Specification of the
Anode Ladder Corrosion Sensor
Anode-Ladder-System for Corrosion Monitoring
Specifications Status 10/2009

1 General
The Anode-Ladder-System is an advanced system for longterm corrosion monitoring, which has been
developed within an extensive research program at the Institute for Building Materials Research at the RWTH Aachen beginning in 1986 on the basic mechanisms of chloride induced corrosion of steel in concrete under Prof. Dr.-Ing P. Schießl and Prof. Dr.-Ing. M. Raupach. It has been successfully installed worldwide into concrete structures in aggressive environment since 1990. Actually it is the only system with extensive experience from installations on site.

This sensor-system is an embedded macrocell system indicating the depth of the critical chloride content initiating corrosion of the reinforcement. Subsequently the time-to-corrosion of the reinforcement can be determined continuously, enabling the owners of buildings to initiate preventive protection measures before damages like cracks and spalling occur.

2 Equipment for the Anode-Ladder-System
The equipment for the system consists of the following elements:

- Anode Ladder (AL) (Ladder-element with 6 single anodes including a temperature-sensor as main monitoring sensors),
- Cathode Bar (C) (40 cm long platinumoxide-coated titanium bar Ø 8 mm as counter electrode for the electrical measurements against AL and CR),
- Cable connection (between sensors and the terminal box),
- Terminal Box (TBox) for 1 AL including the sockets for the measuring-plug,
- Connection to the Reinforcement (CR) (black steel bar with cable connection to monitor additionally the corrosion behaviour of the reinforcement).
3 Description of the Sensor-Elements (AL, C, CR, TBox)

3.1 General

Generally all single elements of the Anode-Ladder-System are delivered according to the specifications described below. We reserve the right to change details to improve the system.

3.2 Anode Ladder (AL)

The standard Anode Ladder AL consists of 6 single anodes (50 mm black steel bars $\varnothing$ 10 mm). They are fixed together forming a ladder element by two U - shaped stainless steel bars of the type AISI 316.

The ladder element is fixed to the reinforcement using the adjustable stainless steel fixation bar, usually coated with isolating black rubber. The distance of the anode bars to the outer layer of the reinforcement can be adjusted variably by two screws with a standard length of 10 cm. The fixation procedure is described in chapter 5.2.

Each single anode bar is individually connected to measuring wires on both ends. In this way short circuit measurements can be carried out to check the cables and cable connections (redundant system).

To avoid crevice corrosion at both ends of the six single anode bars a heat shrinkage tube is provided.

The measuring wires are collected within the side shafts. After connection of the wires to the anode bars and checking of the electrical contact, the side shafts are filled with transparent epoxy-resin to protect the wires and the temperature sensor against mechanical and chemical attack. One of the side shafts contains a temperature sensor type PT 1000. The requirements for accuracy and long-term-stability of PT 1000 sensors are given in DIN IEC 751.

Three cables are normally led out of each anode ladder. They are of the type:

- $2 \times \text{Li TCT } 6 \times 0.24 \text{ mm}^2$ (2x6 wires from anode bars) and
- $1 \times \text{Li TCT } 2 \times 0.24 \text{ mm}^2$ (2 wires from PT 1000 ) or equivalent.

The material of the covering of the cables is highly durable Teflon. By inserting the cables into the side shafts of the elements and the epoxy resin herein and by inserting the cables into the terminal (or junction) boxes at the other sides, access of water to the inside of the cables is inhibited.

The length of the cables will be adapted to the final position of the elements and the terminal boxes or junction box respectively. The basic length is 1.5 m.
3.3 Connection to the Reinforcement (CR)

The connection to the reinforcement will be used to measure the corrosion behaviour of the reinforcement and the corrosion activity if parts of the reinforcement in the area around the cathode should be depassivated (current and potential measurement between reinforcement connection and cathode). This reinforcement connection consists of a black steel bar which is fixed to the reinforcement by welding or using steel wires (black steel wire).

The cable connection to these bars is established by a soldering connection using rivettes. The connection area is protected by a heat shrinkage tube to avoid the risk of crevice corrosion. Like all steel parts of the sensors except the single anodes the rivettes are of stainless CrNiMo-steel of the type AISI 316.

The two wires are collected within one cable of the type Li TCT 2 * 0,24 mm$^2$ or equivalent. The standard cable length is 1.5 m.

3.4 Cathode Bar (C)

The cathode consists of a 40 cm platinum coated titanium bar $\varnothing$ 8 mm. The type of cables and the cable connections are the same as for the reinforcement connections (see 3.3). The standard cable length is 1.5 m.

3.5 Standard Terminal Box (TBox)

The geometry of the terminal box has been designed as small as possible to ensure that it can be moved through the reinforcement from the sensor location to the final measuring position in most cases.

The terminal box is made of glass-fibre reinforced PE which is resistant against alkalis and chlorides. If the box is closed the special sealing between box and cover ensures water-tightness against spray water according to class IP 65.

To ensure that the cover of the box can be opened and closed without problems after being embedded in the concrete the upper side of the terminal box is covered with a polymer layer (thickness about 4 mm).

Two stainless steel ribbons are connected to the terminal box to allow an easy connection to the existing reinforcement or additionally embedded bars. The terminal box has to be installed in a way, that the upper surface of the polymer protecting the cover of the box is pressed slightly against the mould.

The terminal box contains of one plug used for the regular measurements.
The measuring plug fits only into the socket if it is in the correct position. In this way errors due to wrong plug/socket-connections can be excluded. The upside of the box is manufactured with drilled hole in such way that the plug fits through the hole. The plug is subsequently fixed at the standard box using the enclosed Aluminum ring with inside thread.

4 Positions of the Sensors

4.1 General

The basis for the installation of the sensors for the Anode-Ladder-System is a detailed design including drawings of the sensor positions (AL, C, CR, TBox) and the leading of the cables. Generally the following requirements have to be taken into account:

- It should be avoided to influence the concrete flow significantly by the installed sensors. Especially in vertical structures (walls, piers etc.) the Anode Ladders should be installed in a way that the fixation bar is at the bottom. The other sensors (C, CR) should be installed vertically.
- If possible the sensors should be located in positions, where no poke vibrators are used.
- The sensors should have no electrical contact to the reinforcement except the connection to the reinforcement (CR). Therefore about 4 cm long polymer tubes or other insulating material have to be used as insulation layer around the reinforcement where the sensors are fixed or near the reinforcement.

4.2 Position of the Anode Ladder (AL)

The **Anode Ladder (AL)** has to be positioned, where the corrosion risk by the ingress of aggressive substances into the concrete is monitored (the so called "monitoring location"). The concrete cover for the outer anode A1 should be not less than 10 – 15 mm, preferably **15 mm**. The inner anode A6 should be positioned as near as possible to the outer reinforcement layer.

4.3 Position of the Connection to the Reinforcement (CR)

The bar for the **connection to the reinforcement (CR)** has to be installed on two reinforcement bars which are in direct electrical contact to the reinforcement under the anode ladder. To prevent corrosion problems of the CR it has to be installed a the inner side of the reinforcement.
4.4 Position of the Cathode Bar (C)

The Cathode Bar (C) has to be installed near a concrete surface, where sufficient oxygen is available. If the concrete near the monitoring area, where the Anode Ladder is positioned, is not permanently water saturated, the cathodes should be positioned at the outer side of the outer reinforcement in a horizontal distance of about 50 mm behind the inner anode A6.

In the opposite case, when the concrete near the Anode Ladder is water saturated over long time periods, e. g. at submerged structures or within the tidal zone, the cathodes have to be positioned near another concrete surface which is not water saturated. The distance between Anode Ladder and cathode should be as small as possible and normally not more than about 1 m. If larger distances are necessary, two cathodes can be installed near a dry and not coated concrete surface where sufficient oxygen is available at the surfaces of the cathodes to allow special measurements to check the proper operation of the Anode-Ladder-System under the a. m. conditions.

Generally the cathodes shall be electrically isolated against the reinforcement e. g. by polymer tubes.

4.5 Positions of the Terminal Boxes (TBox)

The Terminal Boxes (TBox) have to be installed as near as possible to the accompanying set of sensors to minimize the cable length. The location of the terminal boxes should allow easy access for the measurements. The internal cable length should normally be as low as possible but not much more than about 20 – 40 m.

5 Installation Procedure for the Anode-Ladder-System

5.1 Order of installation

The elements of the system should be installed in the following order:

- Fixation of the Anode Ladder (AL) at the monitoring location
- Fixation of the accompanying sensors (C, CR)
- Laying of the cables by moving of the Terminal Box from the monitoring location to the final position and fixation of the cables
- Fixation of the terminal box (TBox)
5.2 Fixation of the Anode Ladders (AL)

Step 1: Adjust the inclination of the Anode Ladder by turning the 2 screw heads until the designed cover of the outer single Anode A1 has been reached (to check the correct inclination on site the Anode Ladder can be held against the reinforcement)

Step 2: Fix the two screws in their final position by countering against the nuts

Step 3: Fix the fixation bar (isolated with transparent rubber) to the reinforcement using plastic strips

Step 4: If the distance of the outer reinforcement bars is between about 7 cm to 10 cm the fixation of the other end of the anode ladder (near the inner anode A6) can directly be established by fixing the insulation areas on both sides of the single anode A6 with a length of 3 cm (see enclosed figures) against the reinforcement using plastic strips. If the distance between the outer rebars is different, the anode ladder should be fixed at the following 2 points: firstly against 1 insulation area besides the single anode A6 and 1 outer reinforcing bar and secondly between the insulation area on the other side of the single anode A6 and an added steel bar.

Step 5: Fix the lower end of the anode ladder (near A6) to the reinforcement or if necessary to added steel bars covered by the a. m. isolation tubes using e.g. plastic strips.

Step 6: Check that the 6 single Anodes A1-A6 and especially the inner anode A6 is not in contact with the reinforcement and check that the anode ladder can not be moved after fixation. Fasten or add plastic strips if necessary.

5.3 Fixation of the Cathodes (C)

Step 1: Remove protection cap from Cathode bar

Step 2: Cut about 4 cm long pieces from insulating tubes, slit them over the whole length and put them over the reinforcement at the positions where the cathode will be fixed to the reinforcement

Step 3: Fix the cathode to the reinforcement covered by the tubes using plastic strips (normally each sensor at 2 points) in such way that the cable is at the top side.

Step 4: Check and ensure that the bar can not be moved after fixation.
5.4 Fixation of the Reinforcement Connection (CR)

Step 1: Fix the connection to the reinforcement directly without insulation to the inner side of the reinforcement (normally at 2 points). The fixation can be established by welding, screwable steel connections or using steel wires (black steel).

Step 2: Check and ensure that the connection to the reinforcement can not be moved after fixation.

5.5 Fixation of the Cables

Step 1: Lay the cables always along the reinforcement and not through the space between the rebars. If e.g. cables have to be led from one layer of reinforcement to another, the cables shall be placed along a stirrup. Use only the sides of the reinforcement, where the vibrators will not hit the reinforcement.

Step 2: Fix the cables using not less than two plastic strips per meter against the reinforcement.

5.6 Fixation of the Terminal Box (TBox)

Depending on the specific conditions of the structure, the dimensions and fixation procedure for the terminal- and optionally junction- boxes have to be designed individually. Usually the standard boxes as described in section 3.6 are used.

6 Measurements

6.1 Time Table for Check- and Regular Measurements

Before the regular measurements can be started, two check measurements shall be carried out according to the following scheme:

- Installation of AL, C, CR, cables and TBox
- First check measurements (see 6.2) and taking of pictures of the sensors before casting of the concrete
- Second check measurements after casting of the concrete (see 6.2)
- Regular Measurements (see 6.3)
6.2 Initial Check Measurements

As two wires are connected to each single sensor (single anodes A1-A6, reinforcement connection CR, cathode C, PT 1000 temperature sensor, i.e. altogether 2 times about 9 wires) the system is redundant and short circuit measurements can be carried out to check the proper function of the cables and cable connections. The carry-out of these measurements have been presented to the electrician on site.

6.3 Regular Measurements during Operation

The regular measurements of the sensors can generally be carried out by hand using the CANIN-LTM-instrument developed by the company Proceq in Zurich, Switzerland, for the Anode-Ladder-System which is supplied by S+R Sensortec GmbH. Alternatively the signals can also be measured computer controlled via the phone line directly from the office, but it has to be considered, that only about 1 or 2 readings per year are necessary to monitor the corrosion risk, as it is a longterm monitoring system.

During the whole measurement procedure the following signals are measured:

- the potentials between the six single anodes (A1-A6), the connection to the reinforcement (CR) against the cathode (C), i.e. altogether 7 potentials, (please note that the potentials have always to be measured before the el. currents!),
- the electrical currents between the six single anodes (A1-A6), the reinforcement connection (CR) against the accompanying cathode (C) 5 seconds after coupling (altogether 7 data),
- the AC-resistances of the concrete measured between two neighboured anodes A1-A2, A2-A3, A3-A4, A4-A5, A5-A6 (altogether 5 readings between the six anodes),
- the AC-resistance of the concrete measured between the inner anode A6 (with the highest concrete cover) and the reinforcement (CR) and
- the temperature of the PT 1000 temperature sensor (T).

6.4 Limit Values for Depassivation (Alarm Values)

As the result of extensive laboratory investigations and the installations of the Anode-Ladder-System on site the following limit values for the el. currents have been determined:

- El current 5 sec after coupling < 15 µA 
  (and longterm-current e.g. after 24 h < 1,5 µA) indicate no corrosion,
- el. current 5 sec after coupling > 15 µA 
  (and longterm-current e.g. after 24 h >> 1,5 µA) indicate depassivation.
These limit values are related to usual concretes for non-submerged outdoor structures, when the cathodes are placed besides the Anode-Ladders. For extremely unusual concrete compositions or environmental conditions they may be slightly different.

Especially when the cathode is placed at a dry side and the Anode-Ladder at a wet side of a concrete element, the limit values are much higher! In these cases the significant increase of the el. current combined with the sudden decrease of the potential during depassivation will show the individual limit values.

7 Quality Control for the Sensors
Each single element will be individually produced controlled by an internal quality assurance scheme. Special checks are carried out for:

- sound electrical contact of measuring wires to all single sensor elements and the terminal box and exclusion of short circuits to other metal elements, especially the stainless steel frames of the Anode Ladders and
- soundness of all insulation measures.

8 Identification-Code of the Sensors, optionally
Optionally the standard Anode-Ladders can be provided with an integrated resistor-sensor within one side shaft coated by the epoxy-resin. The resistor shows the Serial-Number of the Anode-Ladder by measuring the el. resistance between Anode A6 and the PT 1000 temperature sensor in [kΩ], usually between pins M-N or F-N of the socket.

The actual design provides a control number for each sensor which is marked on the sensor as well as on the terminal box.

9 Expected Durability of the Materials
With respect to the design life of the monitoring system special materials for the sensors and cables are used which are compatible to concrete and corrosion resistant (chloride contaminated concrete!). All the steel parts are made of CrNiMo-steel which is especially resistant against chlorides. Optimal durability can also be assured for the cables by the teflon-coatings.

The designed and expected lifetime of the sensors and cables embedded in the concrete should be higher than 100 years.
Anode-Ladder-System for Corrosion Monitoring

Typical form for measurements of the Anode-Ladder-System

<table>
<thead>
<tr>
<th>Anode-Ladder-No.:</th>
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I.) Short Circuit Tests

<table>
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<td></td>
<td>☐</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>A2</td>
<td></td>
<td>☐</td>
<td></td>
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<tr>
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<td>CR</td>
<td></td>
<td>☐</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>TEMP</td>
<td></td>
<td>☐</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>(REF)</td>
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II.) Measurements

<table>
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<th>Measurement</th>
<th>Value</th>
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</tr>
<tr>
<td>2</td>
<td>A2-C</td>
<td>Potential (Voltage) in mV</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>A3-C</td>
<td>Potential (Voltage) in mV</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>A4-C</td>
<td>Potential (Voltage) in mV</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>A5-C</td>
<td>Potential (Voltage) in mV</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>A6-C</td>
<td>Potential (Voltage) in mV</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>CR-C</td>
<td>Potential (Voltage) in mV</td>
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</tr>
<tr>
<td>8</td>
<td>(REF-C)</td>
<td>Potential (Voltage) in mV</td>
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<td>A1-C</td>
<td>El. Current after 5 sec. in µA</td>
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<td>A2-C</td>
<td>El. Current after 5 sec. in µA</td>
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<tr>
<td>11</td>
<td>A3-C</td>
<td>El. Current after 5 sec. in µA</td>
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<td>Resistance [Ω] / Temp. [°C]</td>
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<td>A1-A2</td>
<td>AC-Resistance in Ω</td>
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<tr>
<td>22</td>
<td>A6-CR</td>
<td>AC-Resistance in Ω</td>
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Date: Signature:
Example for Installation of the Sensor-
(not water saturated conditions)
Example for Installation of the Sensor-
(water saturated conditions)
Anode-Ladder-System for Corrosion Monitoring

Typical Design of the Layout of the Sensor Positions

Configuration Layout of Plug
Fixation of the Anode-Ladder (Trial Installation without Cable Fixation)

Fixation of Anode Ladder with Insulation Tube
Fixation of Cathode with Insulation Tube