Optimization of application Impressed Current Cathodic Protection design on the jetty steel structure to corrosion control

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Abstract. This paper discusses the case study of the impressed current cathodic protection (ICCP) system for jetty of barge loading conveyor (BLC). This impressed current cathodic protection system is corrosion mitigation using an inert anode and an electrical device: rectifier, voltmeter, DC source on the BLC structure, and jetty pile to provide accelerated corrosion protection to parts of the pipe submerged in seawater. In this study, a mapping of the service distribution of inert anode carried out so that it can protect the BLC structure and the pile. The results of the measurement of the structure potential and impressed current cathodic protection (ICCP) at BLC jetty considered to meet the protection criteria according to ISO 15589-2: 2012 standards. The obtained measurement results are in the range between -842 mV to -1197 mV (Ag/AgCl). The results of inspections and measurement of the output of the transformer rectifier show the total output current is safe.

1. Introduction
Barge loading conveyor as a large steel structure used for loading coal using conveyor from the coal terminal or storage, and then transferred to the ship. A typical BLC structure construction uses ASTM A 252 grade-2 carbon steel material for the upper structural or wide flange beam and its ASTM A 252 grade-3 pile pipe [1]. It is carbon steel, which is very susceptible to corrosion if there is a direct interaction between the metal and the marine environment is very corrosive [2].

The prior protection from this BLC structure is coating. Over time several structures have experienced paint damage so that the part will be easily corrosion [3]. The corrosion control so that the lifetime of BLC reaches the design age of 25 years or more, it is necessary to repair the coating, installation of cathodic protection and insulation of jacket pile [1]. The coating repair work was applied to the area above seawater or atmospheric area, while for submerged areas need to be installed cathodic protection. The cathodic protection with impressed current cathodic protection method on the BLC pile structure intended to inhibit corrosion, to extend the lifetime of BLC [4].

The ICCP method has used on many platforms, jetties with a high level of risk [5]. Based on BS EN 15112:2006 about external cathodic protection of wellhead casing, it stated that electric interference would occur if the ground bed cathodic protection system placed close to the earth electrodes of the telecommunications system [6]. There may be interference with the telecommunications circuit. It is
due to the harmonic currents of the fundamental frequency of the alternating current supply that supplies the rectifier unit, which drives unwanted noise voltages into the telecommunications circuit [7]. With a rectifier output current of order 5 Amp or less, interference is not possible.

The required components in the ICCP protection system are DC power sources or rectifiers, anode, electrolyte, pile as a cathode, and cable [8]. The rectifier generated electrons, and it flows to the anode, then through an electrolyte to surface of the structure, then flow together with the structure and back to the rectifier through an electrical conductor [9]. Because the structure accepts electrons, the structure becomes protected.

This paper discusses the impressed current cathodic protection type cathodic protection method using an external source of current, usually from an AC equipped with a rectifier so that it becomes a DC. Some researchers conducted a study on the supply of electricity from renewable energy sources [10,11]—the negative pole connected to the protected structure, and the positive pole connected by the anode. ICCP uses an inert anode, and potential as a basis for calculation. This method is considered more suitable to be applied for large protection areas on BLC jetty compared to the sacrificial anode cathodic protection (SACP) method, which uses the consumable anode [12].

2. Methodology

This design of the cathodic protection system using the impressed current cathodic protection (ICCP) method intended to control corrosion of large BLC steel structures. This protection system includes: (a) drilling deep well for ground bed anode 8 inches, 30 m depth, (b) installation of transformer rectifier, positive junction box (PJB), negative junction box (NJB), (c) installation of cable and bonding system (cad weld). The inspection of the ICCP system on the BLC structure consists of a visual inspection and measurement of the potential and electric current in the BLC structure.

The ICCP cathodic protection installation on the BLC jetty pile designed for a protection period of 10 years or more, according to the ground bed anode of the design system. Under recommended NACE SP0169 that the entire structure of the BLC Jetty pile should be fully cathodic protected [13], a negative (cathodic) potential should be at least -850 mV (Cu/CuSO₄) for the application of cathodic protection pipe/pile surfaces. This potential measured against a copper/copper sulfate reference electrode connected to a sulfuric acid liquid (Cu/CuSO₄); or at least -800 mV (Ag/AgCl) connecting seawater. Usually, this voltage must be measure by the applied protection current.

The current density measurements are distinguished for two conditions. The National Association of Corrosion Engineers (NACE) provisions recommend current densities between 10 and 30 mA/m² for CP steel structures on the ground/seafloor. The current density in structures affected by seawater (for submerged structures) is an average of 70 mA/m². The actual implementation of the system will use a current density between 15.25 and 20 mA/m² for embedded structures, and a bit tighter for submerged structures or seawater is 60 mA/m².

The soil resistivity must evaluate during the preparation step by applying the Four Pin Wenner method. The soil resistivity tested a Megger with 4 (four) pin resistivity meter models of 423 5 ER standard. The pin planted in the soil at the same distance (1 to 3 m). Four connecters of C1, P1, P2, C2 connected from the cable to the input terminals on the instrument. Then the clip/jack is connected to the circuit to provide the resistivity value.

Indonesian seawater resistivity for the underwater structure at the jetty is typically 25 Ω.cm. The Soil resistivity classified in BS 7361 [14]. That for extremely corrosive classification applied to soil resistivity between 0 and 500 Ω.cm [14]. The soil resistivity test has a survey of the intended to find a low resistivity zone or corrosive zone to the anode location. In addition, the soil resistivity tests carried out to obtain the value of soil resistivity for the design of the cathodic protection grounding system for jetty of BLC.

3. Results and discussion

A ground bed is an array of electrodes mounted underground to produce a path with a low resistance to ground. It is a vital component of the grounding system. The ground bed refers to regulation, the anode
in the ground, which provides a way to protect the current from the anode to electrolyte. The application of the ground bed has the aim to protect the cathodic. The ground bed used to provide cathodic protection to surface equipment and pipelines to prevent corrosion and any kind of damage.

A ground bed cathodic protection system is a cheap and very effective option because various BLC components do not need to be interrupted. All that is required is a deep hole for the anode of MMO tubular anode coated with metal mixture oxide [15]. No need to put anode near the structure; the hole can be as far as 30 m because it can produce currents that can reach the structure evenly. Using a foundation to provide cathodic protection simultaneously to a structure can be very beneficial.

3.1. Deep well for ground bed anode

The location of the land to be drilled is determined that for a minimum of 10 years. There will be no building on it and has a low soil resistivity below 1500 Ohm.cm. There is no risk of rocks that will inhibit drilling to a depth of 30 meters. The hole made using an 8 inches’ diameter drill bit.

Before drilling, make a test pit as deep as a minimum of 40 to 60 cm in the location to be drilled to ensure the condition of the site is safe, with no cables and other instruments underneath. The 8-inch diameter PVC casing pipe is used as the upper casing (above the anode boundary) while the MMO tubular anode circuit is placed at the bottom using a steel casing pipe.

The MMO anode, anode cables, vent pipes, and centralizers are firstly prepacked before being installed into the deep well ground bed anode (GBA) hole. Each MMO anode is connected by an XLPE (PVC insulated) cable to the positive/anode junction box (PJB) before the prepackaged MMO anode installed into the ground bed hole. A typical MMO anode connected with one ground bed is nine units. For two ground beds, it needs an additional one terminal cable connection to the rectifier transformer.

The 2 inches’ diameter vent pipe will be installed in the ground bed hole to prevent the accumulation of oxygen and chlorine gases in the ground bed hole. After all the anodes are in the ground bed hole, they backed up using Petroleum Coke Breeze SC-3. After Prepackaged MMO anode is lowered into the ground bed hole and connected to the positive junction box (PJB) anode, then the connecting cable from the positive junction box anode is connected to the positive pole of the transformer rectifier.

3.2. Transformer rectifier and junction boxes

The junction box anode foundation was measuring 50 x 40 x 20 cm placed between two deep well ground bed holes. After the concrete is dry, terminate the MMO anode cable. After cut MMO anode cable, immediately paint the support and concrete foundation to make it last longer. Pull the main cable from the anode junction box to the TR unit through the dug hole that has prepared, immediately buried more or less 10 cm thick sand, and do not forget to give a warning tape depth of 30 cm, and back up with soil.

After installing the cable to the H-beam jetty, the cable connector is pressed with the cable crimping tool and make sure the connection is secure enough. Furthermore, all wires that have tied together inserted into the junction box (JB or NJB) pipe. Junction boxes and concrete foundations placed in a safe position. The positive test lead cables are connected from the digital multimeter successively to each end of the bonding cable in the NJB and the reference electrode cell to the water. Measured potential readings should note in the available form.

Before termination, the natural potential of each jetty pile must be measure using a digital multimeter and a portable Ag/AgCl reference cell. Portable Ag/AgCl reference cell plunged into the surface of the seawater, the tip of the Ag/AgCl cable connected to the negative pole (-) digital multimeter (volt DC). Then, contact the positive test lead cable of the digital multimeter to the connection end of the bonding cable in the NJB and the reference electrode cell to the water.

3.3. Installation of cable and bonding system

The connection of cad weld cable to H-beam has done on H-beam jetty support. Potential monitoring on barge loading conveyor (BLC) piles can do in the negative junction box (NJB). Iron surface/H-beam
pile/jetty structure is clean before connecting cables. The coating layer on the surface of the H-beam jetty is peeled size 6 x 6 cm and then cleaned with dry sandpaper.

The XLPE insulation cables need along the jetty line until reaching the junction box. The end of the cable peeled along 2.5 cm, sand the surface of the cable core with sandpaper, clean and dry. Then, install the ‘disc’ (small, round metal plates) on the inside of the mold. This disc only works to hold the powder inside the mold, so it does not spill. Pour ‘25-gram powder charge’ into the mold. Make sure all the powder comes in, and the last part that poured in the powder at the capsule bottom, which is the powder or starting powder.

The mold that already contains powder and cable installed on the surface of the H-beam jetty. Make sure the mold position is right on the axle and stable. If necessary, the right and left sides of the mold can be propped up with a mastic sealer or molding putty, especially for small pipes. The shape tied with wire to the H-Beam, so the gun powder is shot; it does not need to be held and does not move.

Shoot gunpowder using a flint gun so that 25 gr gunpowder will react exothermally, a flame occurs in the mold, and the powder will melt into liquid copper, which joins the cable/stud bolt with the surface of the iron pipe. It is very important that during the exothermic reaction, the mold must remain stable and must not shake. After the reaction occurs, hold the mold position for about 10 seconds, then the mold can be removed, and be careful because the mold is still hot.

The strength of the joint that formed must try by tapping using a lightweight hammer or rubber hammer and tugging. A connection that is not strong enough or that is doubtful about its strength should be repeated. The mold let to cool and cleaned with scrapper and cloth before it used for the next joint. After the cable connection to the H-beam or jetty structure formed, the surface of the H-beam or structure at the connection and its surroundings, about 10 x 10 cm, is painted with a primer coating evenly. Before the cable terminated in the negative junction box and transformer rectifier (TR), it recommended that the ends of the cable are covered with tape insulation and put together with a cable tie.

3.4. Performance test
In this case study, the BLC jetty steel structure requires cathodic protection at about 2000 Amperes. The current demand supported by four transformer rectifiers, each of 500 Ampere capacity. Each rectifier serves two ground bed holes. Each ground bed hole contains nine MMO anodes by considering the resistance of vertical suspension anodes installation [16,17]. The steel structure of BLC jetty typically needs 72 MMO anodes.

Before the functional test begins, the MCB input on the panel or TR needs to ascertain in the disconnected position. The incoming cable or AC input connected to the power source, and the DC current cable from the anode connected to TR, then the wire from TR connected to the H-beam jetty pile. All bolts are firmly attached. Then connect the rectifier transformer to the alternating current or power source. The ICCP installation map, as shown in Figure 1, is prepared for functional tests and used as a future reference for online data monitoring and integration.

Before testing the rectifier, the TR capacity check includes AC input (3 phases, 380VAC, 50 Hz) and DC output from TR (500 Ampere, 40-50 Volt). Adjust tap settings to the lowest position conditions. The measure jetty potential, namely the natural potential, for example, -0.652 mV, before TR turned on connected position. Connect the transformer rectifier to the alternating current or power source. After the TR turned on, measure the AC input and DC Output. Then check the potential on the jetty. Then change the settings to increase the DC output from TR starting from the lowest to the required needs. Then check again after the DC output set raised. Figure 2 shows the measured electrical potential in each junction box.
The results of the measurement of the potential structure and cathodic protection system at BLC jetty are considering to meet the protection criteria according to ISO 15589-2:2012 standards [18]. Negative potential that is measured at least -850 mV (CSE) or -800 mV (Ag/AgCl). The measurement results obtained are in the range between -842 mV to -1197 mV against Ag/AgCl. The measurement results of the output transformer rectifier conducted on 4 TR varies between 0.10 and 11.27 Ampere. The current output rating of MMO anode is 24 Amp for 15 years’ service life or equals to 36 Amp for ten years for fresh soil seawater application.

4. Conclusion
The ICCP cathodic protection applied has a protection design for at least ten years for fresh soil seawater application. All potential structural measurements have met the protection criteria according to ISO 15589-2:2012 standard. An acceptable negative potential is min -850 mV (CSE) or -800 mV (Ag/AgCl). The measurement range ranges between -842 mV and -1197 mV (Ag/AgCl). The inspection of four transformer rectifiers, the total output current, is still safe. The inspection and trial run results show that the ICCP cathodic protection system has been operated properly per the NACE SP0169-2013 standard.

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