MICROCOMPUTER BASED SYSTEM FOR CONTROLLING REINFORCED CONCRETE STEEL CORROSION

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ABSTRACT

The contribution of this work is the design of microcomputer based system for measurement, monitoring and pulse width modulated power supply (PWM) as integrated control system with strong software suitable for different electrochemical control techniques of the reinforced concrete corrosion and repair locations. The combination of sacrificial (galvanic) and impressed current cathodic protection was laboratory tested with the proposed control system. The corrosion tendencies as measured by potential, are determined according to ASTM C876-87 half-cell method. In this work, the study of reinforced concrete steel corrosion under different conditions is presented. The behavior of Aluminum anode and its stability as a reference electrode was studied.

KEYWORDS: Reinforced concrete, steel corrosion, cathodic protection, sacrificial anode, Aluminum anode, concrete repair, microprocessor controller.

1. INTRODUCTION

Concrete has been popularly used as a primary material for structural engineering since Portland cement was developed in 1824. Reinforced Concrete (RC) structures should be monitored periodically for detection of steel bars corrosion. The problem with iron, as well as many other metals, is that the oxide formed by oxidation does not firmly adhere to the surface

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of the metal and flakes off easily causing "pitting". Extensive pitting eventually causes structural weakness and disintegration of the metal. Other corrosion process can lead to structural failure of the concrete due to the increased volume of corrosion products, which results in cracking and scaling.

A number of electrochemical corrosion measurement and monitoring techniques are available for protection. It has been studied extensively [1].

Inattention to corrosion control, as part of an overall maintenance program for concrete structure facilities has been reported to cost the US (for example) more than $250 billion annually and Canada's concrete infrastructure, of which a significant portion is near the end of its design life, has a replacement value of over half a trillion dollars. [2]

2.CORROSION PROCESS

2.1. Corrosion in Construction

Corrosion of reinforcing steel can occur in two major situations: carbonation, and chloride contamination.

Carbonation is a process in which carbon dioxide from the atmosphere diffuses through the porous concrete and neutralizes the alkalinity of concrete. The carbonation process reduces the hydrogen ion concentration (pH) of the concrete to low level in which the oxide film of steel bares is no longer stable. (pH is the negative logarithm of hydrogen ion concentration) [3].

Chloride ions can enter into the concrete from many sources including chloride containing admixtures which are used to accelerate curing, contaminated aggregates and/or mixing water, air born salts, salts in ground water, and salts in chemicals that are applied to the concrete surface. If chlorides are present in sufficient quantity, they disrupt the passive film and subject the reinforcing steel to corrosion.

When chlorides are uniformly distributed around the steel, local action micro-cells form and dominate the corrosion process. Anodic and cathodic sites may be observed very close to each other on the same bar under such circumstances. This micro-cell effect generally leads to a type of localized corrosion known as "pitting" corrosion. In this case, metal loss from anodic sites creates a pit. As corrosion proceeds, the condition inside the pit becomes progressively more acidic and further loss occurs from the bottom of the pit rather from the sides. The cross-sectional area of the steel is progressively reduced to a point in which the steel can no longer carry the applied loading.

2.2. Concrete Repair

Patch repairs of concrete structures could be carried out to delaminated and spalled areas using mortars or concretes. Strong electrochemical macro-cells are established near the interface between the old chloride-contaminated concrete and the new chloride-free concrete. The short distance between anode and cathode, together with the large difference in chloride concentration, results in strong potential gradients, which accelerate corrosion.

Differential-oxygen cells arise due to the differences in oxygen supply to varying parts of the reinforcement network. Since oxygen movement is largely governed by porosity, significant variations can be introduced by localized remedial work in repair[4]. It is very important to control the corrosion process at repair locations during the wet stage until full drying.

3. ELECTROCHEMICAL TREATMENT

There are many forms of electrochemical treatment for stopping the steel corrosion in concrete structures. Chloride removal, realkalization, and cathodic protection are the most famous. The patented NORCURE methods of electrochemical chloride removal and re-alkalization was reported by Norcure Inc.[ ]

Evaluation of different protective schemes and the application of the cathodic protection technique have been discussed by M.K.Banerjee [9].

3.1. Cathodic Protection

Cathodic protection (CP) is defined as the reduction or elimination of corrosion by making the metal a cathod via an impressed direct current (DC), or by connecting it to a sacrificial (or galvanic) anode according to electromotive force series (galvanic series). Cathodic areas in an electrochemical cell do not corrode. [6-8]

The voltage differences between anode and cathode are limited in sacrificial anode system. Larger voltages of Impressed current systems are more useful in low conductivity environment such as concrete.

In this work, the combination of the two types of CP system are used with Aluminum anode as a reference electrode in the new integrated control system.

A very useful E/pH diagram has been evolved by Pourbaix, it is often called Pourbaix diagrams or Potential-pH diagram. These diagrams are particularly important in the study of corrosion of metals in aqueous media and electro deposition of metals and oxides. These diagrams are used for predicting: spontaneous direction of reactions, stability and composition of corrosion products, and environmental changes which will prevent or reduce corrosive attack.

Referred to Pourbaix diagram for iron, it has been empirically determined that the corrosion protection for mild steel is –840mV with reference to copper/copper sulphate reference electrode [ ].

Walther Nernst discovered the relation between E-cell and concentrations. Nernst equation can be used to calculate: electrode potential (half cell potential) in a given set of conditions, emf and polarity of electrodes in an electrochemical cell, and corrosion tendency of metals in a given set of environmental conditions [ ].

4. EXPERIMENTAL PROGRAM

The scheme of this work is divided into three phases. The first phase studys the performance of unprotected steel in the concrete under different conditions and its corrosion potentials with respect to four types of anodes. The aim of this part is to determine the range of potential difference between concrete and steel to design a suitable control system. The second phase is the design of integrated control and monitoring system. In the third phase the control system is examined under different conditions. In this stage of work, three samples of concrete are compared: 1- the controlled sample, 2- the sample with a sacrificial Aluminum anode (sacrificial CP system), 3- the unprotected sample.

The type of cement used through out the entire study was Ordinary Egyptian Portland Cement produced by Toura Portland Cement Company, which satisfies the Egyptian Standard Specifications E.S.S 373/1991. It complies to both the British Standard Specification BSS 12/1978 and the American Standard Specifications of Type I Portland Cement designated by the ASTM Standard Specifications C 150. Both the fine and coarse aggregates were from natural local sand and gravel quarries located in Suez, Egypt. The mild steel used in this study complies with ES 262-1988.

The composition of concrete used in this work is content of water /cement ratio one and two. The concrete was mixed at room temperature. After 24 hour, some samples were kept in refrigerator for study the low temperature effect.

4.1. Unprotected Steel

In the first phase of work twenty cubes of concrete with steel bare, ten of them mixed with tap water and the other with seawater are used to study the chloride effect on corrosion.

The 20 cubes 10x10x10 cm remolded after 24 hours and initially cured at room temperature. A 10 mm cross-section mild steel bars placed at the center of the cubes. Anodes are located 25 mm apart from the steel bares. Silver, aluminum, stainless steel, and graphite are used to study the performance of anodes with the various mixed concrete environments. Behavior of corrosion with steel 37 and steel 52 is studied. The ratio of cement to water in the mixed concrete and its effective on corrosion of the reinforced steel is recorded. One sample is subjected to successive wetting and drying cycles in fresh water to study the effect of the cycles on the corrosion rate. The effect of temperature is recorded for one sample at –15 C, and other at 0 C; sample at room temperature is considered as a reference. Reading of results for six months are registered. Another reading is registered after three months more.

4.2 Designing the Control System

The second phase of this Experimental work was the design of integrated circuit comprises monitor, measuring, and controlled power supply to control the reinforced concrete corrosion.

4.2.1. Control Procedure

To measure the potential difference between the reinforced steel and concrete, the optimum location for any reference electrode must be as close to the steel surface as possible without short-circuiting. Wherever it is not possible to ensure this condition it is important to recognize that any potential measured on the face of the concrete surface includes the voltage drop (IR) which is the product of the concrete resistance and local current flow of the CP system. Therefore, potential readings need to be corrected for this voltage drop prior before their use in any criteria.

The common method is to switch off the applied cathodic protection and measure the "instant off" value of the reinforcement potential

The potential of the reinforcement does not instantly revert to its original value. The time taken for the steel to depolarize varies dependent on the composition, porosity and thickness of concrete cover as well as the amount of hydroxyl ions trapped between the concrete and the steel surface [10]. Concrete environment is a variable that can change with time and conditions. Lack of adequate calibration is a common cause of control system mismanagement [11,12].

In this work, the switch off period of the circuit was designed for this purpose, and it has the facility to adjust the time needed to make the protected area retain to its steady state value.There is no critical "off time" when using sacrificial anode because its still protect the steel according to theory of galvanic series.

4.2.2. Reference Electrode

A reference electrode is used in measuring the working electrode potential. A reference electrode should have a constant electrochemical potential as long as no current flows through it. The choice of reference electrode depends on accuracy. In ASTEM C876-80, (American Society for Testing and Materials), the use of Cu/CuSo was clearly approved, but this standard was not attempting to recommend a universal test electrode. Silver-silver chloride reference electrode has now commercially developed [10]. In this proposed system, the anode is used as a reference electrode during off period to measure the corrosion potential.

4.2.3. Aluminum Anode

Study of anodes is out of scope of this work, however the performance of AL anode as a reference electrode at off period was considered. Behavior of aluminum in concrete is similar to Zinc [13-15]. It will be passivated in good quality concrete but may suffer slight deterioration in concrete with high alkali content [16]. No problems occur in carbonated concrete, whereas corrosion risk exists in chloride concrete.

In a present investigation, a method to reduce chloride in concrete has been attempted by using aluminum oxide as a chemical admixture [17]. It is a new advantage for using Aluminum anodes in the protection system.

4.2.4. Testing of System and Proof of Protection

Almost without exception, all the accepted criteria of full cathodic protection of iron are based on a potential measurement. The various recommended practices published by the US National Association of Corrosion Engineers (NACE) and the current British Standard Code of Practice (BSCP) gives the value of steel protection as more negative than 0.85 V with respect to Cu/CuSo, with current applied but minimizing IR error [18,19].

The simplest appraisal of half-cell potential readings is that in ASTEM C876,and in Offshore Technology Report (OTR). The values more positive than –200 mV(assuming Cu/CuSo) are assumed to have a low probability of corrosion, and values more negative than –350mV are assumed to have a high probability of corrosion [20,21]. The above considerations are used in this work, as a proof of valid protection.

4.2.5 Description of the circuit

A simple block diagram is shown in Fig.1. The designed circuit has two connecting terminals; one for connecting with reinforcement steel, and the other to connect with the anode. It has two sensors, one for temperature and the other for humidity as shown in fig.1

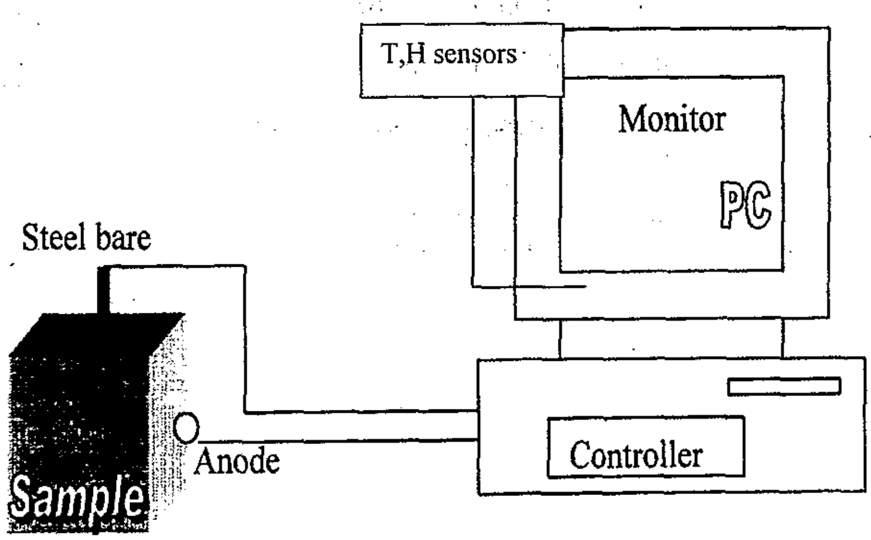

Fig.1 The new integrated system

The main function of this circuit is to measure the potential different between the steel and anode. Then, it gives output voltage equal to the measured value with opposite sign multiplied by a known factor. This factor make the circuit suitable to the different electrochemical protection techniques. It will be 1 in CP technique.

The circuit was designed as a MP based system. The block diagram shown in fig. (2-a) illustrates how the control, the measurement, and the power supply circuits are integrated in one card. Fig. (2-b) is a photocopy of the designed card.

The ADC1001 is a CMOS, 10-bit successive approximation A/D converter. The circuit uses also 8-bit ZN428 Digital to Analog Converter. The output analog voltage is produced by complete PWM power control circuit SG3524.

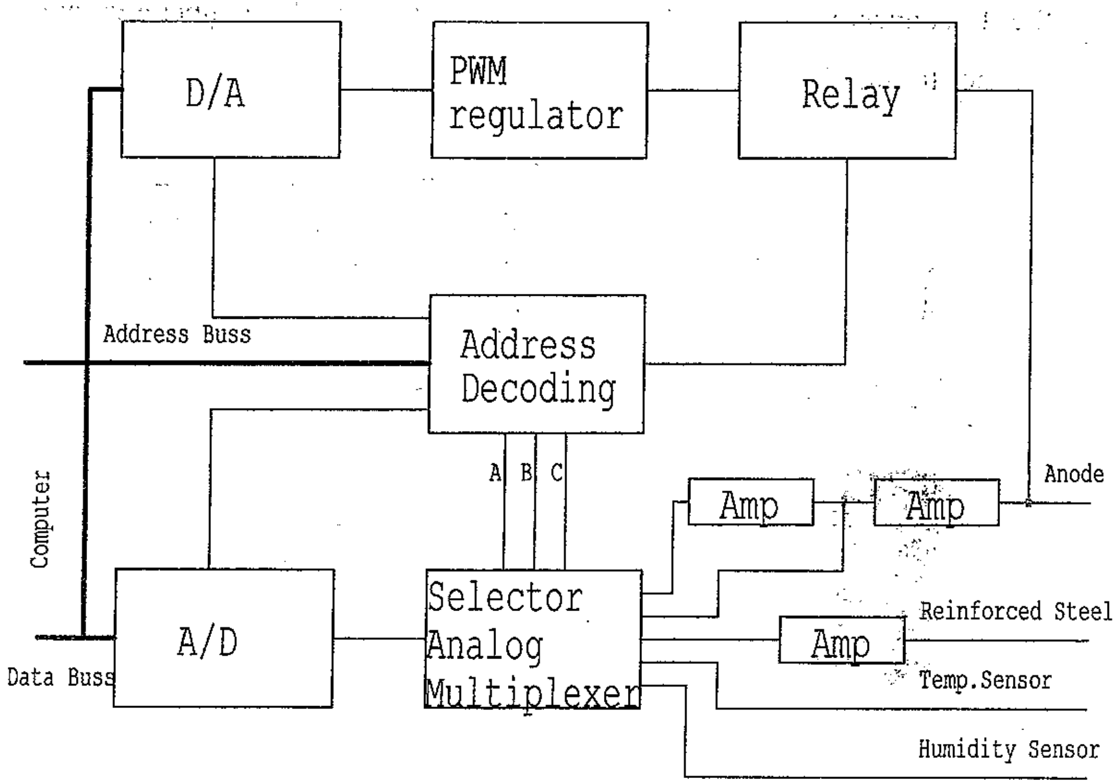

Fig.2.a. Block diagram

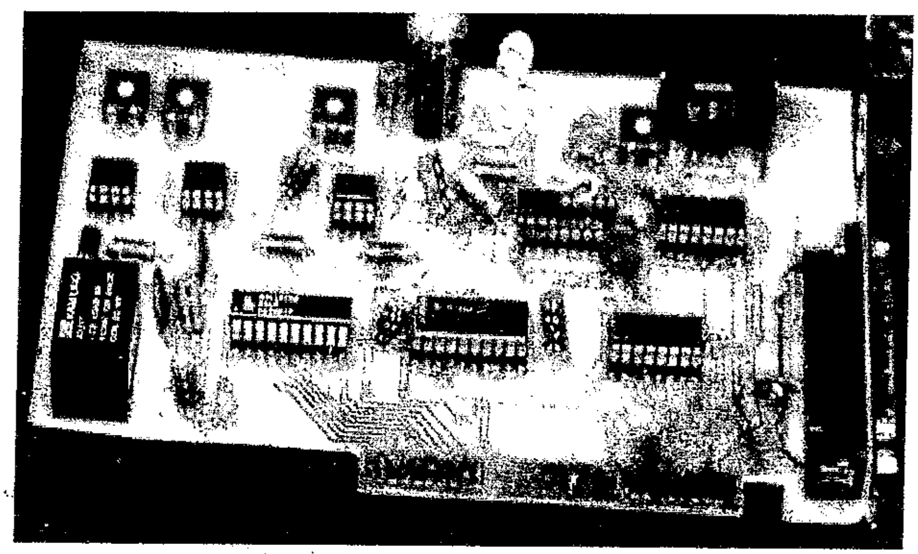

Fig. 2.b. The control circuit

4.2.6 Description of the designed software

The main monitor window program is based on Visual Basic (VB6). Typical print out of the program is showing in Fig.(3). The shown items are:

* Supply voltage: the value of control system potential during impressing the current, measured during "on" period. It read zero at "off" period.

* Concrete voltage: the potential difference between the protected steel and the anode, measured during "off" period of the power supply. It read zero at on period.

* Multiply factor: the factor, which controls the supply voltage. (Supply voltage = concrete voltage multiplied by this factor). The circuit is designed to give a constant 850 mV when the multiply factor chosen as zero.

* Supply current: the impressed current from the control system (computer) to anode.

* Temperature: the value of temperature degree in surrounded weather.

* Humidity: the value of humidity in surrounded weather.

* On-time: the number of hours that the supplay power is on, to impress the current (adjustable period).

* Off-time: the number of hours that the supplay power is off (adjustable period).

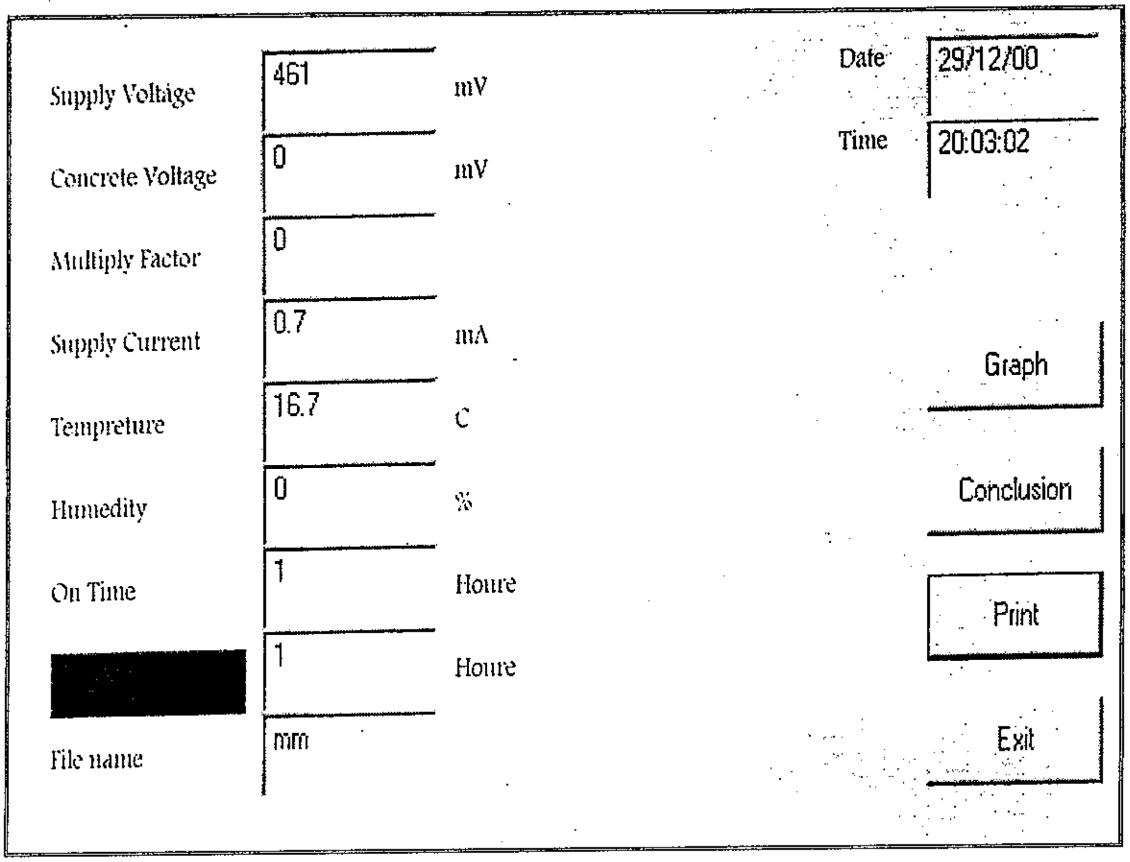

Fig.3-a. The monitor window

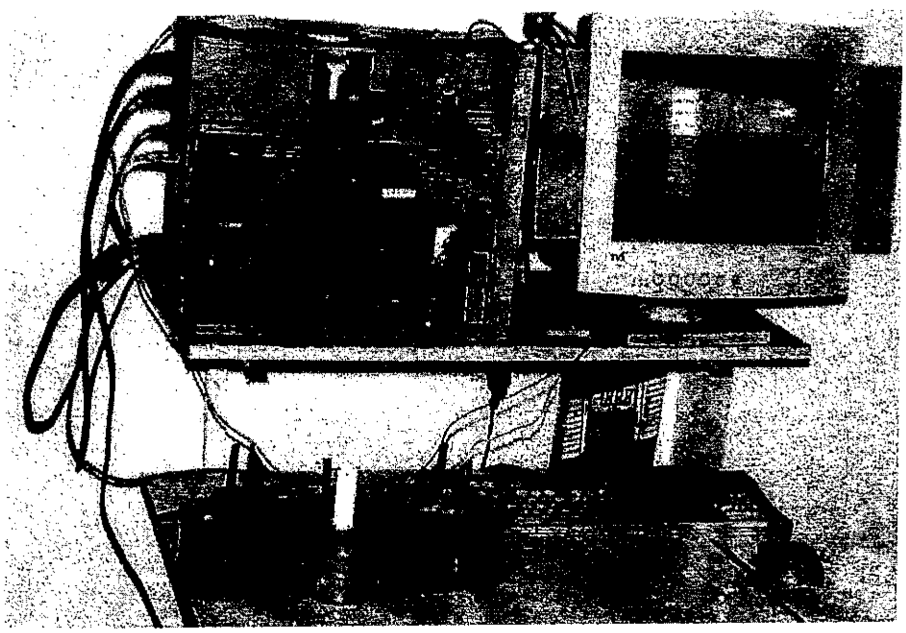

Fig.3-b. MP based system

5. LABORATORY RESULTS AND DISCUSSION

5.1. Unprotected Samples

The results of the study on unprotected samples are considered in the designed proposed circuit.

In the following figures, the steel-to-anode voltages are taken as indication of the corrosion process. The higher voltage means the higher rate of corrosion. This method accepted in many studies according to ASTM C876-87 half-cell method.

Salt effect: If chlorides are present in sufficient quantity, they disrupt the passive film and subject the reinforcing steel to corrosion. The levels of chloride required to initiate corrosion are extremely low. There have been many recommendations, both codes and publications, for maximum chloride concentrations. The American Concrete Institute (ACI) Publication 222R-96 "Corrosion of Metals in Concrete", recommends the chloride limits in new concrete, expressed as a percent by weight of cement for wet conditions 0.10%, and 0.20% for dry conditions.

In this work the ratio of 1.25% used to accelerate the corrosion process. As indicated in Fig. (4), the presence of salt greatly increases the rusting of metals. The range of corrosion voltages is recorded to determine the designed system range.

Performance of anodes: Fig. (5,6,7,8) shows the performance of Graphite, stainless steel, Aluminum, and silver anodes respectively. Fig. (7) shows the constant value between Cu/CuSo reference electrode and Aluminum electrode (anode) against reinforced steel in concrete. That means Al anodes have acceptable accuracy in concrete environment. Hence, the use of Al anode as a reference electrode during off cycle is acceptable. The –ev value is according to its position in the galvanic series.

Type of reinforcement steel: Fig. (9) shows the difference activity at corrosion reaction for two types of steel: steel 37 and steel 60.

Dry wet cycle gives a cycle value shown in Fig. (10).

Temperatures effect for random weather, zero degree, and –15C was registered in Fig. (11).

5.2 Performance of the Proposed Scheme

In the previous section, the unprotected samples were studied to obtain the typical voltage variation under different operation conditions. Consequently the proposed scheme was designed to work with the wrest condition. The power rating is chosen to be capable of supplying the highest possible current.

The integrated computer monitoring system has the advantage of easy using and cheaper solving of corrosion in new or repair location. The wet repairing concrete has probability of corrosion in the first two weeks because the probability of breaking the passive layer of reinforced steel. The designed system controls the different of potential between the steel and the concrete and gives the same generated value (coincident) as shown in Fig. (12). The typical potential of concrete and output means that the system is successful protects the sample. As shown in Fig. (13), the corrosion current was decreased after the concrete drying.

5.3 Visual Observations

Visual examination for the interface between concrete and reinforcement steel showed product of corrosion at the unprotected sample, while no corrosion occur in the protected sample. That means the successful protection of the designed system.

6. FEATURES OF PROPOSED TECHNIQUE

The main contribution of this work is that integrated proposed system. It contains some important advantages when compare with the classic systems which used now as commercial systems in the field of reinforced concrete corrosion protection. These advantages can be listed as follow:

6.1. Simple Card with Ordinary PC

The classic systems contain separate units for power supply, monitor, and control circuit. The wiring and component of these systems are very complicated.

In this proposed system, ordinary computer used as monitor, so the designed of active software makes the same computer a very accuracy control system. The new designed card which fixed on the mother bored of the PC is composing the output voltage of the protection terminals which mean a god controlled power supply, using Pulse Width Modulation technique.

The simple integrated system introduce succeed solving for the problem of the classic complicated system by saving wiring and component.

6.2. Multi Purposed System

There are many forms of electrochemical treatment for stopping the steel corrosion in concrete structures. All these systems depend on impressed current or voltage to the protected steel and a second terminal on the concrete environment. The different of these techniques notes as a difference of the time and value of applied current or voltages. Chloride removal, realkalization, and cathodic protection are the most famous of the electrochemical treatment techniques.

The proposed system is suitable for all these electrochemical treatment techniques because it has the facility of adjust time of power supply and has adjustable multiplier factor which make the output source as a function of the corrosion current according to the designed software program.

6.3. Widely Used System

Cathodic protection can be accomplished by two methods:

By coupling steel with a more active metal such as aluminum. This produces a galvanic cell in which the active metal works as an anode and provides a flux of electrons to the steel, which then becomes the cathode. The cathode is protected.

The second method involves impressing a direct current between anode and the steel to be protected. Since electrons flow to the steel, it is protected from becoming the source of electrons.

The voltage differences between anode and cathode are limited in sacrificial anode system, depending on the anode material and the specific environment. Standard electromotive force series (galvanic series) determine which metal noble (cathodic) or more active (anodic).

The designer of cathodic protection system chose the suitable type according to some variables, for example economic, safety, area, and environment conditions.

In the proposed system, the compound of the two type of cathodic protection makes the system able to work when any of the two systems wanted.

6.4. Safe during Interrupt Power Supply

This proposed system use Aluminum anode which more active or anodic than steel. According to galvanic series, steel is more noble than aluminum and gives potential -0.44 volt while aluminum gives -1.66 volt.

If for any reason the power supply is interrupt, the system will be a sacrificial cathodic protection system.

During the protection process, we need to measure the corrosion potential. The technique of "off" time make the power source off for adjusted time to avoide interference currents.

There is no critical "off time" when using sacrificial anode because its still protect the steel according to theory of galvanic series.

6.5. Direct Measure Saving Reference Electrode

The use of RE in classic techniques has the disadvantage of clearance of IR voltage drop depend on the resistively of concrete and current flow.

The second disadvantage is the complicated of the system.

Third disadvantage is the choice of RE type. In ASTEM C876-80, (American Society for Testing and Materials), the use of Cu/CuSo was clearly approved, but this standard was not attempting to recommend a universal test electrode. Silver-silver chloride reference electrode has now commercially developed.

In this proposed system, the anode is used as a reference electrode during off period to measure the corrosion potential saving the entire problem of classic systems.

6.6. Data Transfer

The system depend on normal CP, which mean the simple connection to the internet for translate the data of the controlled project online. This facility is very important for the observers to control many project at the same time.

7- CONCLUSION

The contribution of this work is the design of Microcomputer based system for measurement, monitoring and pulse width modulated power supply as integrated control system with strong software suitable for different electrochemical control techniques of the reinforced concrete corrosion. The study of reinforced concrete steel corrosion with different conditions was registered. The behavior of Aluminum anode and its stability as a reference electrode was studied. The combination of sacrificial (galvanic) and impressed current cathodic protection was laboratory tested.

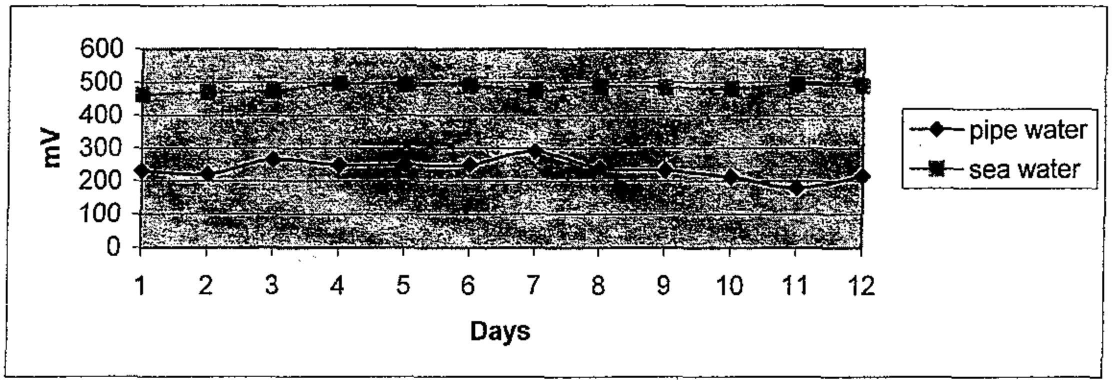

Fig. 4 Effect of salt in concrete

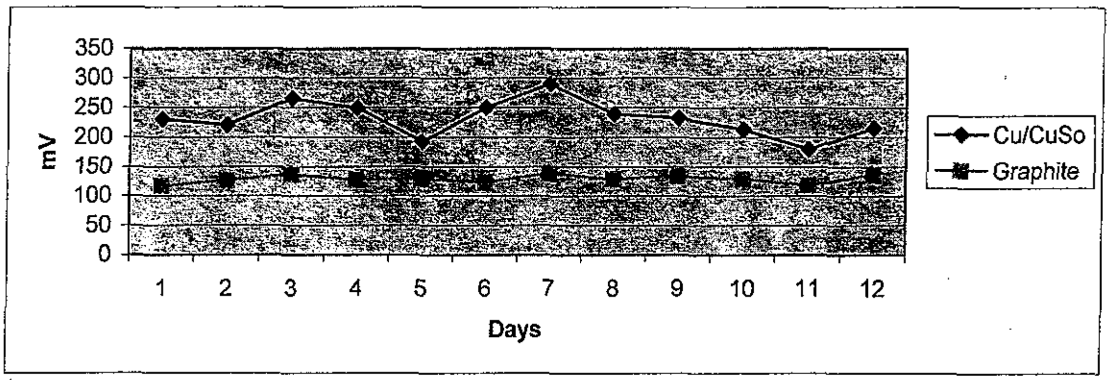

Fig. 5. Graphite anode performance

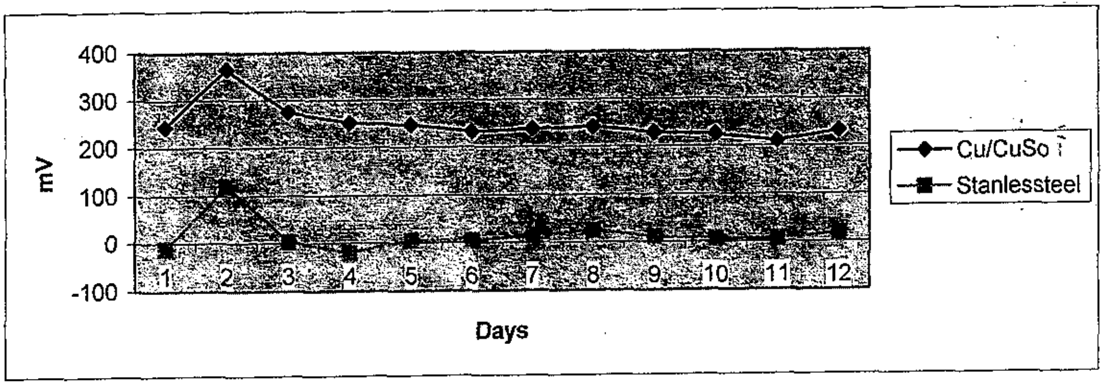

Fig. 6. Stainless steel anode performance

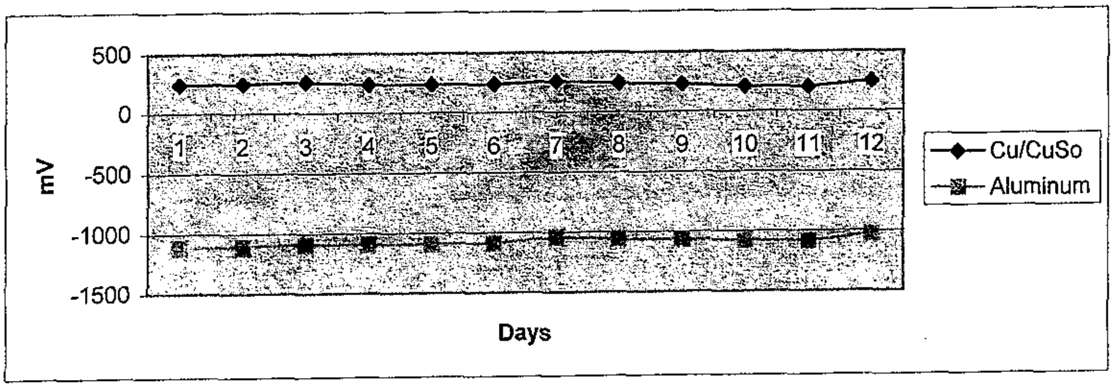

Fig. 7. Aluminum anode performance

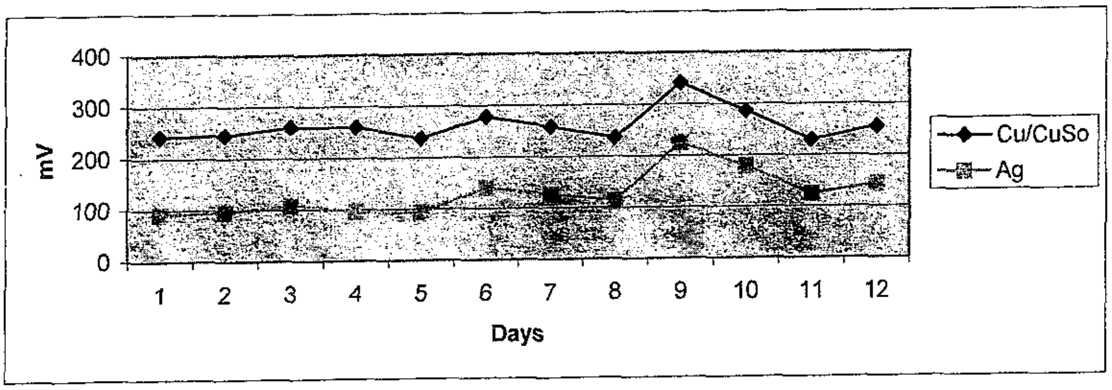

Fig. 8. Silver anode performance

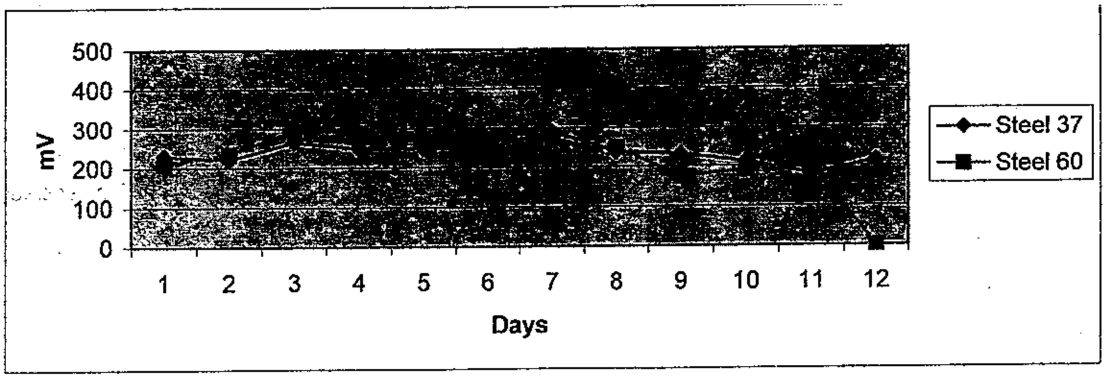

Fig. 9. Type of reinforcement steel effect

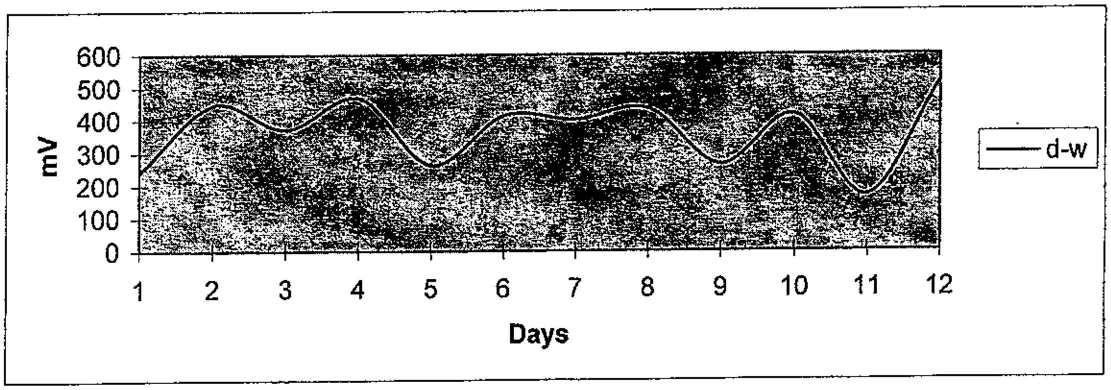

Fig.10. Dry-wet cycle effect

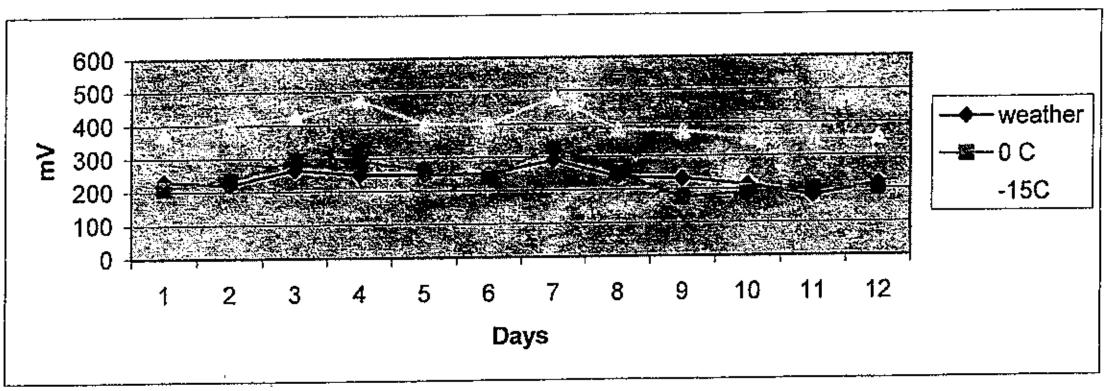

Fig. 11. Temperature effect

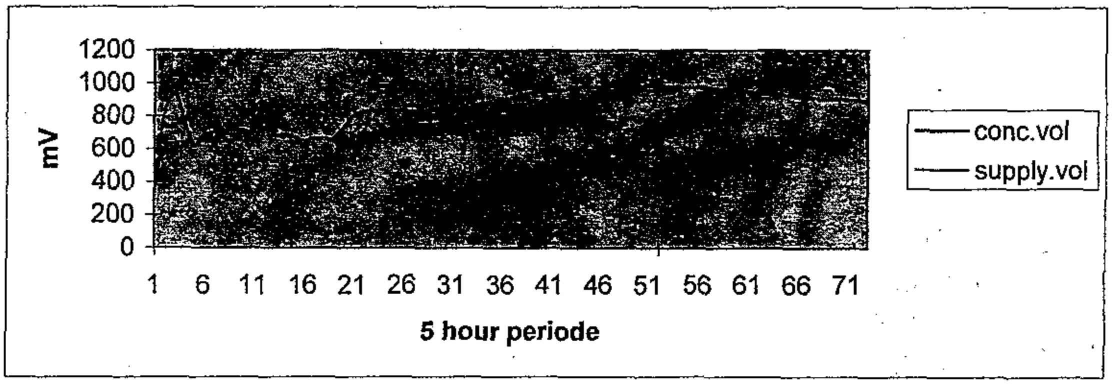

Fig . 12. Performance of the control system

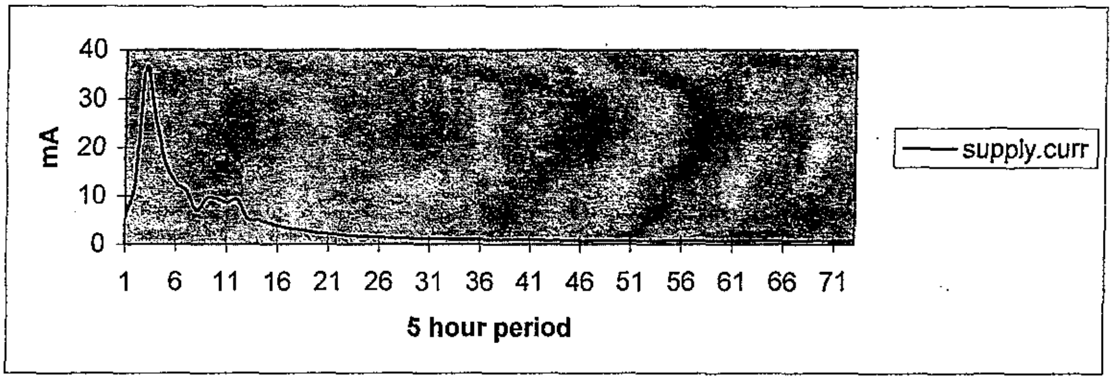

Fig. 13. Impressed current

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نظام مراقبة و حماية معتمد على الكمبيوتر للسيطرة على تآكل الحديد فى الخرسانة المسلحة

ملخص البحـــث :

يعالج البحث مشكلة اقتصادية ضخمة ناتجة عن تآكل حديـد التسـليح داخـل منشـآت الخرسانة المسلحة ، و يقدم حلا مبسطا للمشكلة و خاصة تلك المشكلة المتكونة أثنـاء عملية الترميم للأجزاء المتهالكة من الخرسانة .

يشمل البحث دراسة معملية لأداء حديد التسليح داخل الخرسانة فـى ظـروف مختلفـة ،لإظهار مسببات تآكل حديد التسليح ، و كذلك لتحديد نطاق تغير الجهد لمراعاة ذلك عند تصميم دائرة الحماية و بناء برنامج التحكم الخاص بها ، كما يسجل البحث أداء معـدن الألمونيوم عند استخدامه كآنود داخل الوسط القلوي للخرسانة ، و مدى ثباتـه عنـدما يستخدم كألكترود قياسي و من خلاله يتم ضخ التيار الكهربي اللازم لعملية الحماية ، و ذلك لتوفير الالكترود القياسي المستخدم في الدوائر المشابهة.

و الإضافة العلمية فى هذا البحث تتمثل فى تصميم دائرة كهربيـة بسـيطة و متكاملـة معتمدة على الكمبيوتر الشخصي للتحكم فى تيار الحماية المنبعث ، للسيطرة على عملية تآكل الحديد داخل الخرسانة وفقا لمتطلبات نظام الحماية المستخدم.

و يعتبر استخدام نوعى الحماية الكاثودية معا بمثابة عمل جديد يستفيد من مميزات كـلا النوعين ، فبينما يتميز نوع الأنود المستهلك بالأمان فى العمل ، فان المقاومـة العاليـة للخرسانة تحتم استخدام طريقة ضخ التيار من مصدر خارجى.

و هذه الدائرة و معها برنامج التشغيل الخاص بها مناسـبة لجميـع طـرق الحمايـة الكهروكيميائية ، و قد تم تجربتها بنجاح ، و سجلت النتائج المعملية بالبحث.