. 4 and 6 that the potentials of Slab 1 lie in the no corrosion zone while those of Slab 2 lie in the 90% probability for corrosion.

The data acquired from Slab 1, at the end of each time interval was averaged. This average value was plotted against the corresponding time of measurement and is shown in Fig. 7. In the initial stages, the steel exhibited potentials of about −200 mV with larger variations due to the wetness still present in concrete. It later shifted towards less negative values with lesser variations, mainly due to drying up of concrete. These values were observed to represent 90% probability for no corrosion, as per ASTM C-876-91 (1999).

The data acquisition setup, similar to that used for Slab 1, was used to acquire data from Slab 2. The software utilized for Slab 1 was also used to acquire and analyze the data from Slab 2. The data acquired from Slab 2, at the end of each time

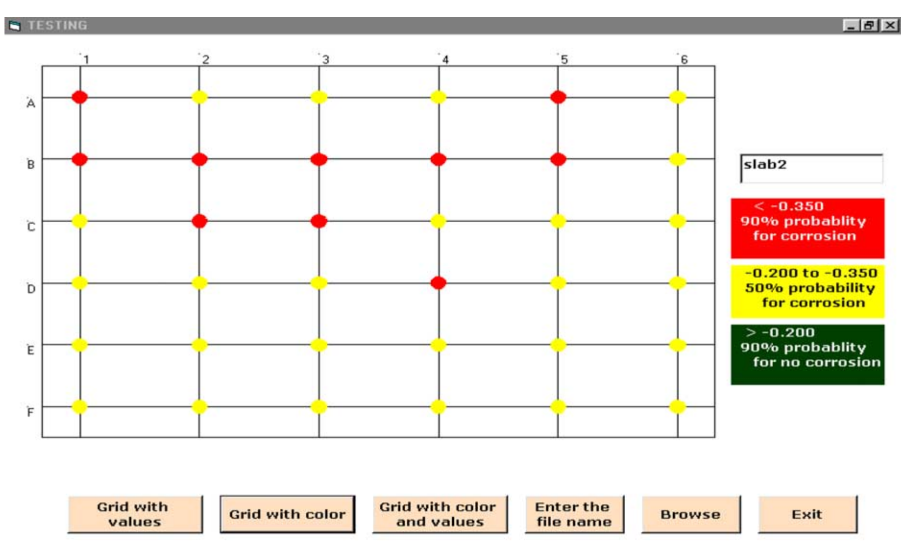


Fig. 6. Potential distribution in Slab 2.

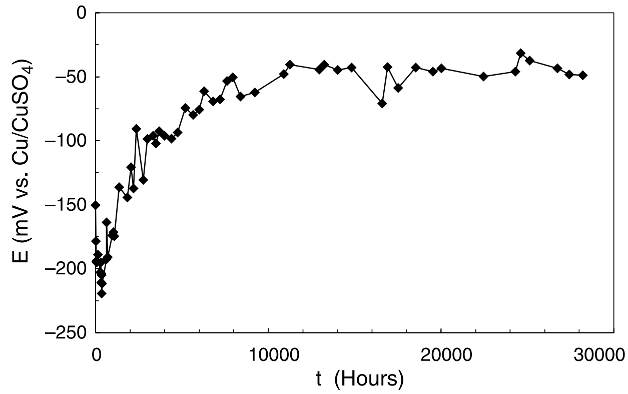


Fig. 7. Variation of the potential of embedded steel with time, in Slab 1.

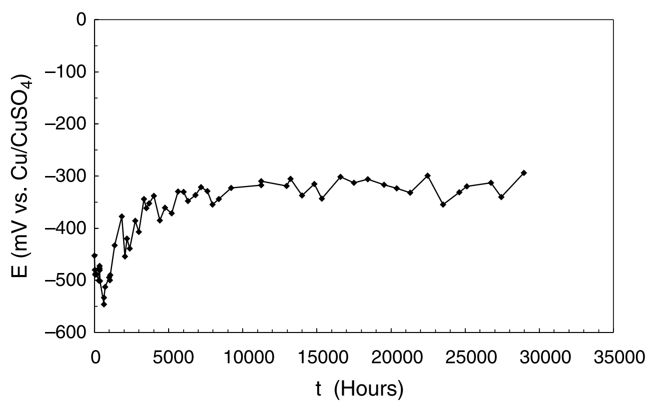


Fig. 8. Variation of the potential of embedded steel with time, in Slab 2.

interval was averaged. This average value was plotted against the corresponding time of measurement and is shown in Fig. 8. At the initial stages, the steel exhibited potentials of about −500 mV with large variations, due to the presence of moisture and chloride. Later the potentials shifted towards less negative values. Here, these values were observed to represent 90% probability for corrosion, as per ASTM C-876-91 (1999).

6. Conclusion

The data acquisition system developed has been observed to function efficiently. Automatic gain setting available in this system, record the changes in voltage levels in the order of microvolts accurately. Automatic recording of data, made at specified time intervals, eliminated the human error. In addition, number of inaccessible regions for measurement was also reduced. The simultaneous measurement of data from different locations facilitated faster measurement and an increase in area to be monitored. The results were simultaneously verified by manual measurements at all locations with a high impedance voltmeter. It was found that the correlation coefficient between all the data points was >0.9, which indicated the accuracy of the developed system. When proper instrumentation exists, these techniques can be extended beyond the laboratory studies, for on-line/process analysis and field studies.

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