

CATHODIC PROTECTION OF MOORING CHAIN IN OFFSHORE ENVIRONMENT

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ABSTRACT

Mooring chains for permanently moored structures – including FPSOs - have shown rapid corrosion of the chain in warm waters. Cathodic protection of mooring lines is normally not provided due to the discontinuous nature of chain links and installation constraints. In recent years, corrosion allowance and pre-emptive replacements of mooring systems are the most common solutions against this corrosion phenomenon.

This study addressed CP of mooring lines with ROV installable clamp anode design. The study is divided into three different sections to examine possible issues and constraints. Including, 1) Mechanical & Electrical properties testing to examine function and continuity between clamp and chain links and between chain links. 2) Development of a computer-based CP model of the mooring chain to simulate CP attenuation with realistic contact resistances between chain links. 3) Sea trials using a section of mooring chain to measure actual contact resistances between chain links and the polarization level of mooring chain links with a single Al anode.

The test results indicate that the subject technology could support new and retrofit CP designs via ROV installable CP System, enhance the operational lifetime of the mooring chains and be beneficial for all other marine and offshore assets.

Key words: Corrosion, Cathodic Protection, Sacrificial Anode Cathodic Protection, SACP Anode, ROV Installable Anode, Mooring Chain, FPSO, Attenuation, Subsea, Remotely Operated Vehicle (ROV), Diver-less Anode.

INTRODUCTION

Corrosion in Mooring systems for permanently moored floating production units has been identified as a problem area by authorities as well as industry. A Joint Industry Project (JIP) initiated by the Bureau of Safety and Environmental Enforcement (BSEE) with participation from major global oil and gas operators as well as equipment suppliers was established in 2014 to review the problem area.¹ Studies performed as a part of this program have shown that especially mooring chains located in tropical waters have shown signs of rapid corrosion, both general and localized with corrosion rates significantly larger than those specified in design standards. Increased corrosion allowance, as well as increased inspection requirements, have been recommended and corrosion has been reported as the leading cause for pre-emptive replacement of mooring.

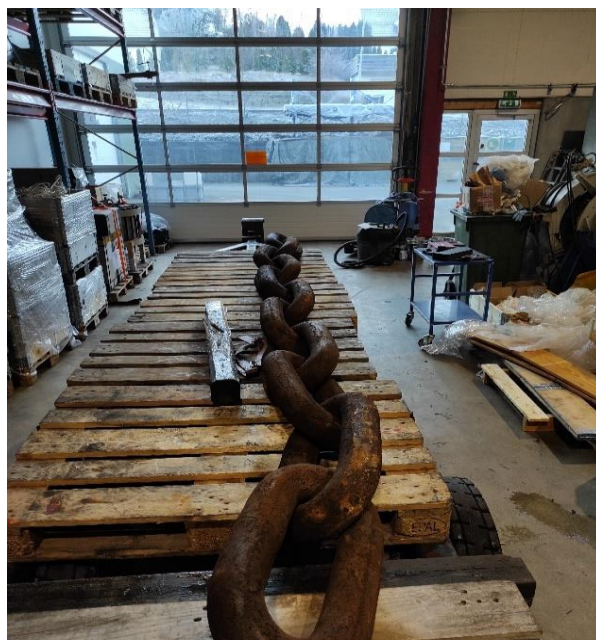


Figure 1: Mooring chain section shown is used for testing

Material losses due to corrosion will result in a reduction of chain integrity. If the material loss is more than the design allowance, the mooring systems may not be able to meet design life and retire earlier than expected which involves a high cost of replacement and associated risks. Mooring chain failure due to corrosion has been reported for several deep-water floating production systems (FPSOs) and “It should be highlighted that corrosion has been the main reason for several pre-emptive replacements of mooring system”.²

Due to the discontinuous nature of chain structures and installation constraints, dedicated cathodic protection is normally not applied to chains. It should however be noted that US Navy⁽¹⁾ recommends that all mooring chains between a buoy and the mudline shall be protected by cathodic protection. Specified methods are by Stud and/or Clump anode system.³ These CP methods are however based on divers for installation, maintenance, and replacements and these methods cannot easily be adapted for deep water mooring chains.

Imenco Corrosion Technology AS* in cooperation with a global FPSO operator accepted the challenge of developing a technology for applying cathodic protection to permanently installed mooring chains in all water depths and review possible solutions.

⁽¹⁾ US Navy. (United States Navy, Unified Facilities Criteria (UFC) UFC 4-150-09.

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This study addresses CP of mooring lines with ROV installable anode clamp design. It involves studying the behavior of chain in the sea in terms of electrical continuity between links, the design of an anode clamp which can be installed via ROV, and measurement of the surface potential of a chain with an installed anode.

EXPERIMENTAL PROCEDURE

For better understanding and establishing a conclusive correlation between different factors, the study further separated into three different sections, including.

- 1) Anode clamp selection and “Fit for Purpose” clamp tests.
- 2) Finite/Boundary Element Method FEM/BEM-based cathodic protection modelling.
- 3) Nearshore sea trial of a sample chain.

Section-1: Anode Clamp Selection And “Fit for Purpose” Clamp Tests

A specialized anode clamp was chosen as a method for anchoring the anode to mooring chains. These clamps have a documented track record for providing earthing and continuity connections, and can be installed via ROV. The clamps were slightly re-scaled and modified to suit larger diameters of the mooring chains and conduct mechanical testing (tensile, torsion, fatigue) as well as electrical continuity tests to ensure the functionality of the system.

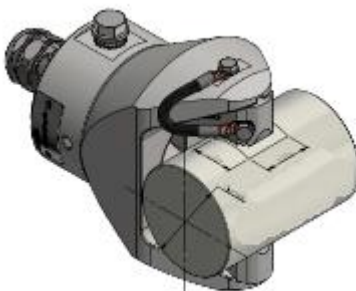


Figure 2: Clamp used for anode attachment to the mooring chain.

Mechanical Tensile Test

The clamp was installed on a test piece of mooring chain $\varnothing 96$ mm grade R4, modified for use in a vertical load test bench. A pulling bracket was installed on the interface for anode brackets on the clamp housing and setup was installed on the vertical test bench as shown below.



Figure 3: Tensile force applied to the clamp attached to the mooring chain section

Mechanical Torsion Load Test

The clamp was installed on a test piece cut off a mooring chain $\varnothing 96$ mm grade R4, modified for use in a vertical load test bench. A pulling bracket was installed on the interface for anode brackets on the clamp housing and setup was installed on the vertical test bench as shown below.



Figure 4: Close-up of Torsion Load Test of Clamp attached to the mooring chain section.

Clamp Electrical Continuity Testing

The purpose of these test was to demonstrate the electrical continuity through the clamp connection to a mooring chain element.

- Test was performed on test subject – Mooring Anchor chain – 11 pcs $\varnothing 96$ mm links – R4.
- The test was performed with a range of clamping torques ranging from 200 Nm to 750 Nm.
- The resistance between the Jaw of the clamp to a cable connection on the test piece (chain link) was recorded.
- To get consistent results, the measuring probes were kept in the same location during the torquing up sequence.

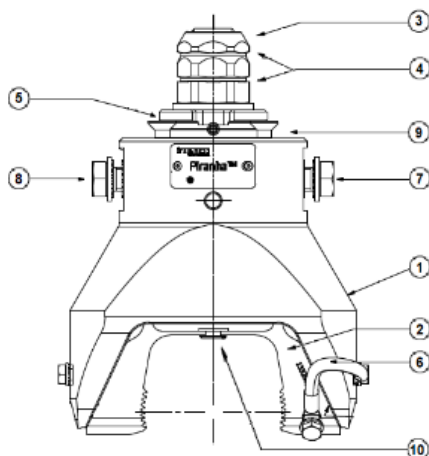


Figure 5: Electrical Continuity Test Setup, Clamp attached to the mooring chain section.

The clamp system (or electric continuity chain) consists of the following elements:

- The clamp housing itself (1).
- The jaw component itself (2).
- The connection cable (6) between the clamp Housing and the clamp Jaw - This connection has two conduits; a connection through direct mechanical contact between the housing and the jaw, and one 170 mm long 16 mm² cables.
- The clamp connection between the clamp jaw onto the chain section. The contact cross-section between the jaw and the structure will vary depending on the actual material properties of the structure and the clamping force i.e. the connection torque of the clamp.

Dynamic Cyclic load test

An experimental campaign was carried out to evaluate the failure mode of the clamp's mechanical grip subjected to dynamic cyclic loading for an extended period of time (cycles/time). This was done to replicate the drag forces exerted by wave motion, storm, or extreme environmental forces onto the clamp assembly.

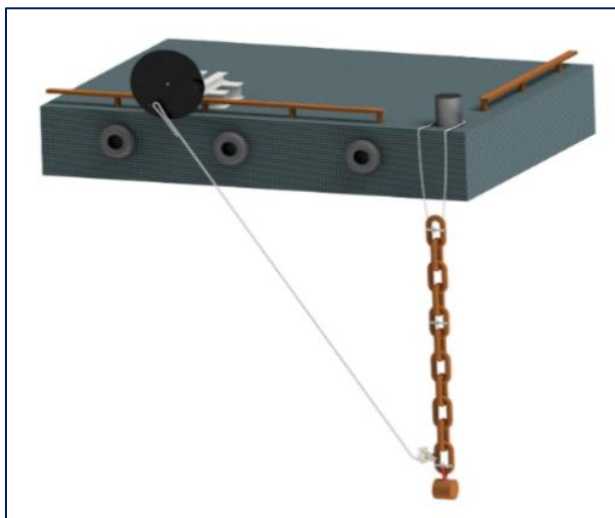


Figure 6: Dynamic Cyclic Load Test Assembly Layout.

The clamp anode attached to the mooring chain was subjected to the dynamic load via surface pulling system, exerting about 60 kg pull force in each cycle, this was to ensure the clamp remains intact and performs its intended function over time. The clamp connected to the chain was continuously pulled and released by the surface pulling system for about a 6-month period. (Test is still ongoing. At present 508 000 cycles have been completed).

Resistance test – Chain links under load

One important design criterion for cathodic protection of a mooring chain is the contact resistance between each chain link. The purpose of this test was to measure the resistance between the chain links while applying an axial load to the links that are submerged in seawater. For detailed arrangements refer to Figures 7 and 8 below.