Modernized cathodic protection system for legs of the production rig – evaluation during ten years of service.

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ABSTRACT

The modernization of cathodic protection system of the Baltic Beta platform legs is described. It was that the sacrificial anodes cone-shaped groups were to be placed on the seabed at a depth of 80 meters. The measurements results of cathodic protection effectiveness during its ten-years operation are presented. The effectiveness was assessed based on the potential value along the entire length of the legs from the sea surface to the seabed. The gained experience indicates that use of sacrificial anode systems mounted on the seabed can be an effective form of cathodic protection of offshore platforms legs. It is basically the only means of anticorrosion protection in case of a platform not able to leave its location for renovation works in a shipyard.

Keywords:

Gas and oil production rig

Sea platform

Corrosion

Cathodic protection

Sacrificial anode

1. Introduction

Gas and oil production rigs require effective and reliable corrosion protection, without which the material degradation may lead to breakdowns or even disasters (Kiran, 2017; Esaklul and Ahmed, 2009; Melchers, 2005; Wu, 2018). Such protection is achieved through the combined use of protective coatings and cathodic protection. These technologies complement each other: the better the barrier properties of coatings, the lower the demand for cathodic protection current. The use of coatings drastically reduces the cathodic protection current demand of the protection object and hence, the required sacrificial anode weight.

Cathodic protection of marine structures can be implemented using systems based on sacrificial anodes (Szabo and Bakos, 2006a), systems with an external power source – impressed current cathodic protection (Szabo and Bakos, 2006b) or by means of hybrid systems combining the two technologies (Larsen, 2019; Hajigholami et al., 2017). Sacrificial anodes designed to work in seawater environment are made of zinc- or aluminum-based alloys. In the classic cathodic protection solutions, cores of anodes are welded to a protected structure, and anodes are arranged so as to provide the protective potential on the entire protected surface (Hartt et al., 2005; Lemieux and Hartt, 2006).

Cathodic protection of marine structures is a complex issue. There are no universal solutions for protection systems of this kind. Each structure requires development of an individual concept for protection implementation. To design a protective installation properly, it is necessary to recognize the corrosion hazards in the facility and estimate the demand for protective current, which is related to the preservation of protective properties of the coatings, seawater temperature (Hong et al., 2018), its oxygenation and salinity (Zakowski and Narozny, 2014), depth, colonization of the constructions by marine organisms (Jeffrey and Melchers, 2003; Liu and Cheng, 2017) and precipitation of calcareous deposits (Zamanzade, 2007; Zakowski, 2013).

During the retrofit of cathodic protection system of the Baltic Beta rig legs, an concept for application of sacrificial anode groups placed on the seabed has been developed (Zakowski, 2011). It was basically the only means of protection in case of a platform not able to leave its location for renovation works in a shipyard. Such solutions have already been used, but in shallow seas (Hartt, 2012; Yin et al., 2019; Rossi, 1998). Meanwhile, the depth of the sea at the workplace of the Baltic Beta rig is about 80 meters.

This publication discusses the main operating experience of the platform's cathodic protection system obtained during its ten-year operation.

1.1 Characteristics of the Baltic Beta production rig

The Dyvi Beta rig (nowadays known as the Baltic Beta) was built for the Norwegian company K / S DYVI DRILLING by the French company Compagnie Francaise d'Entreprises Metalliques (CFEM) at the Dunkirk shipyard in 1975–77 under the ETA Houston Texas license. In the first period of its operation, it was used for development of the Norwegian oil field EKOFISK. Later, it was bought by the Norwegian company Smedvig and used for various purposes, such as construction of a port structure in the area of the Adriatic Sea. In 1994, it was purchased by the Polish company Petrobaltic. Before starting its journey to the

Baltic Sea, the WEST BETA rig was put on a dry dock, where renovation was carried out focusing mainly on the legs structure. Having moved the platform from the Mediterranean, the Baltic Beta began working on the development of the Polish B3 oil field in the Baltic Sea. Since 1995, the Baltic Beta continuously works on the same location. The depth of the Baltic Sea in the area of the foundation of the oil producing rig is about 80 m.

The Baltic Beta rig extracts from beneath the bottom of the Baltic Sea oil, natural gas and associated formation water. At first all three fluids are separated from each other, and each one has it own destiny in a separate technological process. The system responsible for this operations is called GEOSERVICE.

Oil is pumped true a underwater pipe line to a storech tanker ship moored near the rig. Once the tanker has reached it capacity, it is send onshore for discharge or a ship to ship transfer operation is carried out, with allows for a constant production of oil.

Formation water is specially prepared, it is deoxygenated, cleared from oil, special chemical are added to kill any bacteria that can contaminate the oil reservoir. All of the produced formation water is pumped back the oil reservoir by a set of electrically driven plunger pumps by a system called OIL PLUS.

The block diagram of the gas processing systems on board Baltic Beta is shown in Fig. 1. The natural gas separated from the crude oil is used on bard Baltic Beta in three basic processes. The first and most important is the electrical energy production process which powers the rig itself. This is achieved by a gas turbine driving a electrical generator which covers all of the rig power demand. This system is shown in Fig. 2 with field number five-B2G8. The second process is related with the injection of sea water. In this process a second gas turbine is used to drive a centrifugal pump, which inject specially prepared sea water to the oil reservoir in order to sustain the oil pressure at a constant level, this system is called BHPS. The third process uses all of the gas which was not used in the first two processes mentioned above. This remaining gas is dried, filtered and compressed in a four stage electrically driven piston gas compressor. All component of this system are located on the stern of Baltic Beta and are shown in Fig. 2 with field number one- SSG.

Tab. 1. *Gas characteristics separated on Baltic Beta.*

Components	Unit	Parameters values		
		Min. Value	Max. Value	Average Value
Gas density (at 0 ° C)	kg/m^3	0,904	1,14	1,015
Gas chemical composition:				
CH_4	% volume	43,4	51,48	46,6
C_2H_6	% volume	22,92	30,26	26,37
C_3H_8	% volume	13,25	18,99	16,2
i-C_4H_{10}	% volume	0,76	1,43	1,06
n-C_4H_{10}	% volume	1,27	4,42	2,91
neo-C_5H_{12}	% volume	traces	0,026	0,002
i-C_5H_{12}	% volume	0,16	2,28	0,48
n-C_5H_{12}	% volume	0,17	1,27	0,48
C_6H_{12}	% volume	0,02	0,73	0,18
C_7H_{16}	% volume	traces	0,251	0,058
∑C5+	% volume	0,364	3,046	1,196
N_2	% volume	3,27	7,18	5,45
CO_2	% volume	0,03	0,52	0,19
He	% volume	traces	0,05	0,031
H_2	% volume	traces	0,002	traces
Gas calorific value	MJ/m^3	51,26	56,99	54,63

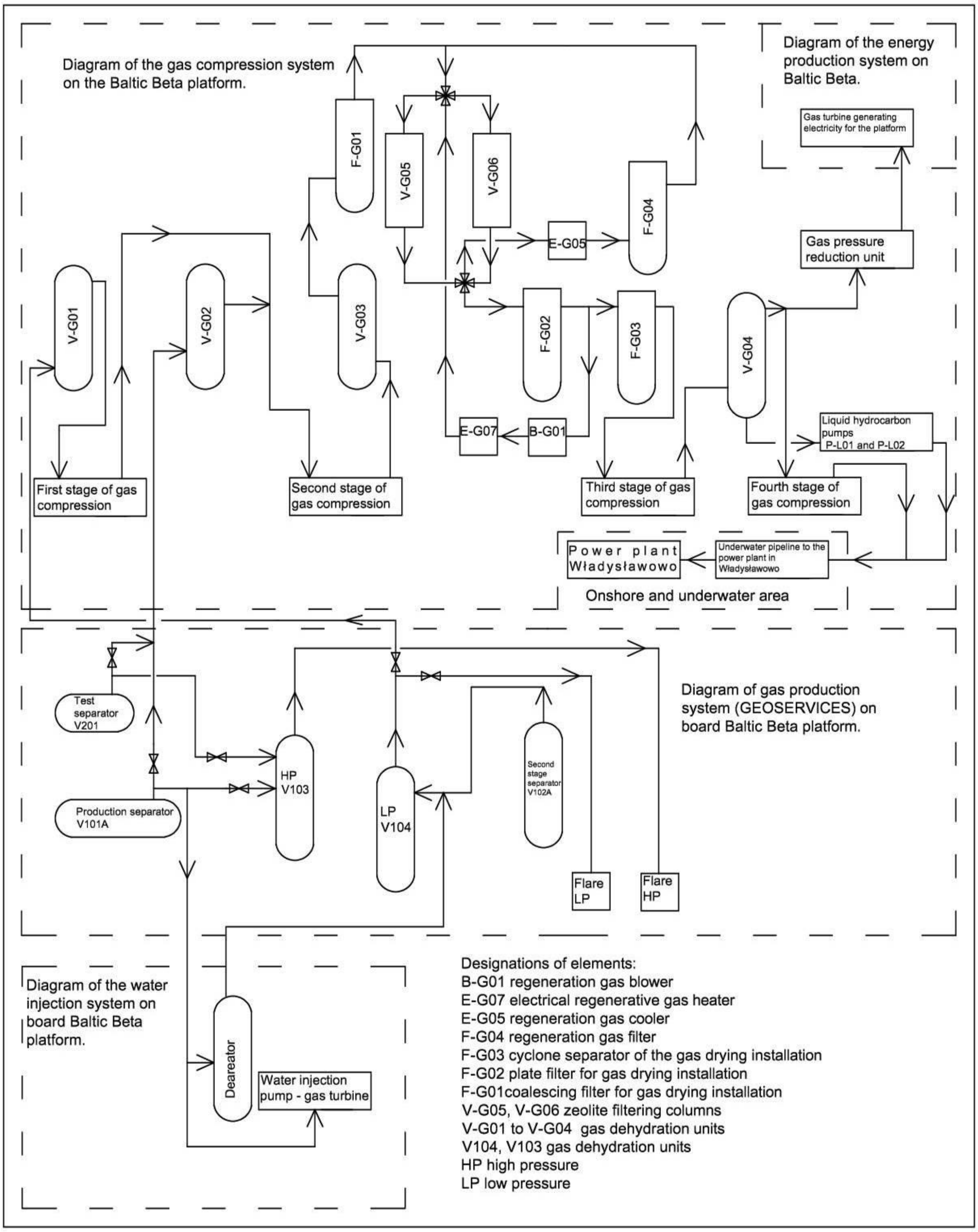


Fig. 1. *Block diagram of the gas processing systems on board Baltic Beta.*

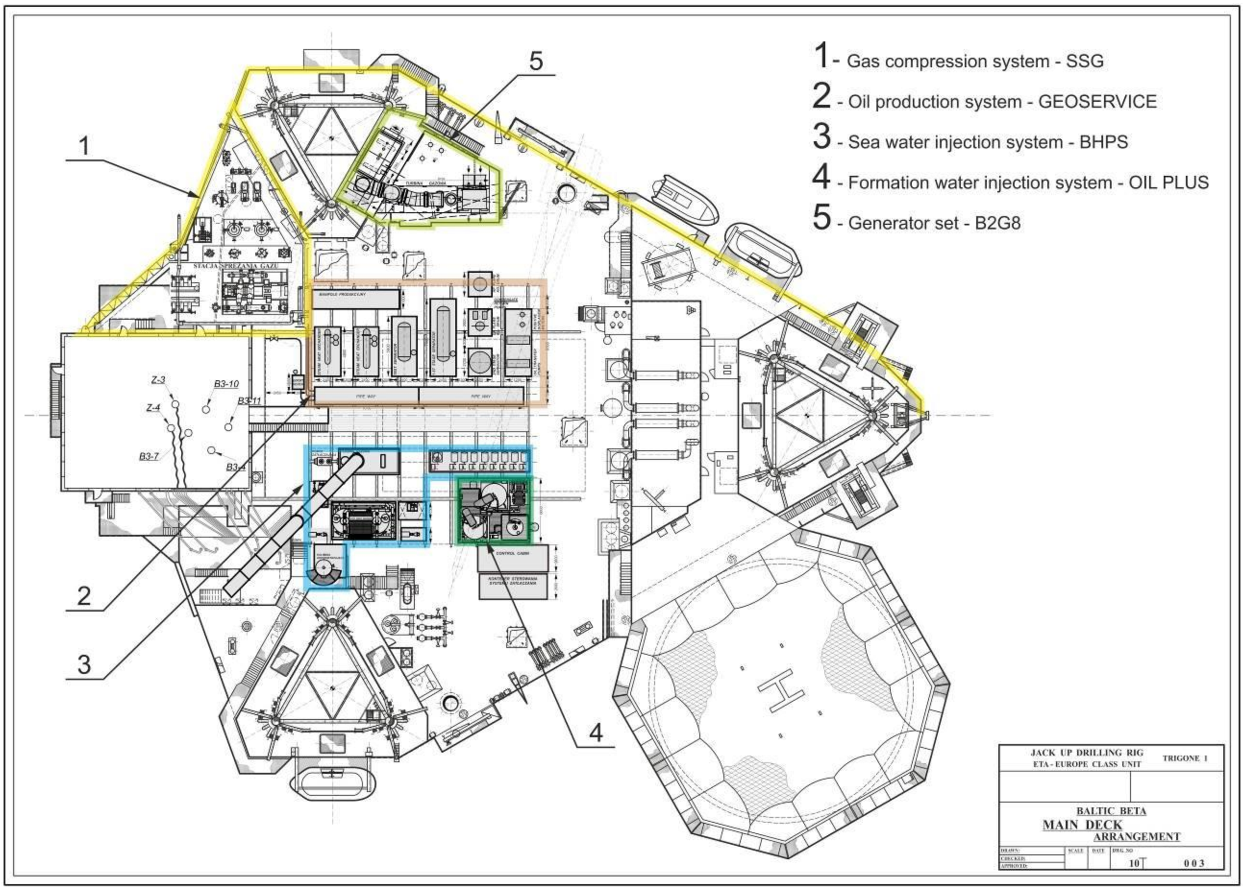
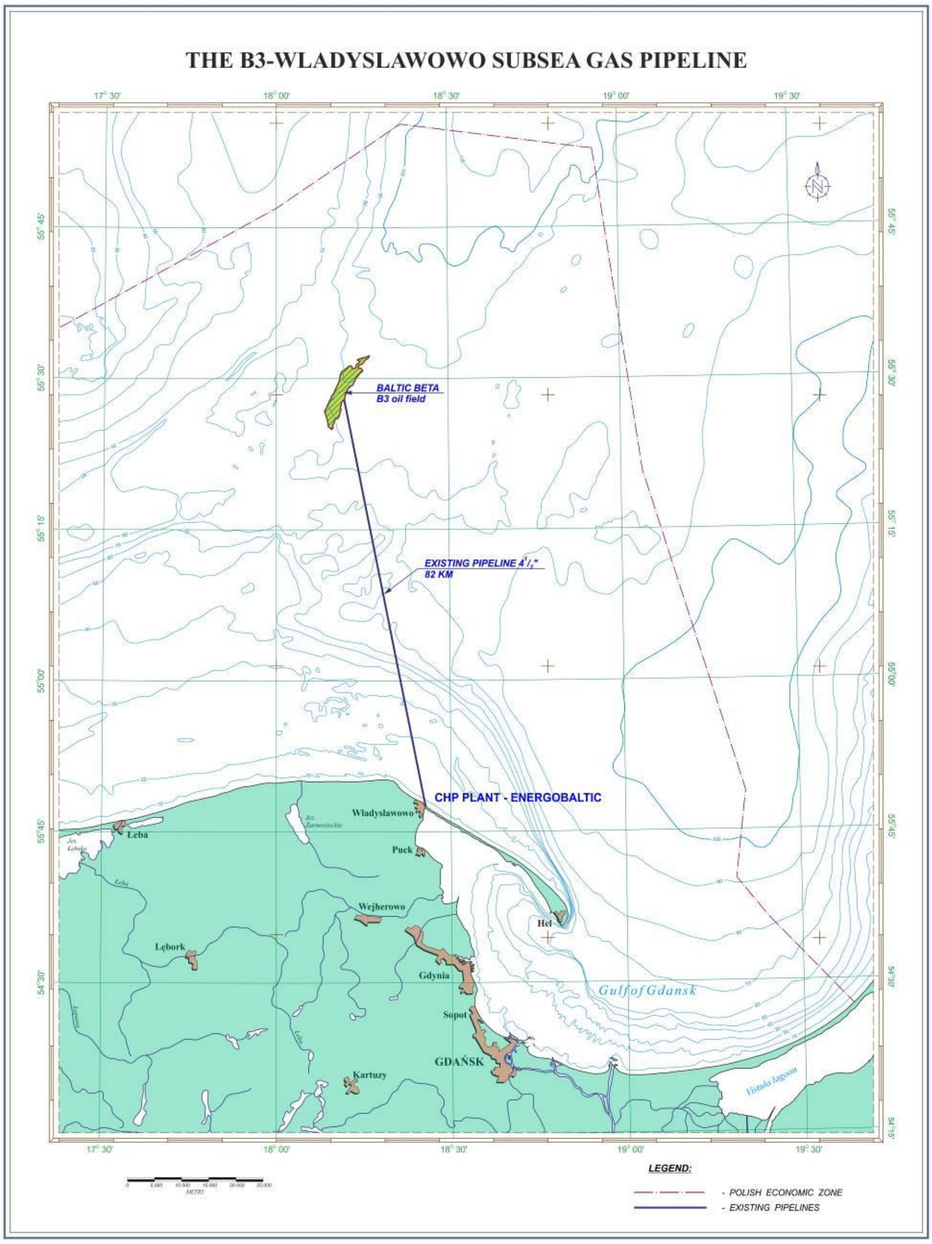


Fig. 2. *Main deck arrangement of Baltic Beta with the indication of all five main systems.*

After the process of drying and compressing, the so called dense phase gas, which is a suspension of hydrocarbons in dry gas, is transferred by the underwater pipeline to the gas separation station in the heat power plant in Wladyslawowo (Map. 1). The gas pipeline is 82.5 km long and its diameter is 115 mm (4 ½ ‟). The pressure of the gas transferred by it reaches 13 MPa.



Map. 1. *Map indicating the route of the gas pipeline on the seabed from the platform to the CHP plant onshore.*

The production process in the heat power plant is divided into two stages. At the first stage, the heavy hydrocarbons fractions are separated from the gas supplied from the rig, in result of which the liquid propane – butane gas (LPG), natural gas condensate (KGN) and dry gas are obtained. At the second stage the dry gas is used for the production of heat and electrical energy.

The work of an oil and gas production rig is continuous by nature, which means that the platform cannot leave the position where it had been originally founded. During exploitation of the reservoir, the platform remains connected to underwater production and water injection wells. In connection to the above, the renovated in the early nineties system of sacrificial anodes welded to the legs and renewal of the rig legs paint coating were the only applied means of the protection of the legs against corrosion.

To sum up, in 2019 the Baltic Beta platform will have ended 42 years of active operation, 25 of which are continuous work on the Baltic B3 gas and oil field.

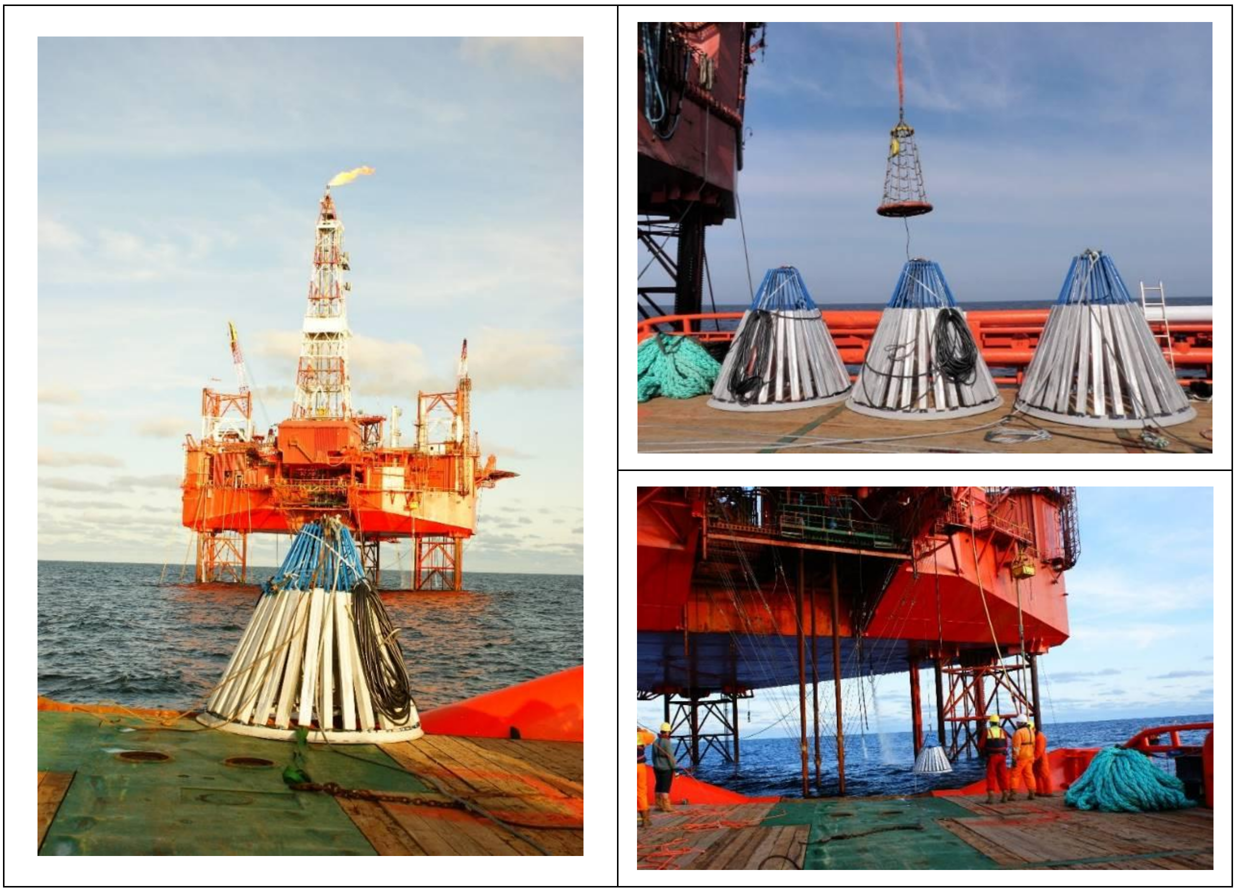
1.2 Modernization of the cathodic protection system

In 2008 there began work on a modernization project for the cathodic protection of the legs. According to the standard DNVGL-RP-B401:2017 "Cathodic protection design", cathodic protection current density for bare steel in seawater is a function of depth and climatic region (based on surface water temperature). The platform works in a temperate climatic region (water temperature 7-12 ^{o}C). Recommended in the standard DNVGL-RP-B401 design current densities needed for the protection of bare steel are 100 mA/m^2 in depth 0-30 meters, and 80 mA/m^2 in depth 30-100 meters. Cathodic protection current demand is lower when the structure is paint coated, therefore the design calculations of the current densities take into account the thickness and age (wear) of the paint coating. This describes the coating breakdown factor. The design current density is calculated by multiplying the current density for bare steel by this factor. If the factor is equal to zero, then coating is considered to provide full insulation, and if factor is equal to 1, coating has no protective properties and the design current density is the same as for bare steel.

The submerged surface area of each of the three legs of the Baltic Beta platform that requires protection is approximately 1800 m^2. In accordance with the design calculations connected with the coating breakdown factor, the demand for cathodic protection current for each leg of Baltic Beta platform totaled about 50 A.

The existing sacrificial anodes welded to the legs of the platform in 1995 turned out to be used up in about 50%, which has been confirmed by a visual inspection of an underwater vehicle (so-called ROV – remotely operated vehicle). As an additional source of cathodic protection current, sacrificial anodes groups were designed in the form of cone-shaped baskets (see Phot.1-3), two for each leg, which were to be placed on the seabed at the distance of about dozen meters from the legs (Zakowski, 2011). The anode groups were electrically connected to the legs with a cable. It was assumed that the anode systems should provide protection current for the next 10 years, therefore each group contains 30 aluminum anodes, 1.5 meters long and 45 kg each.

Works related to mounting and connecting the anode groups were implemented in September 2009. The task of placing the anode groups on the seabed required a cooperation of tugboats, rig cranes and divers. The total time for assembly of the anode groups as well as start-up of the installation was about one week. Photographs taken during the works in 2009 are included herein as Photos 1–3.



Photos 1–3. *The anode groups system installed during the modernization of cathodic protection system of the Baltic Beta sea platform.*

2. Methodology for assessing the effectiveness of the modernized cathodic protection system

Following modernization of the cathodic protection system, its effectiveness was assessed periodically based on measurements of the platform legs potential (Zakowski, 2011). The measurements were conducted in a way allowing to obtain the potential profiles of each leg over its entire height. The potentials were measured versus the zinc/seawater reference electrode, which was lowered on a measuring line along the entire length of the leg from the sea surface to the seabed, as schematically shown in Figure 3. The results were recorded with the accuracy of 0.1 mV using a digital recorder.

The reference electrode was made of high purity zinc (99.99% of weight). It was made in the shape of a cylinder with a diameter of 2.5 cm and a height of 5 cm. The cable connection to the electrode was isolated against water ingress by a resin. The side surface of the cylinder and the cable connection were secured with a heat-shrinkable polyethylene tube with adhesive in such a way that only the base of the zinc cylinder had contact with the electrolyte (sea water). Before the measurements, the potential of the zinc electrode was checked versus a saturated calomel electrode (SCE). The value of the potential of the zinc electrode versus SCE in 1 % NaCl solution was equal to -1020±5 mV. Before measuring the potential of the Baltic Beta platform legs, the zinc reference electrode was immersed in seawater for 30 minutes to stabilize the electrode potential.

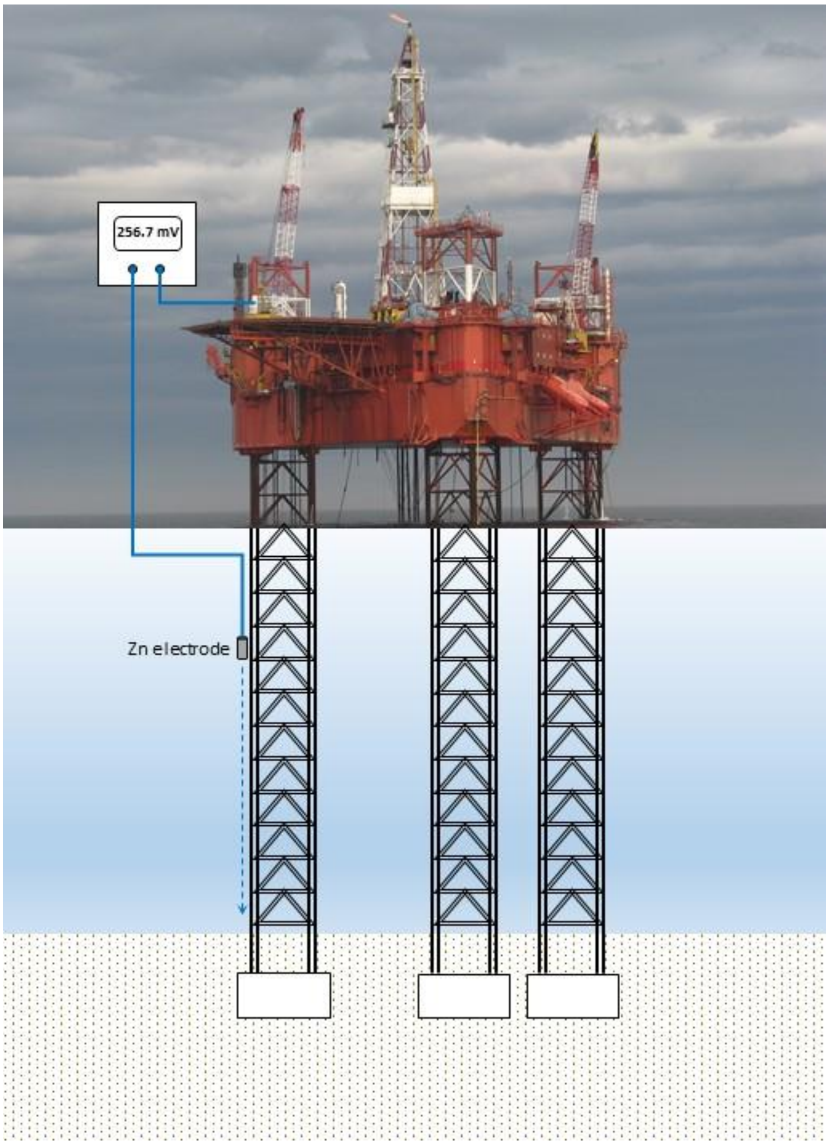


Fig. 3. *A way to measure the potential profile of the platform leg.*

Typical values of the potential of steel corroding in seawater are approximately +0.50 V versus the zinc reference electrode. A more electropositive potential indicates occurrence of intense corrosion of steel structures on the high seas. According to the standard EN 12473:2014-04 "General principles of cathodic protection in sea water", the protection potential of steel structures is between +0.25 V and -0.05 V vs. Zn electrode (so called full cathodic protection). Recognized engineering practice and some standards (e.g. EN 12954:2019-12 "General principles of cathodic protection of buried or immersed onshore metallic structures") indicate that the linear corrosion rate of the structure polarized to the protective potential is less than 0.01 mm/year – a wall thickness of the structure is reduced annually by 0.01 mm. Potential in the range between 0.25 V and 0.40 V versus Zn electrode indicates a partial cathodic protection of steel. In this state the corrosive processes are then limited, but not completely eliminated, and corrosion rate is greater than 0.01 mm/year.

3. Results and discussion

3.1. Effect obtained after installation of the new anode systems

The potential profiles of the leg on the bow of the rig, measured during the assembly of subsequent anode systems in 2009 are shown in Fig. 4. Before assembling the anode groups, the average value of the potential along the entire length of the leg was approximately 0.34 V versus Zn reference electrode (initial state – red dashed line in Fig. 4). A gradual increase in the size of cathodic polarization (i.e. gradual decreasing the value of the potential) on the subsequent days can be observed, which is associated with assembly of each new anode group. The potential change in relation to the potential from before assembly of the systems (the initial state) was about 100 mV in the lower leg, and about 80 mV in the upper part – see pink line in Fig. 4 (7^{th} day). The potential of the lower part of the leg was 0.23 V and potential of the upper part of the leg was 0.25 V. The lower cathodic polarity of the upper part results from the greater distance from the anode group. It is visible in Fig. 4 that polarization to the protective potential, i.e. below 0.25 V, occurred along the entire length of the leg. So, the effect of effective corrosion protection was obtained.

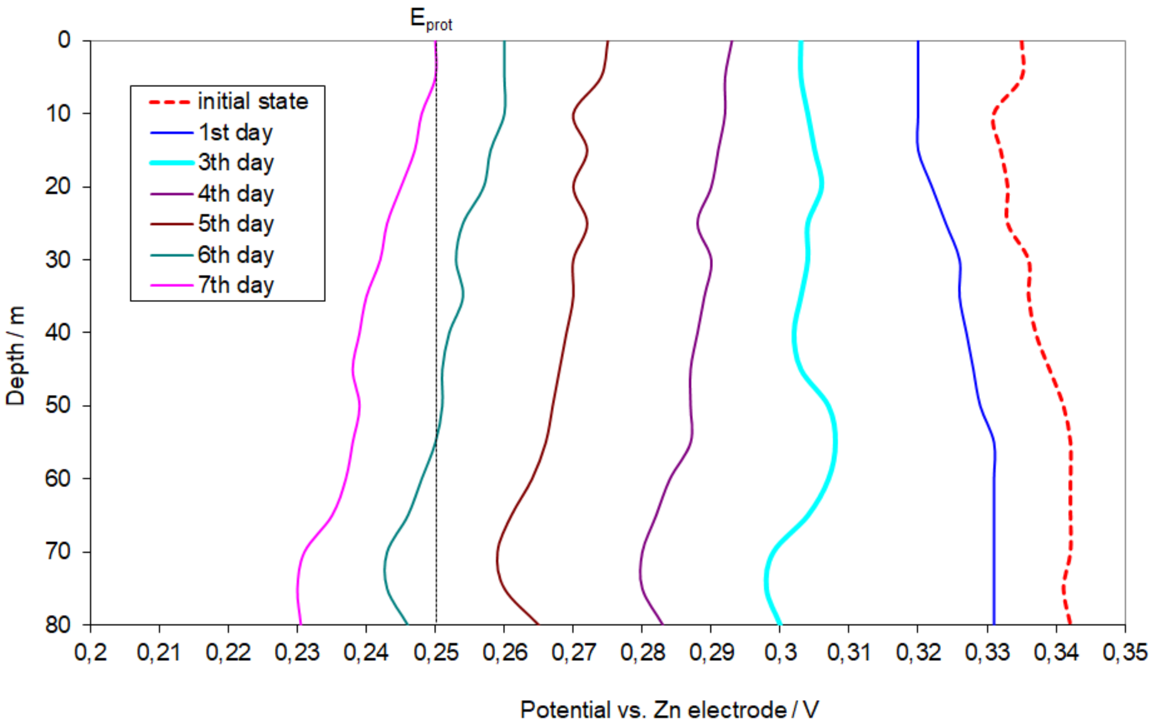


Fig. 4. *An example of the potential profile of the platform leg during assembly and start-up of the installation.*

3.2. Effect obtained during ten-year operation

Fig. 5 and Fig. 6 provide examples of potential profiles obtained for the legs located on the platform stern over 10 years of the cathodic protection system's operation.

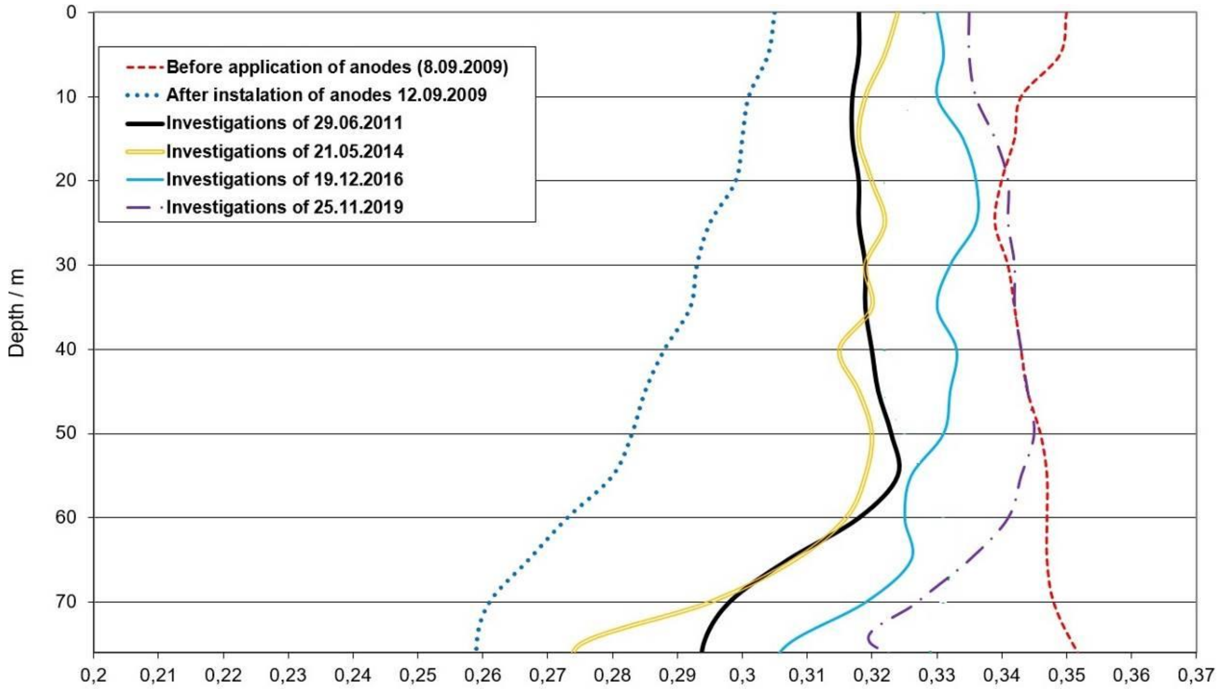


Fig. 5. *Potential profiles of the leg located on the left side of the stern, obtained during ten-year operation of the cathodic protection system.*

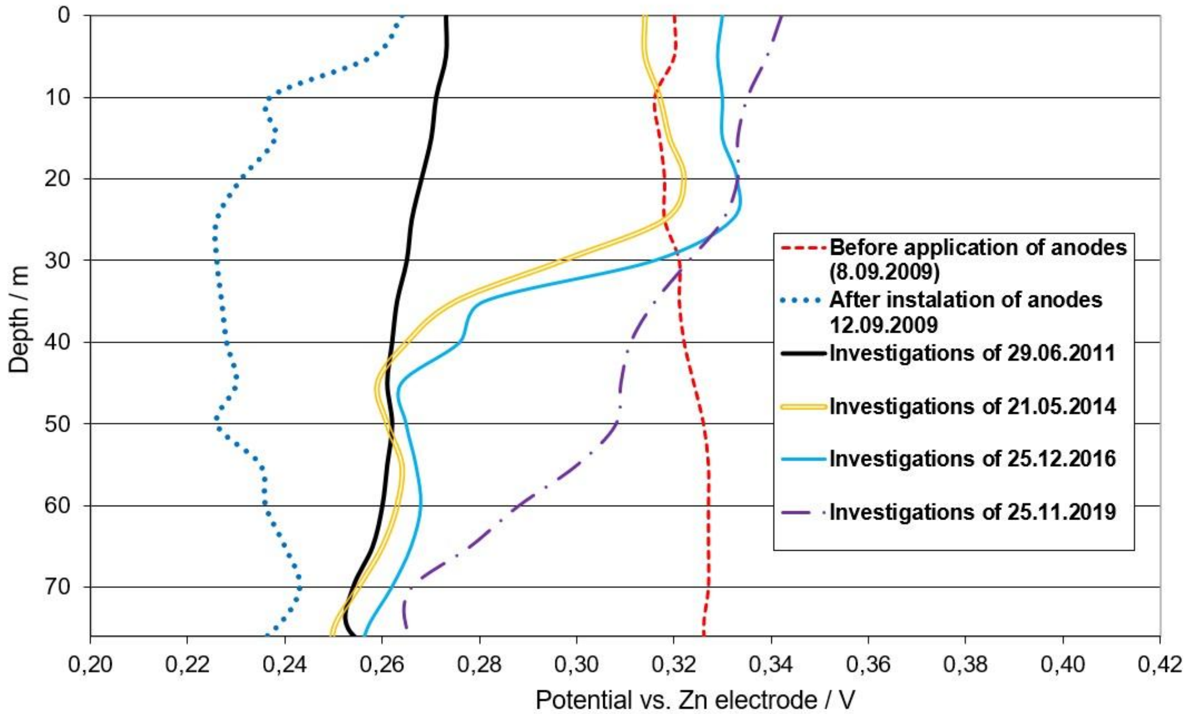


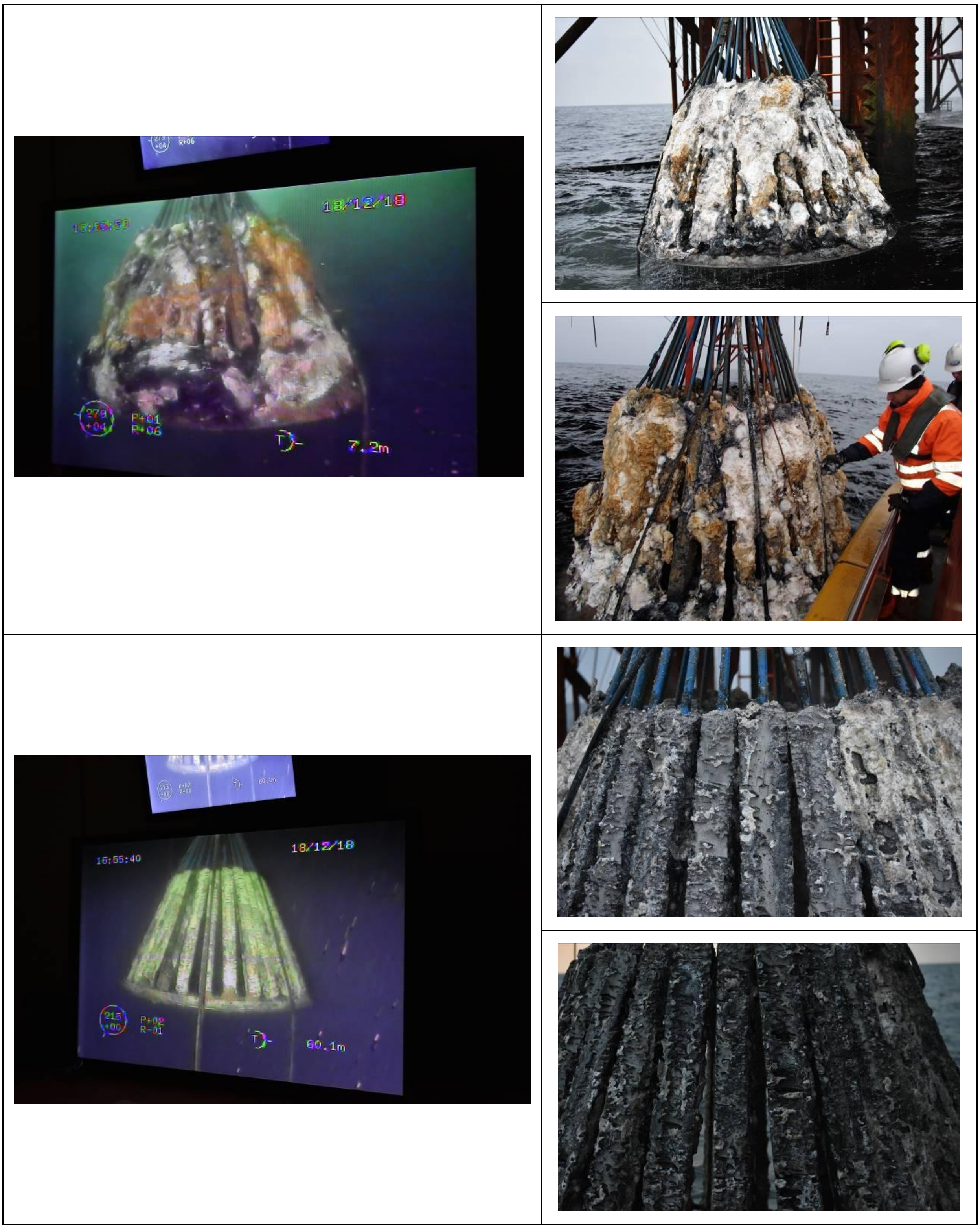
Fig. 6. *Potential profiles of the leg located on the right side of the stern, obtained during ten-year operation of the cathodic protection system.*

In both figures the red dotted line shows the potential distribution over the entire length of the legs in 2009 before applying new anodes. You can see that old, worn anodes welded to the legs (in accordance with the original protection scheme developed for the structure) did not provide enough current to polarize the legs to the potential of full cathodic protection. The value of the potential over the entire length of the leg located on the left side of the stern was in the range 0.34 - 0.35 V (see Fig. 5), and potential of the leg located on the right side of the stern was 0.32 - 0.33 V versus Zn electrode (see Fig. 6).

After installation of a new anode systems in 2009, the potential of the left leg decreased to 0.26 V at the bottom, and up to 0.3 V at the sea surface (blue dotted line in Fig. 5). The potential of the right leg was 0.24 V and 0.26 V, respectively (see Fig. 6).

In next years, there was a gradual deterioration in the cathodic polarization of the legs, which progressed with dissolution of the anode material and degradation of the protective coating over the years. At present, in November 2019, the system causes polarity of the left stern leg to the potential approx. 0.32 V at the seabed, 0.34 V at a depth of 40 m, and 0.33 V at the sea surface (see Fig. 5). For the right stern leg: 0.26 V by the seabed, 0.31 V at a depth of 40 m, and 0.34 V at the sea surface (see Fig. 6). Thus, an effect of partial cathodic protection of the legs is now obtained.

At the seabed, the potential of the leg located on the left side of the stern is more negative (0.32 V – Fig. 5 investigation in November 2019) than the leg on the right side of the stern (0.26 V – Fig. 6). This is due to the presence of bare, non-insulated steel casing pipes for the oil and gas extraction system (risers). These pipes capture the cathodic protection current flowing from the sacrificial anodes, which results in less current flowing to the platform legs. The result is less cathodic polarization, so the potential is more positive.



Photos 4–9. *One of the cone-shaped anodes basket during a cleaning procedure carried out at sea. The upper three photos show the cone before hydro-cleaning, and the lower three photos show the cone after is cleaned.*

Every time during potential measurements a close visual inspection of the anode groups (cones) is carried out. These inspections indicated that all cones are working properly, this is due to the fact that some products of aluminium alloy dissolution are overgrowing the surface of the anodes. Such deposits can reduce the flow of protection current from the anodes, this phenomenon is unwanted when it comes to corrosion protection. In order to obtain the original operating parameters of the anodes, it is necessary to clean them of the anode dissolution products. Due to their design, anode cones can be lifted and moved from the seabed, this property has been useful several times before during their lifetime. This ability is very useful and practical for any this type of objects when it comes to operating a platform at sea. In 2018, a decision was made to recover the anodes cones for a cleaning operation. Photos 4-9 show one of the cone during the cleaning process. Removing the overgrown dissolution products was carried out by hydro-cleaning, all of the loose material was rinsed off so that only the hard, unreacted protective alloy remained on the anodes. Information gathered during each previous visual inspection, gave concerns about the amount of alloy left on the anodes. After the cleaning process was finished it was clear that the amount of protective alloy remaining on the anodes is about 50% of the original volume. After the cleaning operation was completed, all of the cones were returned to their previous location on the seabed.

4. Conclusions

After installation of sacrificial anode groups placed on the seabed, providing complementary protection, the cathodic protection conditions of the platform legs improved significantly. The potential of legs near the seabed was higher than the full protection criterion by approx. 0.01–0.02 V, while closer to the sea surface (at a considerable distance from the anodes) protection conditions were weaker (at the level of 0.04 V above the criterion value). During operation of the system, deterioration of protection conditions could be observed resulting mainly from dissolution of sacrificial anodes and progressing degradation of protective coatings.

The experience gained during the ten-year operation of the cathodic protection system indicates that use of sacrificial anode systems mounted on the seabed can be an effective form of cathodic protection of offshore platforms legs. It is basically the only means of protection in case of a platform not able to leave its location for renovation works in a shipyard. The obtained measurement results indicate that sacrificial anode systems located on the seabed can polarize platform legs even over a length of 80 meters.

Dissolution of sacrificial anodes means that a periodic assembly of new anodes is necessary. The more degraded the protective coating gets over time, the higher the demand for cathodic protection current, which further accelerates wear of the anode material. The sacrificial anode groups installed on the seabed, anticipated for 10 years of operation, have worn out. Therefore, currently work is underway on the next same renewal of the cathodic protection system of the Baltic Beta platform legs. On the basis of experience presented in this publication, it is planned also to use additional anodes welded to the legs at a depth of 0-10 meters. They will provide a better cathodic polarization effect of the upper part of the legs to ensure polarization to the full cathodic protection potential.

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