

GERMANN INSTRUMENTS

GalvaPulse[®]

for Corrosion Rate, Half-Cell Potentials and Electrical Resistance

1. Background

The galvanostatic pulse technique was introduced for field application in 1988, ref. (1), to overcome problems with interpretation of the risk of corrosion of reinforcement in RC structures - refs. (2) and (3) - occurring when half cell potential readings are applied in wet, dense or polymer-modified concrete with limited access of oxygen.

Since the introduction of this technique, development work has been conducted in order to allow corrosion rate estimation as well, that is, how much reinforcement steel is being dissolved per year.

Today, the GalvaPulse is a rapid, non-destructive polarization technique for the evaluation of reinforcement corrosion rate, refs. (4), (5) and (6).



Fig. 1. Testing with the GalvaPulse in progress, on site.

2. Principle of GalvaPulse corrosion rate estimation

A short duration anodic current pulse is induced into the reinforcement galvanostatically from a counter electrode placed on the concrete surface together with a reference electrode. The applied current is normally in the range of 5 to 400 μA , and the typical pulse duration is up to 10 seconds.

The small anodic current results in a change of the reinforcement potential, which is recorded as a function of time. The reinforcement is polarized in the anodic direction compared to its free corrosion potential.

A typical potential transient response is shown in fig. 2.

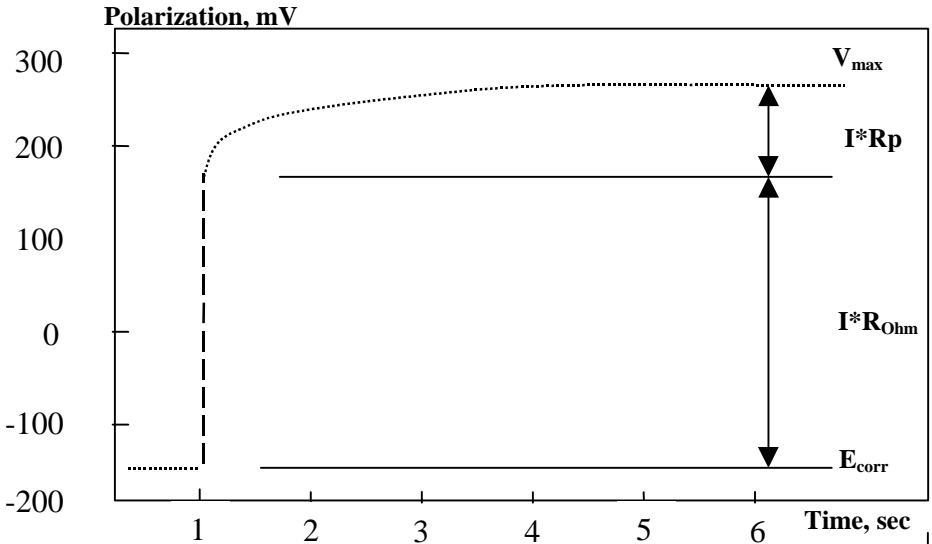


Fig.2 Typical polarization pattern

When the constant current I_{app} is applied to the system, the polarized potential of reinforcement V_t , at given time t , can be expressed as:

$$V_t = I_{app} [R_p [1 - \exp (-t / R_p C_{dl})] + R_{\Omega}] \tag{1}$$

where:

- R_p is the polarization resistance
- C_{dl} the double layer capacitance and
- R_{Ω} the ohmic resistance

In order to obtain the values of R_p and C_{dl} separately from the ohmic resistance R_Ω , equation (1) can be transferred to linear form:

$$\ln(V_{\max} - V_t) = \ln(I_{app} R_p) - t/(R_p C_{dl}) \quad (2)$$

where V_{\max} is the final steady state potential value, fig.3.

Extrapolation of this straight line to $t = 0$, using least square linear regression analysis, produces an intercept corresponding to $\ln(I_{app} R_p)$ and a slope of the line of $1/(R_p C_{dl})$.

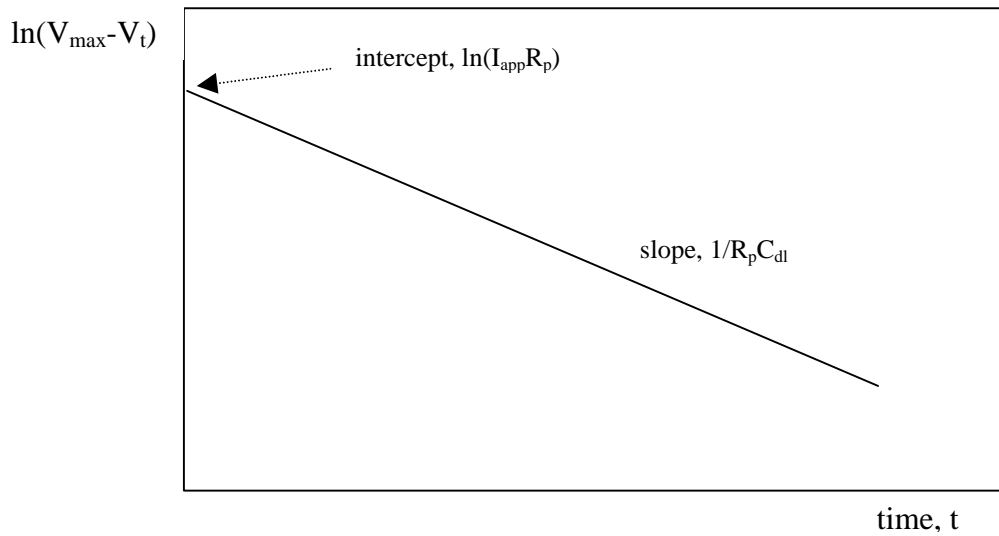


Fig. 3. Transformation for calculation of the $\ln(I_{app} R_p)$ and $1/(R_p C_{dl})$ values

The remaining overpotential corresponds to $I_{app} R_\Omega$, the ohmic voltage drop. After the polarization resistance R_p is determined by means of this analysis, the corrosion current I_{corr} can be calculated from the Stern Geary equation, ref. (7):

$$I_{corr} = B/R_p \quad (3)$$

where B is an empirical constant determined to be 25 mV for actively corroding steel and 50 mV for passive steel.

The DC polarization resistance technique with calculation of the instantaneous corrosion current I_{corr} from the Stern Geary equation, has been used extensively since 1970 for a number of industrial laboratory applications.

When used on RC structures, in-situ, the problem is that the area of the counter electrode is much smaller than that of the working electrode (the reinforcement) and that the electrical signal tends to vanish with increasing distance (cover).

As a result, the measured effective polarization resistance cannot be converted to a corrosion rate, unless a second concentric counter electrode, a “Guard Ring”, is introduced, to confine the current to an area equivalent to the central counter electrode, fig 4.

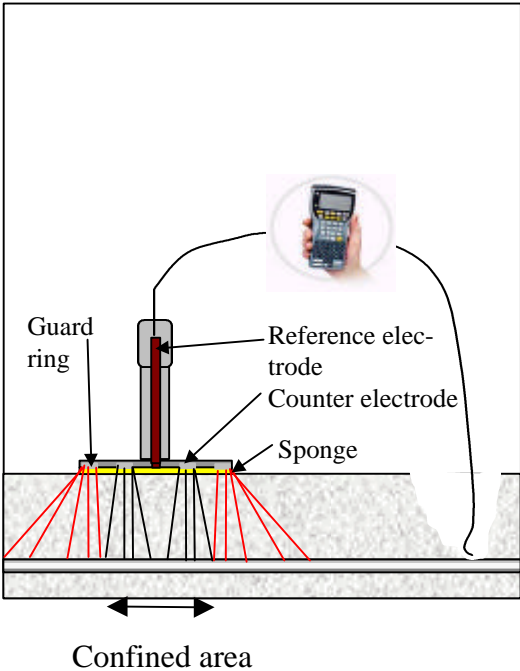


Fig.4. Illustration of the GalvaPulse showing the confined measuring area.

When the diameter of the corroding reinforcement and its exposed length are known, the confined reinforcement area can be calculated.

Faraday’s law of electrochemical equivalence states that $1\mu\text{A}/\text{cm}^2$ corresponds to an approximate cross section loss of $10\ \mu\text{m}/\text{year}$ for black steel. The corrosion rate can therefore be estimated as:

$$\text{Corrosion Rate} \sim 10 \cdot I_{\text{corr}} / A \tag{4}$$

where:

- The corrosion rate is given in $\mu\text{m}/\text{year}$
- “ I_{corr} ” is the corrosion current in μA
- “ A ” is the confined area in cm^2 of the reinforcement

3. GalvaPulse measurements

Besides estimating the corrosion, rate the GalvaPulse simultaneously measures the potential and the electrical resistance of the cover layer.

4. Uncertainties on-site on the corrosion rate estimate

It is important to emphasize that the obtained corrosion rate is an instantaneous measure for the confined area of the reinforcement that applies strictly to the measuring conditions at the time of testing. In this manner, the corrosion rate estimate is an “apparent” one.

Radical changes in the exposure conditions, especially the temperature and the concrete humidity, will alter the I_{corr} by a factor of 100 or more, ref. (8).

Experimental data from on-site measurements has shown that the average corrosion rates determined from the GalvaPulse underestimates the real corrosion rate by a factor of 5-10, or even more in the case of chloride induced, localized corrosion (“pitting”) where the active corroding area is much smaller than the confined area of the reinforcement.

From an engineering point of view such local reduction of reinforcement cross section is dangerous for the safety of structures, especially in zones with high tensile or shear forces.

In addition, it is obvious that erroneous estimation of the area of reinforcement below the guard-ring, e.g., caused by close parallel bars or crossing bars, results in a higher corrosion rate than if a single reinforcement bar is positioned below the guardring.

Cracks and delaminations are often the reason for erroneous corrosion rate estimates as well.

For service life predictions a more detailed knowledge of the daily and seasonal changes of corrosion rate is required in order to obtain meaningful corrosion rates.

It is essential to combine the corrosion rate measurements with a number of other NDT or limited invasive methods to determine the concrete integrity and penetration rates, e.g. of chlorides, or to use post-mounted corrosion and chloride sensors.

5. References

- (1) Elsener B.: "Elektrochemische Methoden zur Bauwerksüberwachung", Zerstörungsfreie Prüfung an Stahlbetonbauwerken, SIA Dokumentation D020, Schweizer Ingenieur- und Architektenverein, Zürich, 1988,27.
- (2) Arup, H.: "Potential Mapping of Reinforced Concrete Structures", The Danish Corrosion Center Report, January 1984
- (3) Hansson, C.M.: "Comments on Electrochemical Measurements of Corrosion of Steel in Concrete", Cement and Concrete Research, Vol.14, 1984, pp 574-584
- (4) Elsener, B., Wojtas, H. & Bohni, H.: "Galvanostatic Pulse Measurements - Rapid on Site Corrosion Monitoring", Corrosion and Corrosion Protection of Steel in Concrete, Vol. 1, pp 236-246, Proceedings of International Conference held at the University of Sheffield, 24-28 July, 1994
- (5) Klinghofer, O.: "In-Situ Monitoring of Reinforcement Corrosion by means of Electro-Chemical Methods", Nordic mini seminar. Lund, February 1995
- (6) Klinghoffer O., Frølund T., Kofoed B.: "Monitoring of reinforcement corrosion by means of embedded sensors and portable polarization technique. International conference: Corrosion and Rehabilitation of Reinforced Concrete Structures. Orlando, December 1998
- (7) Stern, M. & Geary, A.L.: "Electrochemical Polarization. A Theoretical Analysis of Shape of Polarization Curves", Journal of the Electrochemical Society, Vol. 104, 1957, pp 56-63
- (8) Broomfield J P.: "Rebar Corrosion- What Do We Know For Sure ?" International conference: Repair of Concrete Structures. Svolvær, Norway, May 1997
- (9). Klinghoffer O., Frølund T., Rislund E., Elsener B., Y. Schiegg Y., Bohni H.,: "Assessment of reinforcement corrosion by means of galvanostatic pulse technique" International conference: Repair of Concrete Structures. Svolvær, Norway, May 1997