Development of an Embeddable Microinstrument for Corrosivity Monitoring in Concrete

The degradation of the reinforced concrete infrastructure of the U.S. represents a monumental cost in terms of unscheduled maintenance and repair as well as a potential public safety concern. This degradation is expected to become increasingly important as the infrastructure continues to age.

Although concrete provides protection to the steel as both a barrier and through the formation of a passivating environment, its presence also complicates detection of corrosion or other degradation. Current technology for the monitoring of concrete corrosivity relies upon either correlation between chemical parameters such as chloride concentration and corrosion rate or upon external measurements of rebar behavior. Although it is generally accepted that chloride ingress leads to the initiation of corrosion, such indirect measures of corrosivity ignore other effects that may dominate in certain situations such as during carbonation.

Measurements of rebar behavior include destructive sampling, potential surveys and electrochemical measurements with reference electrodes or probes embedded in the concrete. Potential surveys can locate areas of active corrosion by sensing the decrease in open circuit potential that occurs when steel begins to corrode in concrete at an appreciable rate. However, conversion of potential survey results into maps of corrosion *rate* cannot be accomplished without additional information concerning the electrochemical parameters of the steel, their spatial variation, and a full galvanic corrosion analysis of the entire reinforcing mat. In addition, such potential surveys are only snapshots in time, and are generally coarse with respect to spatial variations. Embedded, commercially available corrosion measuring probes offer direct measurements of corrosivity of the concrete to which they are exposed. However, the concrete to which they are exposed may not be directly related to the concrete composition adjacent to the reinforcing steel. In addition, the polarization measurements require fairly expensive equipment and highly trained users in order to take into account the effects of uncompensated ohmic potential drop. As with the potential survey, electrochemical probes provide snapshots in time and severely limited spatial resolution. Direct electrochemical measurements of the reinforcing mat have been attempted. However, the complexity of deconvolution of the responses of the various portions of the mat make this approach untenable for widespread practice.

Thus, there exists a need to develop a corrosivity measurement system that can be completely contained within the concrete and provide direct measurements of the corrosivity of the environment in order to provide an early warning system that has information concerning the spatial distribution of the corrosivity. A complete corrosion measurement system should be capable of making accurate measurements not only of electrochemical parameters related to corrosion rate (*e.g.*, polarization resistance), but also simultaneously other important environmental parameters (*e.g.*, temperature, chloride ion concentration, and conductivity). The operator could then use all this information to assess the situation and make a fully informed decision concerning what mitigation strategies, if any, to apply.

A complete corrosion measurement system would therefore have a high-level design as shown in Figure 1 and would contain the following components:

(a) one or more sensors (*e.g.*, for electrochemical measurements of corrosion, pH, temperature, chloride ion concentration, conductivity),
(b) a potentiostat with an autoranging zero resistance ammeter (ZRA) for electrochemical measurements,
(c) high input impedance amplifiers for the various sensors,
(d) analog-to-digital (A/D) and digital-to-analog (D/A) converters,
(e) a microprocessor capable of controlling the electrochemical measurements, managing the measurements from the sensors, integrating the information from the various sensors into an intelligent assessment of the corrosion situation, and communicating with the external world,
(f) a means of communicating with the external world via either a serial communications port or microwave telemetry,
(g) a reliable power source.

Such systems are commercially available. However, these systems are composed of individual instruments, each of which is on the size scale of tens of centimeters. When combined, the measurement system often has a size on the order of 1 meter.

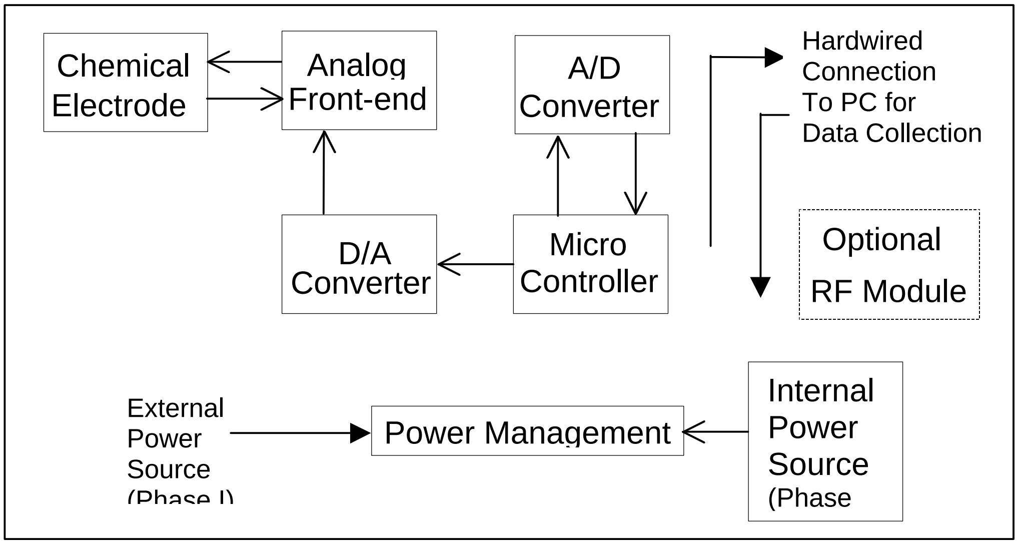

Figure 1. Block Diagram of Corrosion Measurement

In many corrosion monitoring applications, strict constraints are imposed on the size of the monitoring equipment. Such constraints often preclude the monitoring of key structures by conventional corrosion monitoring systems. For example, in the corrosion monitoring of the reinforcing bars in bridge decks, the need to spatially map variations in the corrosion rate puts limits on the size of the probes to be used. In addition, direct measurement of corrosion rate is highly desirable, as opposed to indirect measurements such as external potential mapping or concrete conductivity. High installation expense represents an additional constraint on corrosion monitoring of extensive structures such as bridges, aircraft, chemical plants, and pipelines. Commercially available systems made of large, discrete instruments are not well-suited to the introduction of a large network of independent corrosion monitoring systems. In some instances, it would be advantageous if the entire microsystem were embeddable. Monitoring of corrosive conditions in reinforced concrete or on off-shore structures represent two cases in which the need to have the measurement system physically tethered to an external site (*e.g.*, a data logger or computer) prevents aggressive corrosion monitoring. The limitations on system reliability for such arrangements and the difficulty in sealing the sites at which the tethering cables emerge from the structure can be key hurdles in the implementation of real-time corrosion monitoring in such applications.

The development of an embeddable, intelligent corrosivity measurement system requires a wide range of expertise:

(a) Electrochemistry and corrosion,
(b) Corrosion in reinforced concrete structures
(c) Electrochemical instrumentation and measurement methods,
(d) Digital and analog circuit design, manufacture, and testing,
(e) Electronic system design, integration, and manufacture/production,
(f) Instrument programming,
(g) Field testing.

Our approach to the design of the concrete corrosivity microinstrument followed a set of key tenets:

1. It is more practical and reliable to make direct measurements of corrosivity rather than corrosion of actual structure.
2. By coupling several different types of measurements related to corosivity, the reliability of the overall assessment is increased.
3. We should seek to design circuits to be sufficient for the task rather than to be overendowed with features in order to minimize power consumption. For example, most data processing should be done outside the device.
4. The microinstrument should be made sufficiently small and inexpensive to allow networks of systems to be deployed cost effectively.
5. We should aim to deploy a completely wireless system that is embeddable in the structure during construction or repair; neither communications nor power should require hardwire connections from the device to the outside.
6. The system should be long-lived to allow slow degradation processes to be followed.

Commercial prototypes are being created by Virginia Technologies, Inc., a Charlottesville-based electronic instrumentation company with activities in research, development and manufacturing. Field testing will commence in the spring of 2002.

http://www.vatechnologies.com/corrosion.html