FORCE Technology

– Catalogue for Products related to Corrosion Monitoring in Concrete

FORCE Technology has been deeply involved in the problems of corrosion of steel and other metals cast in concrete since the 1970s. The ever-increasing rise in the amount of corrosion related damage to concrete structures has resulted in continual and expanding development by FORCE Technology in this area.

FORCE Technology offers a wide range of special and advanced techniques for most aspects of concrete condition assessment backed up by decades of experience in different sectors of industry such as bridges, tunnels, nuclear power plants, offshore, housing, harbor structures etc. In this respect the spectrum of technology offered by FORCE Technology is quite unique.

Installation of corrosion sensors in concrete pillar of marine bridge

Services for evaluating corrosion activity in reinforced concrete structures include:

- Electro-chemical methods for assessment of the corrosion condition of reinforcing including Half-Cell Potential measurements and corrosion rate by means of linear polarization measurements

- Permanent monitoring of reinforcement corrosion by means of embedded sensors

- Evaluation of condition and potential durability of concrete structures and preparation of suitable strategies for maintenance and repair

- Laboratory analysis of concrete, measurement of chloride distribution and threshold chloride concentration for initiation of corrosion.

In the following pages alle mentioned products and their applications will be described in details.

ERE 20 Reference Electrode

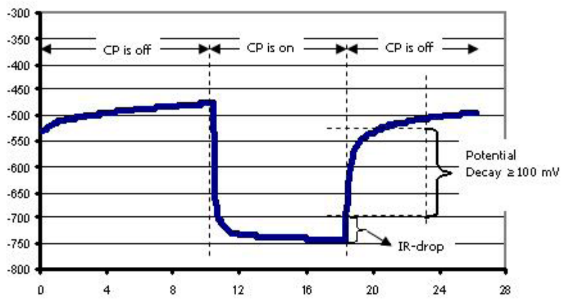
ERE 20 fixed to reinforcement before pouring of concrete

The ERE 20 is a true, long life Reference Electrode, which can be cast into the cover concrete, normally in newly cast in concrete structures, to check the cathodic protection and to monitor the corrosion state of reinforcing steel. The potential of ERE 20 is nearly independent of changes in the chemical properties of the concrete. It can, therefore, be used in wet or dry concrete, whether exposed to chlorides or to carbonation.

Based on proven battery technology, the ERE 20 is a true half-cell using a manganese dioxide electrode in steel housing with an alkaline, chloride-free gel. The steel housing is made of a corrosion resistant material. The pH of the gel corresponds to that of pore water in normal concrete, so errors due to diffusion of ions through the porous plug are eliminated. The ERE 20 can easily be attached to a logger in order to monitor data. Remote monitoring by modem is also possible.

Example

The ERE 20 is used to check the correct operation of the cathodic protection in structures. Figure below shows a typical curve showing the potentials found on checking a CP-system.



Check of cathodic protection by means of potential decay criterium

In this example the current is turned off after 18 hours and the potentials are found to shift 100 mV within 4 hours. Thus, one of the criteria for correct function of the cathodic protection is seen to be fulfilled. According to EN 12696 the Polarisation Decay should be met within 24 hours.

ERE 20 may easily be connected to a data logger to transmit measuring data and remote surveillance via modem is also a possibility.

Furthermore, measurements may be performed by use of a handheld voltmeter with high input impedance (>100 M Ohm).

Advantages:

- Easy to install in new or old structures
- May be exposed to chlorides and carbonation
- Very stabile potential with linear function to pH in the alkaline area
- Suitable for monitoring cathodic protection (EN 12696).

Specifications:

Potential: Typical potential value measured in saturated $Ca(OH)_2$ at 23°C is + 165 mV versus saturated calomel electrode (SCE) equal to + 410 mV in hydrogen scale.

The potential of a single electrode is not expected to be lower than + 150 mV vs SCE and higher than + 200 mV vs SCE. ***Note***: These are typical values measured in saturated $Ca(OH)_2$ at 25°C at time of delivery.

Potential of ERE 20 Reference Electrode is checked prior to shipment and the potential versus saturated calomel electrode is supplied with each electrode.

After installation there is no way in which the potential can be accurately checked, except by comparison with an other ERE 20 electrode in approximately the same position. Comparisons with surface mounted electrodes will give highly variable results, depending on the properties of the concrete surface.

Connecting cable: 5 meters single core, stranded copper conductor (flexible, 2.5 mm^2) with XLPE insulation and PVC sheathing, color: blue.

Other types and lengths of cable can be fitted on request.

Service life: The half-cell is in chemical equilibrium with the surrounding environment. Furthermore the manganese oxide, which exists as a natural mineral in the earth´s crust, will be stable in the long-time period. The life time is governed by the amount of cell electrolyte, which has been set for more than 30 years of service.

Testing of ERE 20 Reference Electrode prior to shipment

Checking of the ERE 20 Reference Electrode before use is carried out in a thermostated bath of saturated calcium hydroxide (min. 2 g/l $Ca(OH)_2$), at 25°C versus a saturated calomel electrode (SCE) using a high impedance voltmeter (min. 10M Ohm). The pH value of the testing solution must be checked prior to measurements. This pH should be approx. 12.4.

ERE 20 Reference Electrode is connected to the volt terminal and saturated calomel electrode is connected to the common terminal of the voltmeter. The potential readings are taken at DC volt with positive polarity.

Major application areas:

ERE 20 reference electrodes for measurements of electrochemical potential were developed under the 2^{nd} EU Framework project that ended by 1986. Since this time more than 15,000 ERE 20 Reference Electrodes have been used world wide to monitor reinforcement corrosion and to control cathodic protection.

CorroWatch Multisensor
Early Warning System for Initial Stages of Corrosion

CorroWatch sensor with four anodes

Principle

The CorroWatch acts as an early warning system to predict the initial stages of corrosion in concrete structures. It is cast into the cover concrete, normally in newly cast concrete structures. The sensor can measure most of the relevant corrosion parameters.

The CorroWatch is a multisensor, which in the standard version consists of four black steel anodes and one noble metal cathode. The anodes are placed in varying, but defined distances from the exposed concrete surface. The height of the anodes is flexible and can be adjusted according to the concrete cover thickness.

To predict when the reinforcement will start corroding, the current between the single anodes and the cathode is measured, either with an ammeter or a specially designed data logger. When corrosion starts, the current will increase significantly.

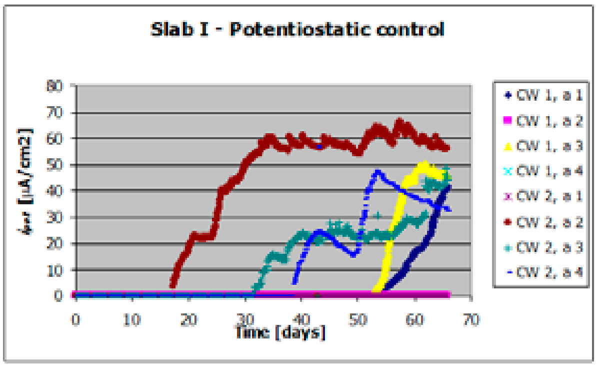
The CorroWatch can easily be attached to a logger for monitoring of data. Remote monitoring by modem is also possible.

Example

The photo below shows the standard CorroWatch with four anodes attached to the reinforcement in a tunnel construction. The photo on page 4 shows CorroWatch with both four and six anodes and also a staircase probe for measurements in casting joints installed in the mould of slabs to be used in laboratory testing.

In the figure on the next page an example of measurements from the above mentioned laboratory test is shown indicating when the corrosion initiates at each of the four CorroWatch anodes.

CorroWatch and ERE 20 fixed to reinforcement in tunnel



CorroWatch measurements of corrosion current

The anodes 1 and 2 had a concrete cover of 18 mm and the anodes 3 and 4 a cover of 15 mm. These small covers are maintained in order to achieve soonest possible the visible results from measurements by means of CorroWatch sensor.

Specifications:

The standard CorroWatch probe is supplied with specifications as follows:

Dimension: Body Ø85 mm, Height 55 mm, Width 165 mm

Cable: Screened 8-conductor, Length 5 m (standard), Colour Black

Anodes: Length 60 mm, Diameter Ø12 mm

Weight: Approx. 0.5 kg

Cathode: Red cable

Rebar's: White cable, if connected

Anode1: Brown cable (about 55 mm high)
Anode 2: Blue cable (about 50 mm high)
Anode 3: Green cable (about 45 mm high)
Anode 4: Yellow cable (about 40 mm high)
Temperature sensor: Pink and Grey cables.

Major application areas:

The major application areas of CorroWatch sensors are in:

- Inaccessible areas e.g. in tunnels and bridges in marine environments
- Structures exposed to de-icing salt, e.g. bridge decks, parking lots and houses
- Structures under great influence of acid rain, e.g. chimneys/funnels/smokestacks
- Bridges in marine environments
- Splash zones, e.g. pillars in sea water.

The major application of CorroWatch to date is Øresund Tunnel where 189 pcs of this sensor were installed in 1998 with aim to detect corrosion in the concrete cover and thus act as a warning system when the corrosion on reinforcement should be expected.

Additionally CorroWatch sensors were installed in a number of medium size highway bridges in Denmark. During the last year the CorroWatch sensors were delivered for installation in the TVO Nuclear Power Plant in Finland to monitor the corrosion in the cooling water channels of a new OL3 reactor.

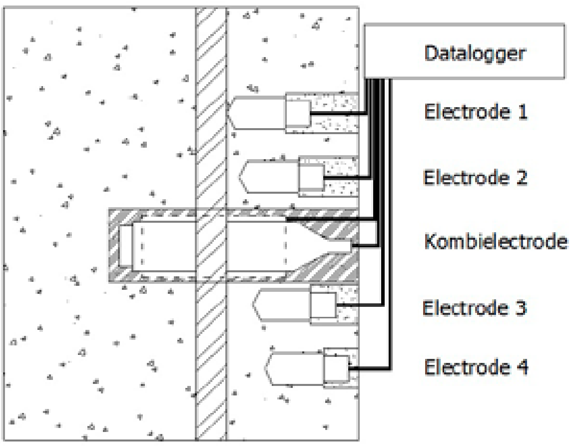
CorroWatch with six and four anodes and staircase sensor for casting joint measurements

CorroRisk sensor for detection of corrosion start in existing concrete structures

Photo of CorroRisk installation on marine bridge pillar

The CorroRisk sensor has been developed for existing concrete structures and is based on the same measuring principle as the CorroWatch sensor for new structures. The probe ensures that reinforcement corrosion may be predicted a long time before it is initiated.

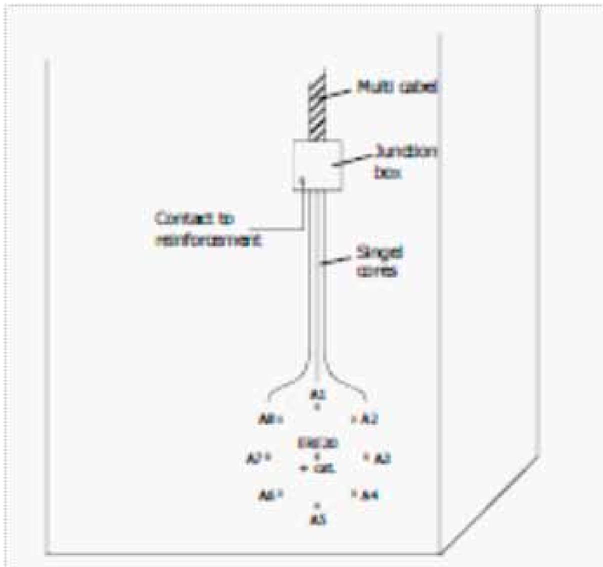
Photo of anodes of CorroRisk sensor



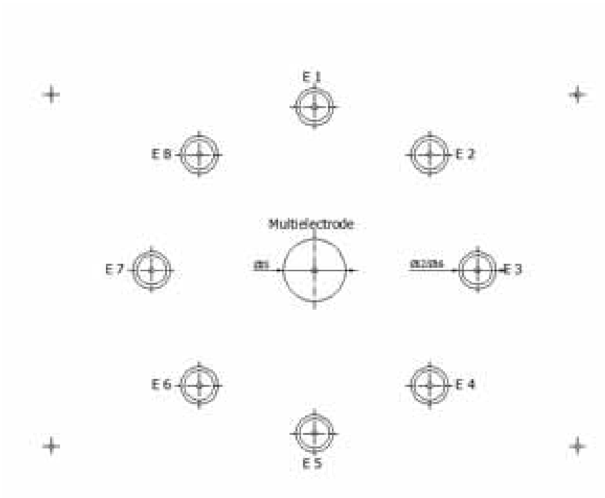
Sketch of CorroRisk sensor

The CorroRisk sensor is usually placed in the concrete cover between the surface and the outermost layer of reinforcement. The measuring electrodes (anodes) are specially designed to be mounted in various, and well-defined depths of the cover layer.

Measurements may be performed by use of handheld Zero Ohm ammeter or by means of a data logger and evaluated by the same principles as illustrated for CorroWatch sensors.



Proposal of arrangement of CorroRisk sensor installation



Cables

We recommend that the cables are protected by a lattice, trays/tubes or in a groove, which are milled directly into the surface. It is possible to extend the cables with suitable, screened cables, and the type depending on conditions.

Marking

When several CorroRisk sensors have been installed, it is very important to mark the individual cables so that no doubt arises as to which sensor each cable belongs. Use the working sheet.

Termination of mounting

A monitoring box is placed in an accessible spot, and all cables are led to the box. The final mounting may take place via a terminal board or directly to a data logger. When choosing materials for this task, it is important to consider any risk of moisture impacts, vandalism and/or the environmental conditions.

Installation check

Via multi-meter the Multi-electrode is connected alternately between the working electrodes. The potential is measured and must not float more than 1 mV/minute, 2 hours after the installation. The values should be noted in the working sheet.

Major application areas:

In general, this probe is recommended for installation in all types of concrete structures exposed to aggressive environment, and in locations where visual inspections are not easily performed. The examples of such applications in Denmark are as follows (the year of installation is written in the bracket:

- Skovdiget highway bridge (2000)
- Sallingssund marine bridge (2004)
- Farø marine bridge (2001)
- Bernstorffslund tunnel (2007).

In Norway the CorroRisk sensors were installed in Sørstraumen marine bridge in 2004. In Croatia the CorroRisk sensors were installed in Dubrovnik bridge in 2010.

In 2011 the CorroRisk Sensors were used in Germany to control the efficiency of a cathodic protection system applied in car park suffering from corrosion problems due to de-icing salts.

CorroZoa
Zero-ohm Ammeter for Measurements on CorroWatch and CorroRisk Sensors

CorroZoa under measurements on site

Principle

Measurements of small currents, in the range of microamperes, with a conventional ammeter result in inaccurate readings due to loading by the meter. Standard measurement devices insert a resistance into the circuit and report the current as the voltage across the resistance divided by the resistance. In most circuits, where a small current measurement is to be taken, the insertion of this resistance by the ammeter can cause significant error.

In contrast to standard devices Zero Ohm Ammeter counters the effect of the inserted resistance by keeping the voltage drop across the input terminals below a few microvolt.

The current used to maintain the null voltage across the terminals is precisely measured, displayed and made available at the output measurement pins. Because there is no burden on the measured circuit, the reported current is extremely precise.

Due to above mentioned properties CorroZoa is an ideal instrument for measuring very small corrosion currents in the range of microampere produced during the measurements by means of CorroWatch and CorroRisk sensors.

Special properties:

- Unique battery-powered instrument for measuring low corrosion current
- Can be preset for measurement of up till 6 carbon steel electrodes
- Possibility of programmed measurement and data collection
- Registers connected values of potential and temperatures
- Measuring results are transferred via USB interface.

Measuring channels:

- Corrosion current and potential, up to 6 channels
- Temperature
- Storing function, up to 999 measurements.

Other specifications:

- Designed for use in harsh environment (IP 65)
- Battery lifetime of approx. 60 hours.

The CorroZoa will run for approx. 200 hours on a fully charged battery at 20 °C. Charge time for a full charge is approx. 2 hours.

CorroZoa specifications:

Voltage input range Current input range	±2000 mV ±2 mA
Input impedance - on state - shut down state	 > 20 Mohm < 100 kohm
Resolution	1 mV / 1uA
Temperature coefficient	< 20 ppm/°C
Power source	Internal NiMH AAA
Battery lifetime	Approx. 200 hours
Auto power down	4 minutes
Start up time	3 seconds
Display refresh rate	1 second
Sealed	IP58
Ambient temperature range when - Measuring - Charging	 -10 to 40 °C - 5 to 40 °C
Size including terminals	H: 40mm W: 85mm L:185mm
Weight	375 g
Log size	999 measurements

Camur II datalogger for permanent corrosion monitoring in concrete

Camur II node

Camur II is a distributed data logger system designed for recording measurements in concrete and controlling cathodic protection systems. It is a scalable system. Cost-effective solutions are available for systems with few or many sensors installed in small or large areas respectively.

Most important features

General:

- Simple and cost-effective cabling (digital bus)
- Galvanic separation between analogue and digital side for trouble-free installation and long term, reliable operation
- Software for monitoring and control
- ERE 20 Reference Electrodes check the cathodic protection and monitor the corrosion state
- CorroWatch/CorroRisk sensors detect corrosion initiation and measure corrosion rate.

Camur II controller

Permanent system:
- Clear trends with continuous measurements
- No operator required, all automatic and remotely controlled.

Distributed & modular:
- Signal may be digitized close to the sensor for best possible signal integrity
- Scalable, easy to adapt and expand
- Plug and play, easy installation.

Monitoring of corrosion by means of CAMUR II and ERE 20 Reference Electrodes

CorroWatch and ERE 20 prepared for measurements with Camur II system

Special features:
- Converts electrochemical potential measured against ERE 20 Reference Electrode to digital value
- Galvanic separation between analogue sensor and digital (bus) side
- Functionality for performing scheduled decay measurements (Cathodic Protection)
- Continuously measures and records potential
- ERE 20 Reference Electrodes may be installed in both new and/or existing concrete structures.

Monitoring by means of CAMUR II and CorroWatch/ CorroRisk probes

Special features:
- One CorroWatch-node can handle one probe
- Each CorroWatch-node also supports the ERE 20 Reference Electrodes and Pt-100 temperature sensors used with CorroWatch probe
- Additionally the CorroWatch node continuously measures corrosion rate at scheduled intervals using LPR (Linear Polarization Resistance) and temperature on the four anodes of the probe
- CorroWatch probes are embedded in the concrete cover of new concrete structures
- CorroRisk probes are developed for use in existing concrete structures.

CorroMap - handheld equipment to measure corrosion rate in concrete

CorroMap equipment

General information:
CorroMap equipment uses galvanostatic pulse Linear Polarisation Resistance technique (LPR) for determination of corrosion current density and thus corrosion rate. LPR can usually be done in less than 5 minutes. This is accomplished by applying a voltage signal to the sample which potential value is very close to the corrosion potential E_{corr}.

The linear polarisation resistance is obtained from the slope of the graph of current versus potential. The bigger the value of the slope, the lower the value of the electrical resistivity. The value of the slope is inversely proportional to the corrosion rate. Qualitative pitting tendency measurement is an advantage to linear polarisation resistance monitoring.

CorroMap instrument is designed to replace the Galva-Pulse instrument that has been on the market since the year 2000. CorroMap instrument is based on the new Psion Workabout Pro terminal with colour touch screen. Unlike

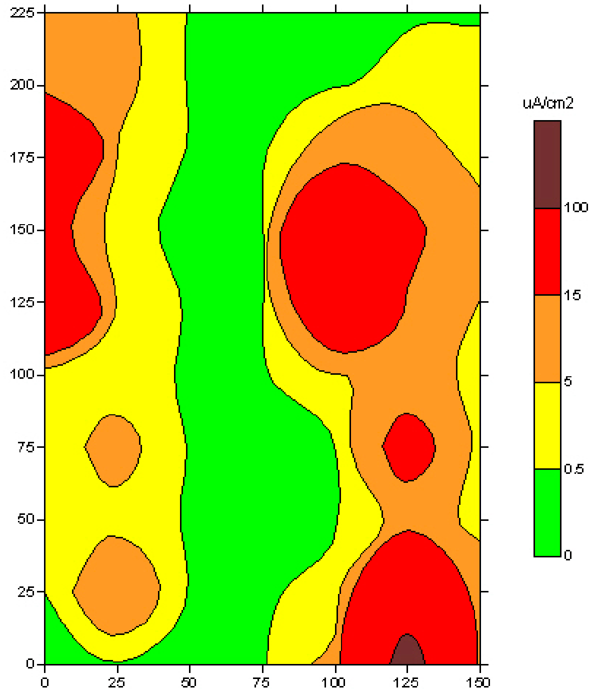
GalvaPulse the CorroMap instrument has no guard ring. The instrument also uses a new algorithm for calculation of polarisation resistance and corrosion rate values.

Special features:

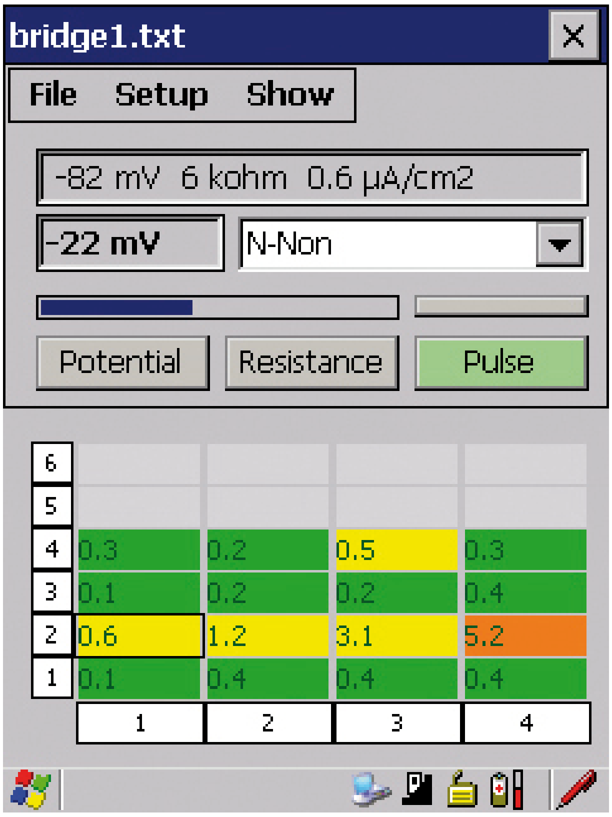
- New handheld Psion Work About PC with Windows CE 5.0 and colour Touch Screen
- Protected against dust, rain and snow (IP 65)
- Up to 2400 automated measurements, one-man operated with "auto trigger" and "auto increment" options
- Can measure related values of corrosion rate, electrochemical potential and electrical resistance
- Estimation of corrosion rate can be carried out in 15 sec.

Overview of evaluation of corrosion condition:

- On site graphic display - in colour
- Each colour represents a measurement interval for corrosion rate, potential and resistance
- Zoom function of detail area with display of measurement values
- Measuring results in Excel-format are easily transferred to PC for further processing and presentation.



Contour plot from concrete deck in swimming pool



Screen picture taken during measuring in "zoom function"

Based on a combination of research and field experience the guidelines for interpretation of corrosion current densities, i_{corr}, measured with the CorroMap are given in the table below. It should be noted that the guidelines in this table cannot be compared with the guidelines for interpretation used by other commercial corrosion rate instruments.

Corrosion rate	Corrosion current density i_{corr} [µA/cm²]
High	... > 15
Medium	5 < ... < 15
Low	1.0 < ... < 5
Negligible	... < 1.0

Although the measured corrosion current densities, i_{corr}, allow for quantitative interpretation of the corrosion rate, variations and gradients in the measured corrosion current densities, i_{corr}, over the surfaces should also be considered (as done for half-cell potential and ohmic resistance measurements).

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