

Marine Biofouling, Corrosion, and Wear Protection Of Power Take Off Rods For Wave Energy Conversion - Laser Cladding And Scraping

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ABSTRACT

Power Take Off steel rods are key components in wave energy. Their surfaces are exposed to among others, marine corrosion, marine biofouling, and mechanical wear. Protective coatings are sought for, and test and validation protocol for these coatings are needed. In this study metallic matrix coatings applied by laser cladding, have been tested. Accelerated testing and field methods have been employed. The goal is to use these coatings as study case for evaluation of methods itself for corrosion and wear resistance validation. The methods and preliminary results are presented and discussed. In particular: a) field test of a biofouling control strategy using mechanical scraping at different intervals; b) continuous salt spray test in three different media (conventional NaCl; artificial seawater; and natural seawater); c) cyclic potentiodynamic polarization measurement (ASTMG61) for ranking of nickel- and cobalt-based coatings and study susceptibility to localized corrosion; d) Critical crevice temperature test for nickel-based alloys (ASTMG48–D); d) Multi-degradation testing where synergy effects from wear and corrosion are considered (only discussed). The goal is to evaluate methods and experimental design to both reduce uncertainty, assist in material selection, and finally provide a pathway for final validation of PTO coatings toward a third-body certification.

Key words: Marine Biofouling, Corrosion resistant alloys, Marine environment, Marine Corrosion, Validation, Seawater corrosion, Test methods, Laser cladded coatings.

INTRODUCTION

Harvesting ocean energy will play an important role in supplying fossil-free energy for future generations.¹ The oceanic environments around the world are unfortunately of the toughest possible to operate in. Most technologies use a power take-off (PTO) unit with mechanisms that are placed inside protective enclosures or sealed buoys to protect from the harsh environment in seawater. This gives a barrier from the corrosive electrolyte and biological activity that can deteriorate the components. The energy from the oceans in form of relative movements and forces are transferred to the PTOs with help from complex dynamic sealing systems. To guarantee their performance and reliability, dynamic sealing systems include engineered surfaces (for example hard metallic coatings on piston rods), combined with specific polymer sealing materials that can cope with high velocities and provide good media separation. These elements operate together and need to be kept in good condition of cleanliness over their entire lifetime. One need to find an optimal combination of properties from the system which can minimize risks from corrosion, wear, and biofouling. To ensure a high level of reliability efforts need to be focused on R&D, tests, and demonstrations of critical subcomponents such as PTOs, seals, and moorings.² This work has focus on reliability testing for biofouling and corrosion mitigation which is also linked to the wear of coatings and seals. The study case is a wave energy converter (WEC) developed by “CorPower Ocean AB” and the test methods aim to creating valuable knowledge on antifouling and anticorrosion solutions to minimize risks and maximize reliability of components in the marine energy sector.

Study case – CorPower Ocean PTO for Wave Energy Conversion

The CorPower Ocean WEC is of point absorber type, with a heaving buoy on the surface absorbing energy from ocean waves, and which is connected to the seabed using a tensioned mooring line. Novel “phase control” technology makes the compact devices oscillate in resonance with the incoming waves, strongly amplifying the motion and power capture. This offers five times more energy per ton of device compared to previously proposed technologies.

A schematic of the CorPower Ocean WEC is shown in Figure 1. It can be thought of in two parts – an oscillating part, and a stationary part. The oscillating part consists of the hull structure and is designed to move with the motion of incoming ocean waves. The stationary part consists of the anchoring system, mooring line, ocean rod, and PTO system. The anchoring system and mooring line hold the WEC in position in the ocean. There is relative motion between the stationary and oscillating parts caused by the incoming ocean waves, and the ocean rod helps facilitate this smooth relative motion. The PTO includes the gearboxes and generators that allow the motion of the waves to be converted into useful electricity.

There is a seal gland that acts as one of the interfaces between the oscillating and stationary parts. The seal gland is built into the hull structure, and interfaces with the ocean rod (see Figure 1). The sealing system can therefore be thought of as the combination of the ocean rod surface and the seal gland. The sealing system is critical to the WEC’s functioning. Firstly, it has to offer low-friction relative motion between the oscillating and stationary parts to deliver maximum efficiency in the conversion of wave motion to electricity. Secondly, it must prevent ingress of seawater inside the hull.

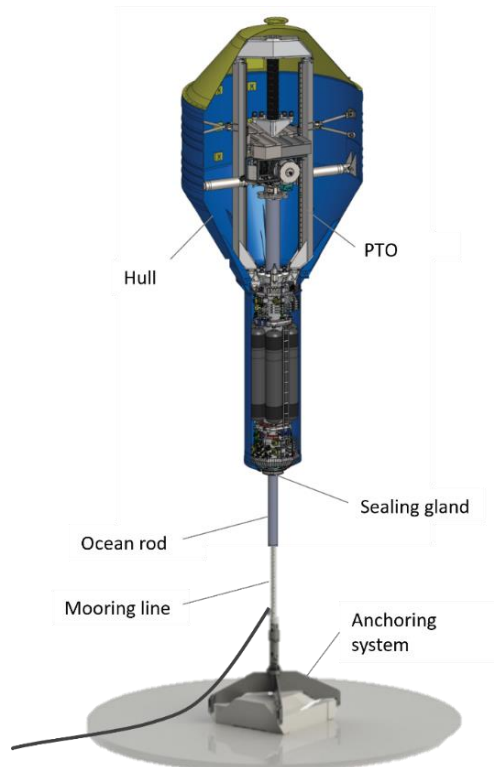


Figure 1: Schematic of CorPower Ocean WEC.

This is challenging for several reasons. The ocean rod is submerged in seawater at a relatively shallow depth (around 5-10 m) and is therefore subject to corrosion. The ocean rod is also subject to biofouling, with invertebrates such as barnacles and mussels attaching and growing on the rod over time. Corrosion and biofouling increase the surface roughness of the ocean rod, which increases the friction experienced by the seals. This not only decreases the efficiency of energy conversion, but also causes increased wear of the seals, which can shorten their service life considerably, increasing maintenance costs. Both effects increase the levelized cost of energy (LCoE) that the WEC can deliver, and hence decrease the competitiveness of wave energy. It is therefore critical to minimize corrosion and biofouling on the ocean rods.

Biofouling control strategy – mechanical scraping of PTO ocean rod

Ocean waves vary in terms of amplitude and frequency. The WEC is therefore designed to be operational over a wide range of wave amplitudes to maximize energy capture. The maximum operational wave amplitude dictates the length of the ocean rod, with such a wave causing the seal to carry out one full stroke of the ocean rod (i.e., traverse the entire rod length). However, there is a median wave amplitude which the WEC experiences, with most of the oscillation happening around the mid-stroke of the ocean rod. Hence, the mid-stroke region of the ocean rod will be cleaned through scraping when moved regularly through the sealing gland from natural movement. There will however be regions of the ocean rod which will not be cleaned regularly, and one might need to introduce artificially induced full strokes at some point to keep the rod free from detrimental fouling. One of the proposed mitigation strategies is therefore to perform active cleaning strokes. This causes the seals to traverse the full length of the ocean rod. This cleaning stroke consumes energy since it is an active process, and it is therefore advantageous to minimize how frequently it is carried out. It is therefore desirable to find a trade-off between added friction from biofouling accumulation and cleaning stroke frequency. For biofouling mitigation, mechanical removal through scraping when the rod moves through the seal-area will offer an environmentally friendly solution. The effect of this type of grooming of the surface would be highly dependent of the interval as biofouling pressure could increase over time.

These induced rod movements associated with mechanical scraping has been chosen as biofouling control strategy to study. In this case the coatings have been evaluated for cleaning easiness (cleaning force needed) and resistance to mechanical stress (surface roughness before and after scraping). A scraper rig and a field test procedure has been designed and ran simultaneously in two geographical locations during a summer season, Swedish (north Atlantic) and Portugal (Atlantic) west coast. The sealing system associated with the scraping system has also been tested for resistance and possible fouling intrusion in the system. The repetition of cleaning intervals on the same surface has been implemented in the test method as it is well known from other sectors that time to recruitment of biofouling on a cleaned surface is shorter than on a pristine surface. Thus, this element is an example of important details to find optimum operation and maintenance scheme, as the full stroke of the PTO rods consume energy and need to be used only when necessary.

Corrosion protection of PTO ocean rod

Besides biofouling mitigation, it is important to find a good hard coating for protection against corrosion and wear. Several industries linked to marine/offshore operations have developed metallic anti-corrosion coatings for rods, together with heavy-duty scrapers and seals. For example, riser tensioners on oil platforms can have very similar working conditions as the study case of this work.³ State of the art hard coatings for piston rods in offshore environment include nickel-chrome plating. However, the plating processes involve chemicals such as hexavalent chrome which have increasingly constraining regulatory framework.⁴ An alternative to hard chrome coatings is high-velocity-oxy-fueled (HVOF) thermally sprayed coatings.⁵ Weld overlay coatings such as laser cladding, and plasma-transferred arc (PTA) are often seen as the most promising developing technologies due to their excellent ductility and corrosion resistance.⁶ The very strong bonding prevents any delamination of the coating, but generally offer lower hardness which represents a challenge to wear/erosion.^{7,8} Laser cladding is seen as a promising alternative to the hard chrome coatings with the advantages of good metallurgical bond, small dilution rate and heat-affected zone, forms a fine microstructure, and considered environmentally friendly, flexible, simple, and material saving.⁹ The new developments of high speed laser cladding technique makes it a competitive alternative with thinner, non-porous, crack-free coatings that can be produced more efficiently and thinner.¹⁰

The latest state-of-the-art coatings described in the previously have not been used on a WEC before, and therefore there is a need to perform tests of these different solutions and analyze the effect on the seals. These different solutions each have their pros and cons, which need to be systematically evaluated for the wave energy applications. To show test procedures for corrosion and biofouling mitigation strategies of PTOs, this project has a specific user case PTO unit to gain new valuable insight in reducing risks and increase performance lifetime of WECs. This project includes field tests to study an environmentally friendly antifouling strategy, and accelerated corrosion tests for investigation of test methodologies evaluating the durability/reliability of ocean rod coatings for WECs.

Among most suppliers of corrosion protection solutions, a continuous salt spray test such as ISO 9227 or ASTM B117 is used as a proof of good quality and corrosion protection.^{11,12} For hard coatings, they are evaluated for time to first base metal corrosion according to ISO 10289, i.e. when protection rating drops below, Rp 10.¹³ Normally suppliers state that the coating lasts more than 1000 hours in such a test. While this test is useful for quality control checks of batches, it lacks usefulness for validation of life-time assessment. It is not representative of the environment of intended use and can't provide information of performance in the field. It is still the most commonly used standardized corrosion test and it is therefore included in this study to evaluate its usefulness as a tool towards validating corrosion protection of ocean rods or other critical components for WEC's. In this work, test with artificial (ASTM D1141) and natural seawater have been performed for comparison with the standardized sodium chloride solution to see if usage of a media more applicable to the intended environment would improve the test performance.¹⁴

Another test of interest for studying and validating hard coatings is ASTM G61 which utilizes cyclic polarization scan to study the susceptibility to localized corrosion attacks on various alloys of iron, nickel, and cobalt.¹⁵ For the coatings and design of WEC's this is of high relevance since crevices and fouling can cause detrimental deterioration of critical components and function. During the experiment the voltage is swept across a range from open circuit potential (OCP) while measuring the current. When the current reaches 5 mA the voltage is reversed back to OCP. This allows for studies of the electrochemical changes on the sample's surface. An alternative or a complementary standardized test for validation or ranking of pitting and crevice corrosion resistance of stainless steels and related alloys is ASTM G48.¹⁶ In this test, the sample is exposed to a ferric chloride solution (pH 1) for 72 hours with a special crevice former of inert material attached onto the surface. The temperature at which the sample exhibit corrosion attacks at the area of the crevice former deeper than 0.025 mm is determined by iterating the experiment at multiple temperatures.

Other tests for validation of the reliability can include a monitoring of the corrosion potential of the coatings in seawater to see how stable it is over time, and a tribocorrosion test where the wear resistance is tested in combination with a corrosive media. For instance, the corrosion potential can be monitored in an electrolyte while the wear resistance is being tested simultaneously through rubbing an alumina ball over the coating and measuring the coefficient of friction. This will generate a better understanding for how the coating can resist the combinatorial stresses caused by corrosive media and any wear from the movement of the WEC.

EXPERIMENTAL PROCEDURE

To study the user case specific biofouling and corrosion strategies, a small-scale PTO rod was selected as most appropriate model of the full-size system. PTO ocean rods (80 mm in diameter) were prepared in 10 m lengths and treated with five different coatings (Table 1) to see if the tests included in this study could be of interest for validation/test programs. The rod for biofouling test was coated with the same coating (Coating 4), cut into shorter pieces of 500 mm length, and fitted with end caps of high-density polyethylene (HDPE) to avoid seawater entry to the inside of the rod. A scraper ring with scraper assembly was mounted on the samples (Figure 2) and used for cleaning/scraping strokes in a custom-made scraper test rig (Figure 3). The biofouling rod samples were mounted on aluminum frames or deployed at a depth of about 1-3 m from the surface using ropes, see figure 4.

Table 1
Coatings used in the field and corrosion tests

Test	Coating Number	Thickness (μm)	Alloy	Hardness	Process
Corrosion tests	1	30	Electroless nickel + electrolytic chrome.	800 HV	Plating
	2	250	NiCr. Modified nickel chromium matrix.	310 HV	Laser cladding
	3		NiCr. Reinforced nickel chromium matrix.	330 HV	
	4		NiCr-W. Post-treated, reinforced nickel chromium matrix.	450 HV	
	5		NiCr-WC	1000 HV	
Biofouling management test	4	250	NiCr-W. Post-treated, reinforced nickel chromium matrix.	450 HV	