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”Corrosion problems and corrosion mitigation experiences on 6Mo stainless steel seawater systems on the Sleipner platforms-North Sea”

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ABSTRACT

Sleipner A was installed in 1992/93. The seawater piping was made in 6Mo stainless steel with some 25Cr duplex valves. The piping system contained chlorinated seawater. After approx. 18 months in service several leaks were observed in the firewater system due to crevice corrosion in valve components, flange sealing areas and threaded components.

To avoid more leaks it was decided to install internal cathodic protection in both the firewater and seawater systems. In 1996 Resistor controlled Cathodic Protection - RCP was installed using available flanges and fitting access points. This was one of the pilots in the early phase of the Resistor controlled Cathodic Protection system designs. The design gave a range of anode lifetimes from 5 to 30 years. The paper will review 10 years of operational experiences from the Sleipner A & T platforms, from solving some initial problems with the CP system, through historical monitoring data with comparisons between monitoring data and design values and change out of anodes after ended lifetime.

Keywords; Resistor controlled Cathodic Protection, 6Mo stainless steel, chlorinated seawater piping

INTRODUCTION

Sleipner A, the first of three platforms on the Sleipner field was commissioned in 1992 and 1993. At that time stainless steel alloys like austenitic 254 SMO and 25 Cr super duplex steel were widely used in seawater piping systems on offshore oil and gas installations in the North sea, so also on the Sleipner platforms where the seawater piping consist of 6Mo stainless steel with some 25 Cr duplex valves with PRE values down to 36. These alloys where in general qualified and accepted for use in chlorinates seawater systems for temperatures up to 30-53 ^{o}C. However, after relatively short time one could experience extensive corrosion attacks on many seawater systems even if the temperatures just periodically peaked above the defined temperature range, but also at temperatures below 30-35 ^{o}C. This lead to development of the galvanic resistor controlled cathodic protection system now known as RCP^{TM}.

CATHODIC PROTECTION DESIGN FOR STAINLESS STEELS

General

This paper will not treat cathodic protection designs for stainless steels. It is however appropriate to state that for several years it has been accepted that stainless steel can be cathodically protected with potentials far more positive than carbon steel, and with only 1-4% of the current density values for carbon steel. There are several options for cathodic protection of stainless steel. Stainless steel seawater piping and components such as filters, strainers, pumps and also heat exchanger tubing can be very well cathodically protected for a long operational lifetime with a special designed CP system as installed on the Sleipner platforms.. This patented system consists of galvanic Zinc anodes where the current is controlled by a specifically designed resistor. More detailed description and history of the system is described elsewhere /1 -6/. A schematic sketch of the principle is shown in Figure 1.

DESCRIPTION OF THE SLEIPNER CATHODIC PROTECTION SYSTEM

The actual CP system treated in this paper is quite extensive with a total of 418 anodes whereof 345 flange mounted anodes and 73 anodes mounted in NPT fittings. As of today a total of 135 flange mounted anodes have been selected for monitoring. The NPT fitted anodes cannot be monitored as they have no accessible connector.

The upper cathodic protection potential limit for the 6Mo is considered to be 100 mV SCE. The different types of anodes designed for the project, flange mounted and NPT fitted were fitted into existing available nozzles and fittings. Further one calculated the current demand for each pipe sections from those available nozzles to the point where current from other anodes would meet in order to maintain a potential below 100 mV SCE on sections farthest from the anodes. All design calculations, current demand, required anode potentials and thus the resistor value of each anode were done manually in spread sheets by the inventors of this system. The spreadsheets show that a pipe potential between -50 mV SCE and -800 mV SCE was used in the design calculations to ensure a conservative design.

MONITORING THEORY

Monitoring of the CP systems performance is done by recording the voltage drop over the anode resistors. On the Sleipner platforms this is now carried out annually and the data is analysed and trended by the vendor. In addition to the anodes voltage drops, the residual chlorine level and seawater temperature are essential parameters affecting the performance of the CP system. The data form a basis for planning replacement of anodes and evaluating the potential level and protective range from the anodes. Analysis of the CP systems performance is based on the following:

- The pipe potential is monitored by measuring the anode voltage drop. The relationship is shown in equation (1):

$$E_{(pipe\text{-}SCE)} = -1000 \text{ mV} + \Delta E_{(measured)} \qquad (1)$$

Where
- $E_{(pipe\text{-}SCE)}$ = pipe potential with reference to Saturated Calomel Electrode
- -1000mV = the natural Zinc potential in seawater with reference to Saturated Calomel Electrode$^{1)}$
- $\Delta E_{(measured)}$ = the designed anode voltage drop

- In addition the anode current output, anode mass consumption and remaining lifetime of the anodes is calculated. The current output from the anode is calculated by Ohms law:

$$I = \Delta E/R \qquad (2)$$

Where:
- I = Curren output (mA)
- ΔE = the measured voltage drop over the anodes resistor (mV)
- R = installed resistor (Ohms) = $R_{(installed)}$

The calculated current output is then utilized to calculate the anode lifetime (L) by the following equation 3:

$$L = (M \times U \times \theta) / (I \times 8760) \qquad (3)$$

Where: M = net mass of anode
U = utilization factor
θ = electrochemical efficiency
I = calculated current output (mA) from equation (3) above

The accuracy of the calculated lifetime of an RCP anode can be increased by use of an average value of the anode current output defined from a series of measurements over time.

PRACTICAL EXPERIENCES IN OPERATION AND MAINTENANCE

The actual CP system in operation

The galvanic CP system is kept in operation by:

1. Replacing anodes at the end of their design life
2. Measurement of anode voltage drop

1. Replacement of anodes

The variation in anode lifetime from 3 to 30 years poses an operational challenge. A system to keep track of which anode to change when is the first necessity. This was originally done in an excel-program with lists showing the replacement history and expected end-of-life for all anodes. The follow up of the CP systems performance has later been handed over to the vendor where all data and analysis are being treated in a special designed data base. This will be shown in the sections below.

The firewater system is a closed loop with supply from either side. Isolation of any anode for replacement is therefore easy without affecting the availability of the firewater. Unfortunately, this does not apply for system 50, seawater cooling. Some anodes are placed in small pipes or in branches which are easily isolated and drained. Others are placed in main headers or in central areas which may not be accessed without closing down the entire seawater system. Even during a platform shut-down, seawater is needed for crucial functions such as fresh water production and power generation. Therefore, replacement of anodes in system 50 requires careful planning and coordination with other maintenance activities.

A heat exchanger maintenance program in the summer 2004 turnaround (TN4S), implicated significant rerouting of the seawater system with temporary hoses. At the same time, a lot of anodes ended their design life between 2004 and 2006. All anode replacements up to and including 2006 in the rerouting area was therefore included in TN4S and installed while the seawater system was drained and easily accessible. This totalled 75 anodes ranging from ¾” plugs to 3” flange anodes. Due to the large quantity of anodes a delivery time of 3-6 months had be taken into account. Close cooperation between supplier, maintenance planners and offshore crew was a crucial success factor.

2. Anode voltage drop measurements

In total there are four systems; seawater and firewater on SLA and SLT. Voltage drop measurements were made on 6 anodes for each system twice a year the first years of operation. This is replaced by annual measurements on all anodes with measurement ports. This gives a better view of the potential profile throughout the system, and also enables numerical analysis with FDM (Finite Difference Modeling) carried out with computer simulations of suspected problem areas.

In general the measurements are useful to monitor the anode performance. However, some pitfalls have been found. The potential is measured across a resistor and as such represents the current output from the anode. Low voltage drop readings mean low anode consumption and may be interpreted as a good sign with plenty of anode lifetime to go. High voltage drops on the other hand may be problematic because of a high ohmic drop which may cause the pipe potential to rise above the protective limit. On this background a maximum acceptable voltage drop of 900mV SCE was set, but a minimum acceptable voltage drop was not considered. However, a low voltage drop may also mean that the anode is passivated and does not provide the necessary current output. Indeed this was seen on several large anodes upon replacement, ref picture 1. It was also seen after shut-downs or periods with irregular flow. These upsets caused mechanical removal of oxides from the anode thereby an increased voltage drop as the anode current output increased. On this background a minimum acceptable voltage drop of 200 and 100 mV for the seawater cooling and firewater respectively was imposed. The latter is based on that a low voltage drop, say 100 mV, which theoretically may indicate a very good piping potential (-1000 [1)] mV + 100 mV = -900 mV SCE (see equation (1) above), but which experience has shown may come from passivation of the anode by oxide deposits.

Some difficulties are seen with the old measuring ports with 6-pin configuration, see picture 1. Due to water collection in the port, some ports have a poor or lost connection which gives faulty or no

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[1] -1000 mv is chosen as a conservative free Zinc potential vs SCE. In theory the free Zinc potential in see water vs. SCE is -1050 mV

potential readings. This problem is solved in the new anodes with replaceable anode resistances and jack plug connections.

Experience from retrieved anodes

Anodes have been replaced every year since 1999. This is attributed to the mentioned span in design life, with the lowest of only 3 years.

The replaced anodes ranges from ¾” plug or cap to 4” anodes. The smallest anodes have performed as expected, and are normally fully consumed when removed. The only disadvantage, apart from the short design life, has been the occasional broken anode. Picture 2 shows examples of ¾” anodes.

The larger anodes were originally installed with a protective cover to avoid pieces of the anode falling off, ref pictures 3-4. This design was not successful because;

1. The cover in several cases became brittle and broke off.
2. The perforated end-plate was poorly fastened, causing it to fall off more often than not.
3. The cover caused the Zinc oxides to accumulated and eventually passivate the anode.

The passivation of the large anodes reduce the current output and thereby the ability to protect the surrounding piping. Picture 5 show a leak discovered in a 18” seawater pipe which should be protected by a 4” flanged RCP anode. The anode was also placed about 8 m downstream the leak. It had a design life of 15 years, but when measured after 8 years it showed a potential of only 180 mV. This indicated that it did not deliver the necessary current to provide adequate protection to the entire piping sections as designed for and may explain the observed leak.

Optimisation of data analysis

As mentioned above recordings, trending and analysis of the CP system’s performance have now been transferred to a special designed data base which is programmed with the generic equations above, and thus carries out the following adequate calculations;

- Anode current output
- Maximum, minimum and average voltage drop reading
- Number of voltage drop recordings
- Remaining lifetime

In the database the upper and lower anode voltage drop limits have been set to 900 mV and 100 mV respectively which automatically generates recommended actions. These voltage drop limitations deviates some from the acceptance criterias set in the original design, and are based on the following:

- Upper limit of 900 mV: This voltage drop might indicates a high current output with possible a too positive potential. A recommended action of visual control is generated by the database to visually check the anode consumption and the anodes condition.
- Lower limit of 100 mV: This voltage drop gives a theoretical long remaining lifetime of the anodes which might not be true. Practical experiences have also revealed that one can see such values if the anodes are to some extent passivated, and also when the Zinc anodes are almost completely consumed. Therefore an automatic recommendation of replacing the anode is generated regardless of the theoretically calculated remaining anode life.

Examples from the database are shown in figure 2, Sleipner A firewater, and figure 3, Sleipner T seawater respectively. The calculations listed above are visible above the graphical plot for each anode in the actual module where the anodes are located. Hence, they can also easily be traced on the platform when actions are sent over to the operator.

In figure 2 one can see several fluctuations on the anodes voltage drop. This is normal and accepted on firewater systems as they face partly stagnant seawater for periods where the chlorine and oxygen will be consumed. Anode number 71-EU-096 clearly show the trend of a decreasing voltage drop, especially after 2004 which for the analyser indicate that this anode must be followed more closely, and might be due for replacement shortly. For anode number 71-EU-002 one can see that only two readings have been done since 1996.

In figure 3, showing a selection of anodes from the seawater cooling system one can see more stable readings where most of the anodes show a decreasing voltage drop from 2005.

In addition to the database analysis selected pipe sections are modelled in a Finite Difference Software where the exact piping lay out is modelled. Here the results are shown as potential distribution colour plots throughout the piping system.

MECHANICAL IMPROVEMENTS OF THE CP SYSTEM

The experiences with partly or extensive passivation of anodes on Sleipner and also other installation from the same period in the 90`ies and also some requests for a more flexible system executed several changes on this special CP system. As a first step the front screen seen in picture 3 was removed to prevent clogging of Zinc oxide on the anode surface, see picture 6. Later also the entire anode housing has been permanently removed to allow flushing seawater to wash the Zinc surface, and to get a more uniform consumption of the Zinc mass. Furthermore the Zinc mass is now replaceable, so rather than replacing the entire component with the blind flange one now mount on a new Zinc anode on the existing flange and anode holder, see picture 6. This has been important in order to reduce the replacement costs and delivery times of these special CP systems. In addition the connector with the jack plugs for monitoring has been made interchangeable allowing the anode characteristics to be changed by changing the resistor if analysis results should require changes, or if the seawater parameters changes.

CONCLUSIONS

- The RCP system has provided protection for the Sleipner seawater and firewater for more than 10 years, thereby avoiding replacement of the piping with a more noble and costly alloy.

- The RCP has system has performed as expected with respect to anode lifetime and replacement of anodes. However, some problems are seen with passivation of the old type of anodes due to build-up of oxides.

- Some debris from damaged anodes has entered the piping system, but this has not caused any operational problems.

- The RCP system requires follow-up with potential readings and deaeration of anodes. Replacement of anodes may be challenging due to limited access/no downtime on seawater system.

- The data trending and analysis carried out with the data base, and additional computer simulations have been found useful for evaluating the performance of the CP system, and also to plan the anode replacements.

- Mechanical changes are made on the new anodes to avoid passivation problems and improve replacement flexibility and cost.

- Cooperation between the operator and the anode vendor has been successful and ensured an optimised data analysis and operation of the CP system.

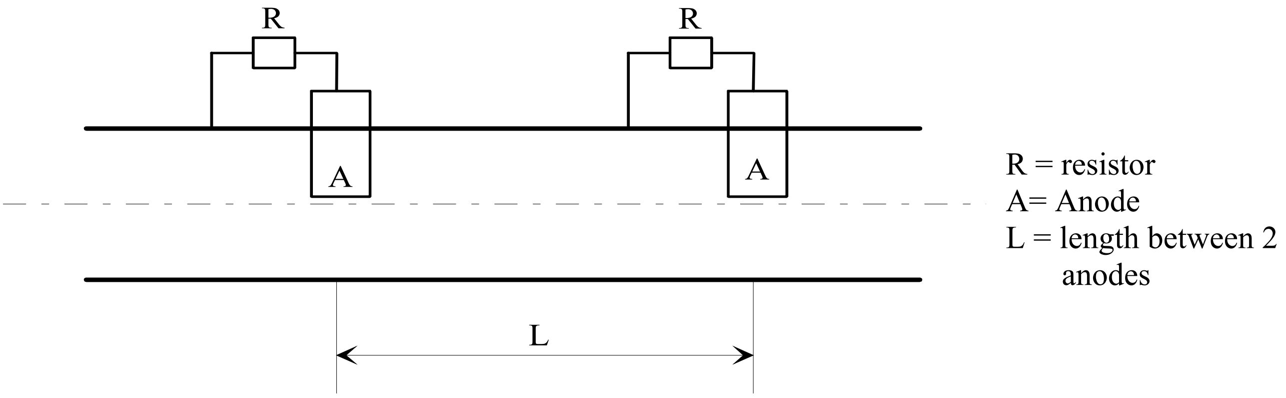
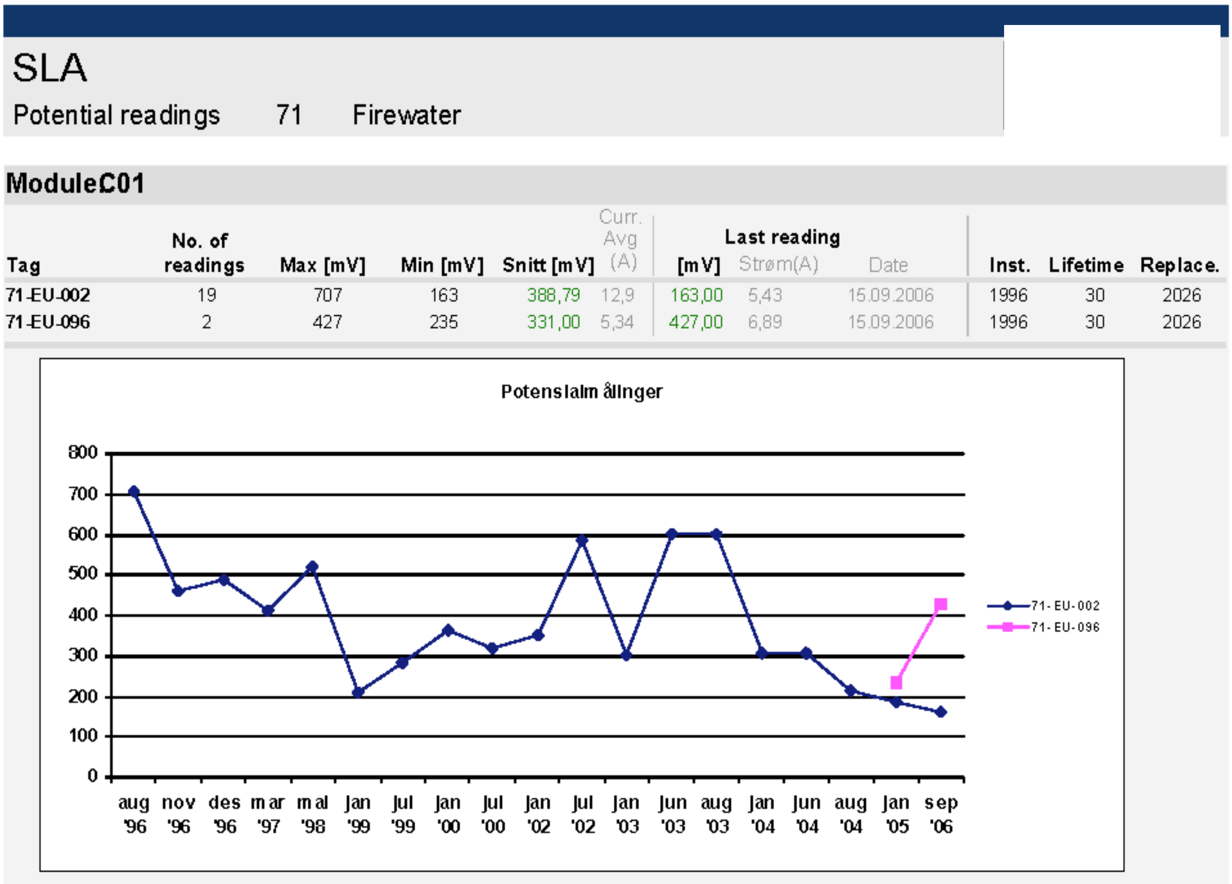


Figure 1: Schematics of the RCP principle



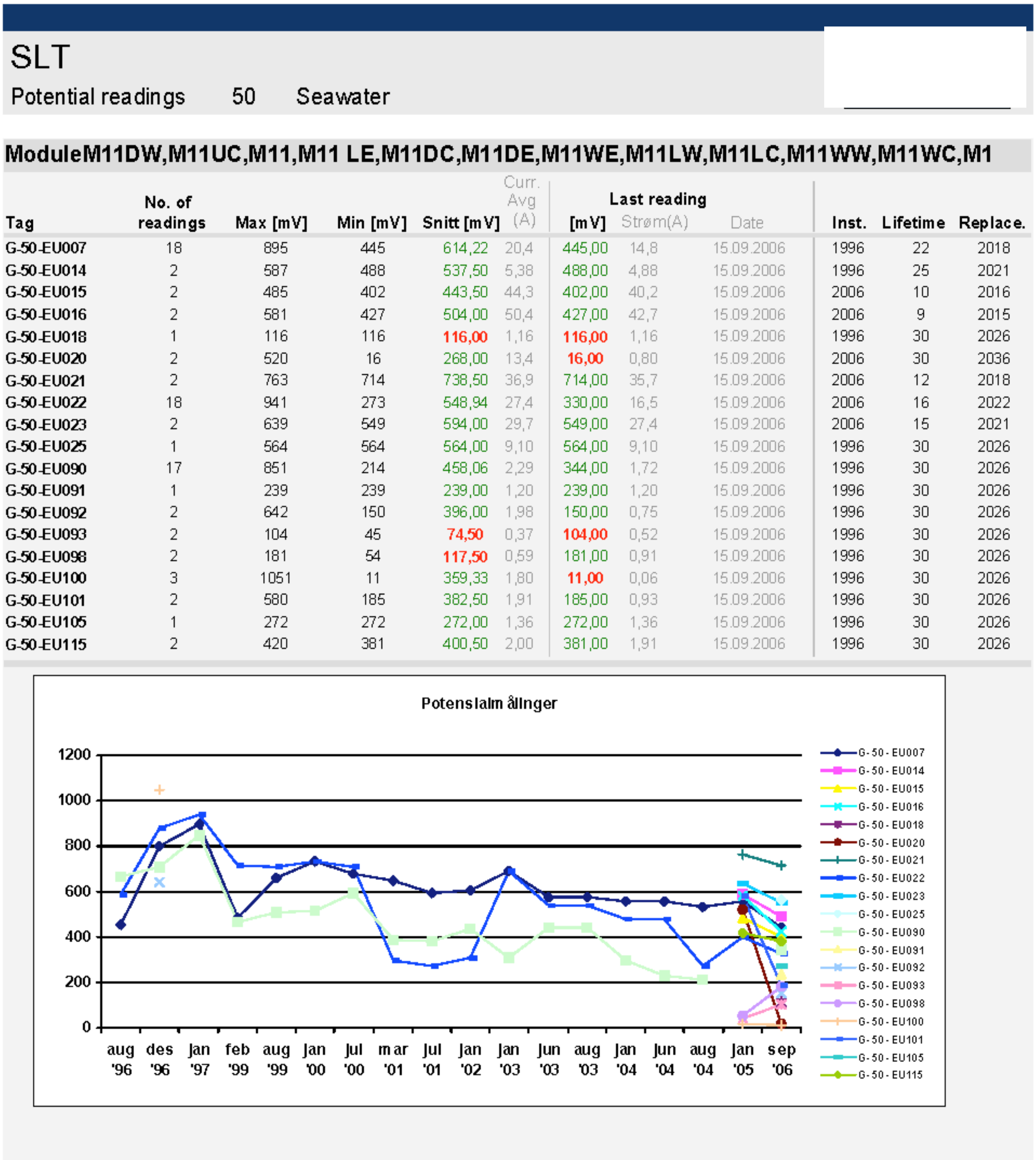
SLA

Potential readings 71 Firewater

ModuleC01

Tag	No. of readings	Max [mV]	Min [mV]	Snitt [mV]	Curr. Avg (A)	Last reading [mV]	Strøm(A)	Date	Inst.	Lifetime	Replace.
71-EU-002	19	707	163	388,79	12,9	163,00	5,43	15.09.2006	1996	30	2026
71-EU-096	2	427	235	331,00	5,34	427,00	6,89	15.09.2006	1996	30	2026

Figure 2: Voltage drop example readings from Sleipner A firewater system with trend and calculated current, lifetime and replacement year for two selected anodes



SLT

Potential readings 50 Seawater

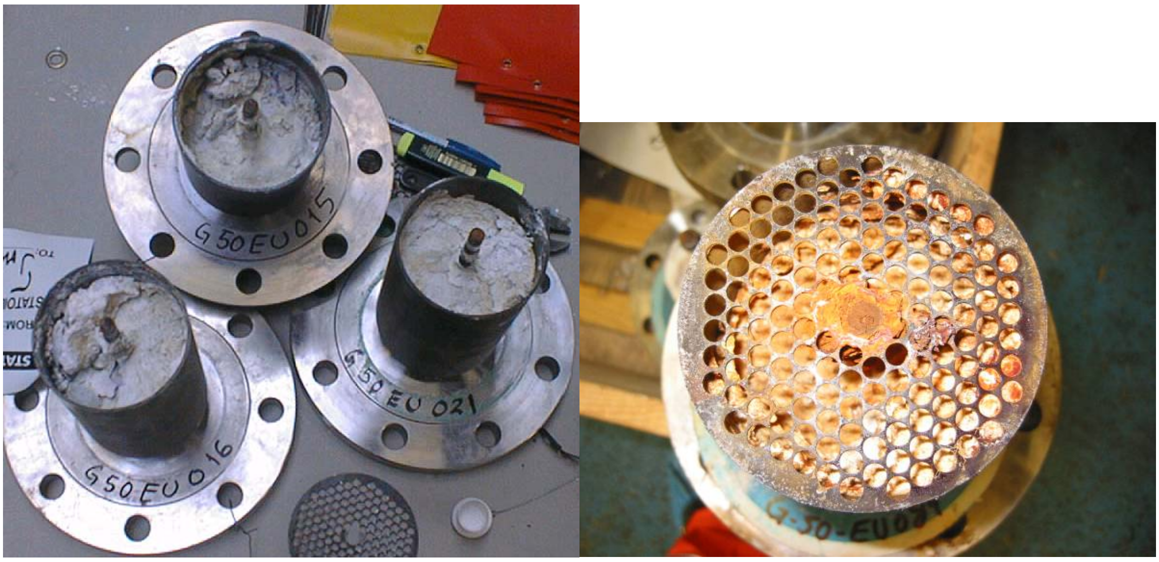
ModuleM11DW,M11UC,M11,M11 LE,M11DC,M11DE,M11WE,M11LW,M11LC,M11WW,M11WC,M1

Tag	No. of readings	Max [mV]	Min [mV]	Snitt [mV]	Curr. Avg (A)	Last reading [mV]	Last reading Strøm(A)	Last reading Date	Inst.	Lifetime	Replace.
G-50-EU007	18	895	445	614,22	20,4	445,00	14,8	15.09.2006	1996	22	2018
G-50-EU014	2	587	488	537,50	5,38	488,00	4,88	15.09.2006	1996	25	2021
G-50-EU015	2	485	402	443,50	44,3	402,00	40,2	15.09.2006	2006	10	2016
G-50-EU016	2	581	427	504,00	50,4	427,00	42,7	15.09.2006	2006	9	2015
G-50-EU018	1	116	116	116,00	1,16	116,00	1,16	15.09.2006	1996	30	2026
G-50-EU020	2	520	16	268,00	13,4	16,00	0,80	15.09.2006	2006	30	2036
G-50-EU021	2	763	714	738,50	36,9	714,00	35,7	15.09.2006	2006	12	2018
G-50-EU022	18	941	273	548,94	27,4	330,00	16,5	15.09.2006	2006	16	2022
G-50-EU023	2	639	549	594,00	29,7	549,00	27,4	15.09.2006	2006	15	2021
G-50-EU025	1	564	564	564,00	9,10	564,00	9,10	15.09.2006	1996	30	2026
G-50-EU090	17	851	214	458,06	2,29	344,00	1,72	15.09.2006	1996	30	2026
G-50-EU091	1	239	239	239,00	1,20	239,00	1,20	15.09.2006	1996	30	2026
G-50-EU092	2	642	150	396,00	1,98	150,00	0,75	15.09.2006	1996	30	2026
G-50-EU093	2	104	45	74,50	0,37	104,00	0,52	15.09.2006	1996	30	2026
G-50-EU098	2	181	54	117,50	0,59	181,00	0,91	15.09.2006	1996	30	2026
G-50-EU100	3	1051	11	359,33	1,80	11,00	0,06	15.09.2006	1996	30	2026
G-50-EU101	2	580	185	382,50	1,91	185,00	0,93	15.09.2006	1996	30	2026
G-50-EU105	1	272	272	272,00	1,36	272,00	1,36	15.09.2006	1996	30	2026
G-50-EU115	2	420	381	400,50	2,00	381,00	1,91	15.09.2006	1996	30	2026

Figure 3: Voltage drop example readings from Sleipner T seawater system with trend and calculated current, lifetime and replacement year for several anodes

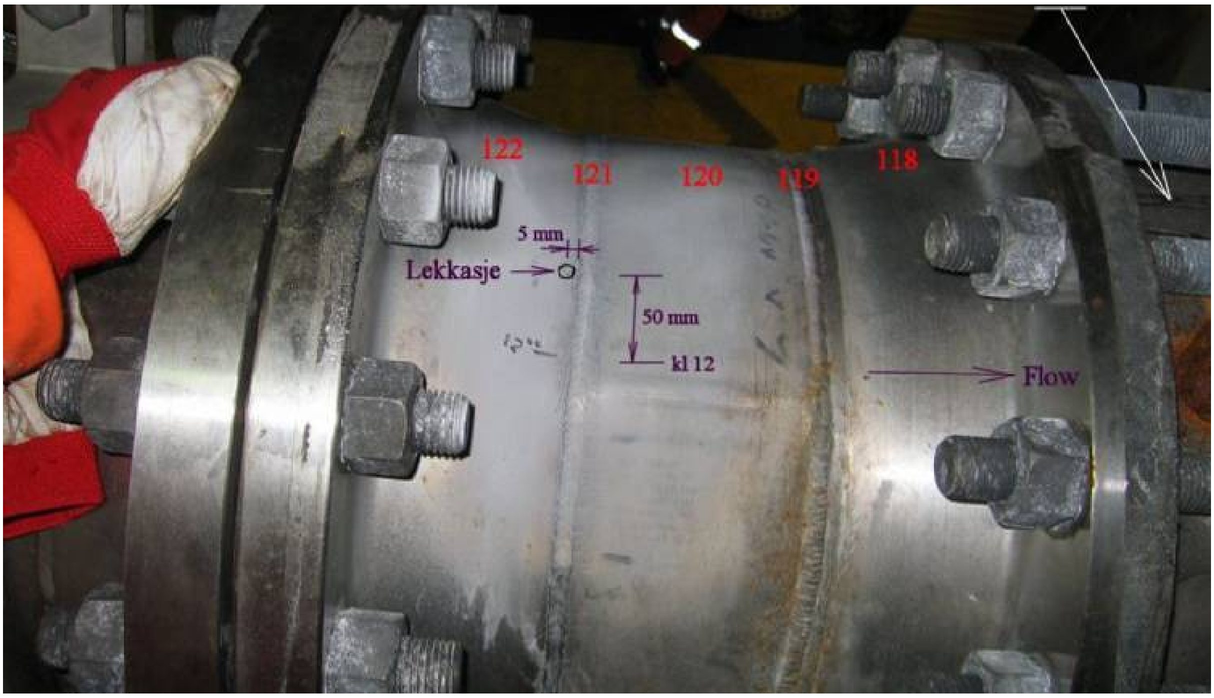
Picture 1**:** Old 6-pin plug to the left and new jack plug connector to the right

Picture 2**:** ¾" NPT plug anodes, showing three used and replaced anodes (one broken) and one new anode (far right)

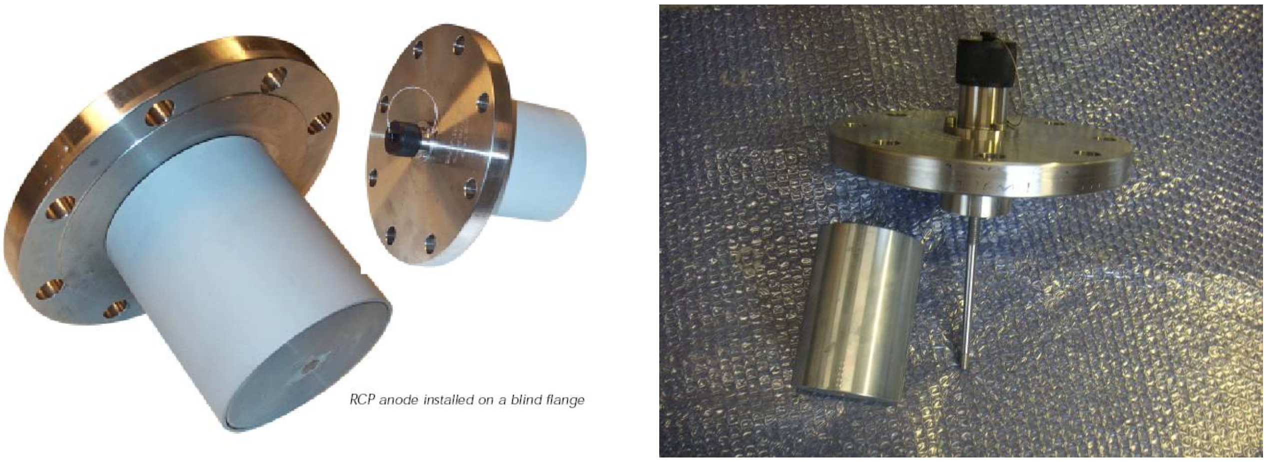


Picture 3: Old type flanged anodes, passivated due to accumulation of zinc oxides.

Picture 4**:** Flange mounted anodes with damaged and missing covers



Picture 5**:** Leak in 18” seawater line.



Picture 6 Improved anode design with front screen removed on the left, and the latest version with replaceable anode mass on the right.

REFERENCES

1. R. Johnsen, P. O. Gartland, S. Valen and J. M. Drugli: “Internal Cathodic Protection of Seawater Piping System by the Use of the RCP Method”, Paper No. 559, Corrosion’96, Denver.

2. J. M. Drugli, U. M. Steinsmo and T. Rogne: “Design Data for Resistor Controlled Cathodic Protection of Stainless Steels in Chlorinated Sea Water”, SINTEF Report No. STF24 F96217.

3. Guri Nustad, Tone Solem, Roy Johnsen, Harald Osvoll and Per Olav Gartland, Mike Brameld and George Clapp: “Resistor controlled Cathodic Protection for stainless steels in chlorinated seawater. A review after 8 years in service”, NACE paper no 03082-2003

4. Svenn Magne Wigen, Harald Osvoll, Queck Chew Hai: ”Resistor controlled Cathodic Protection. 10 years of experience with Resistor controlled Cathodic Protection of stainless steel”, Paper no IBP1396-05 RioPipeline-2005

5. Svenn Magne Wigen, Siw Hege Hansen, Trine Solheim: “Material selections for seawater piping systems. A cost comparison between applicable material selections and possibilities for lower alloyed materials and internal cathodic protection”, EuroCorr 2006.

6. Svenn Magne Wigen, Harald Osvoll, Per Olav Gartland and Weiji Huang: Efficient Cathodic Protection of Stainless Steel Small Bore Tubing. NACE paper no 07078-2007.