CATHODIC PROTECTION OF SUBSEA SYSTEMS: LESSONS LEARNED

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ABSTRACT

Coatings and cathodic protection (CP) are the principal measures for external corrosion control of subsea equipment. Each subsea structure or component of an offshore development has its own independent cathodic protection design generally performed by the equipment supplier. Once all subsea equipment is installed and connected, the cathodic protection systems function as one integrated unit providing corrosion control throughout the entire subsea field. To ensure the proper functioning of the CP system over the service life of the field, development and implementation of a planned inspection and CP monitoring program is required. This paper describes CP issues experienced offshore and guidelines to avoid some of these issues. A key objective of this paper is to share experiences that will aid in optimizing cathodic protection designs and improving integrity management practices.

Key words: Cathodic protection, electrical continuity, anode, inspection

INTRODUCTION

Subsea equipment typically utilizes protective coatings as the primary measure for protection against external corrosion, but in any real world application, coatings may provide less than 100% coverage, due to a variety of reasons which includes poor surface preparation or application, damage, and degradation over the service life. CP is used as a backup system to prevent external corrosion on surfaces not protected by coatings. This is typically accomplished using sacrificial aluminum alloy anodes for subsea equipment, but an impressed current cathodic protection (ICCP) system may be used in rare cases. These CP systems must be designed for the service life of the equipment and function in tandem with other electrically continuous CP systems in the subsea development including fixed or floating production structures, pipelines and risers, and subsea structures. The scope of this paper covers sacrificial anode CP systems and does not include ICCP systems.

Due to the nature of a fieldwide CP system, a thorough system wide corrosion control design review and verification is important to determine that the individual equipment CP systems are not only adequate, but also will function as a part of an integrated system. The system verification should include a review of all corrosion control design documentation to assure that client specific requirements and those of governing design standards such as DNVGL-RP-B401 [1] and DNV-RP-F103 [2] are met. Anode sizing and layout should be reviewed to assess efficiency with respect to current output and to help assure uniform anode consumption over the service life.

Electrical continuity between the sacrificial anode system and all subcomponents of subsea facilities is key to assuring adequate cathodic protection to all equipment over the service life. Procedures and instrumentation used for determining electrical continuity or isolation should be reviewed to ensure they will accurately determine any potential concerns.

Once assets have been installed, a baseline CP survey confirms that the system is operational and can help identify any unexpected anomalies that can be tracked over the service life. The baseline survey is also the starting point for tracking trends in CP system performance over the service life. This aids in proactive planning for any required remedial action such as anode retrofit or continuity bonding.

The objective of this paper is to share lessons learned related to CP systems and issues that have been observed in the field.

ELECTRICAL CONTINUITY

Electrical continuity between the sacrificial anode system and each subcomponent of an underwater structure or assembly is required to ensure that the entirety of the structure receives adequate CP over its service life. Since sacrificial anodes are typically welded to the structure being protected, electrical continuity with the weldment or any subcomponents in a direct weld path is achieved and no further testing is required. However, electrical continuity between the anodes and non-welded subcomponents of the structures requiring cathodic protection cannot be assumed. Continuity measures, such as coating removal, serrated washers, or bonding cables may be required to assure electrical continuity between non-welded subcomponents such as fasteners or across hinged or mated connections.

Electrical Continuity Testing

Electrical continuity or isolation tests should be performed in conjunction with factory acceptance tests (FAT). Care should be taken to include all non-welded equipment or parts requiring CP such as fasteners. The accepted criterion for electrical continuity is an electrical resistance between the anode and the subcomponent less than 0.1 ohm, as measured with a digital milli-ohmmeter with a minimum resolution of 0.01 ohm.

Note that any structure subcomponents that cannot feasibly be electrically bonded to the CP system should be either 1) constructed of corrosion resistant materials, or 2) be equipped with a dedicated CP system consisting of galvanic anodes. An electrical discontinuity would result in a part of the subsea equipment not receiving adequate CP. DNV-RP-B401 [1] specifies that for continuity a resistance measurement between two locations on subsea equipment should not exceed 0.1 ohms. Electrical continuity is therefore a key part of CP system design and verification.

Case Study – Electrical Discontinuity

During a baseline CP survey, a subcomponent for a subsea tree was noted to be discontinuous from the subsea tree CP system. The subcomponent is bolted to the frame of the subsea tree which is equipped with weld-on type aluminum alloy anodes. Potentials taken on the subcomponent were approximately -650mV to Ag/AgCl/seawater, which is indicative of freely corroding carbon steel. Potential values on the tree frame across the bolted connection were more negative than -1000mV to Ag/AgCl/seawater. The bolted connection did not establish electrical continuity between the main subsea tree and the subcomponent and thus had to be remediated with an electrical continuity strap installed by an ROV. Proper electrical continuity testing during factory acceptance testing would have detected the discontinuity and thus prevented the need for remediation and associated costs in early service life.

Current Drains

In addition to electrical continuity across a single piece of subsea equipment, the electrical continuity of the entire subsea field should be considered during design. A CP design should include all ancillary equipment that requires cathodic protection and ensure that current drains to structures not equipped with a dedicated CP system are addressed in the CP design. These structures may include well casings, anchor chains, or installation aids.

Case Study – Current Drain

As an example, a top tensioned riser (TTR) system equipped with a thermal sprayed aluminum (TSA) coating was installed in a deepwater development. A general layout of a TTR is shown in Figure 1. The subsea wellhead assembly on each riser was equipped with sacrificial anodes. As part of the risk based CP surveys, the wellhead assembly anodes were observed to be prematurely depleted, the TSA coating on the associated riser was activated, and a declining trend of measured cathodic potentials were recorded specifically on the bottom third of the TTR as shown in Figure 2. TSA coating activation was evidenced by presence of a white powdery corrosion product on the TSA coating resulting from the activating aluminum. Research into the cathodic protection design for the wellhead assembly showed that current drain to the well casing had not been considered in the CP design. As such, the large current drain to the well casing resulted not only in premature depletion of the wellhead anodes but also to activation of the TSA on the connecting top tensioned riser. Remediation was accomplished by retrofitting a sacrificial anode sled to the wellhead assembly to satisfy current drain to the casing and to provide supplemental CP current to the wellhead assembly and the riser for the remaining service life.

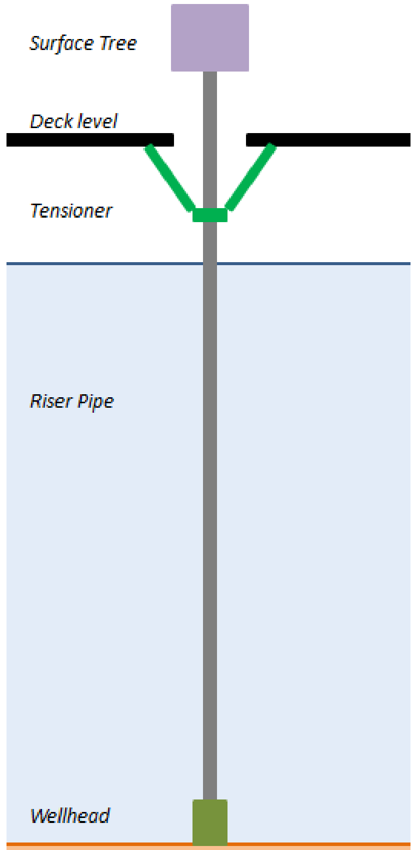

Figure 1: An Example TTR Stack-up

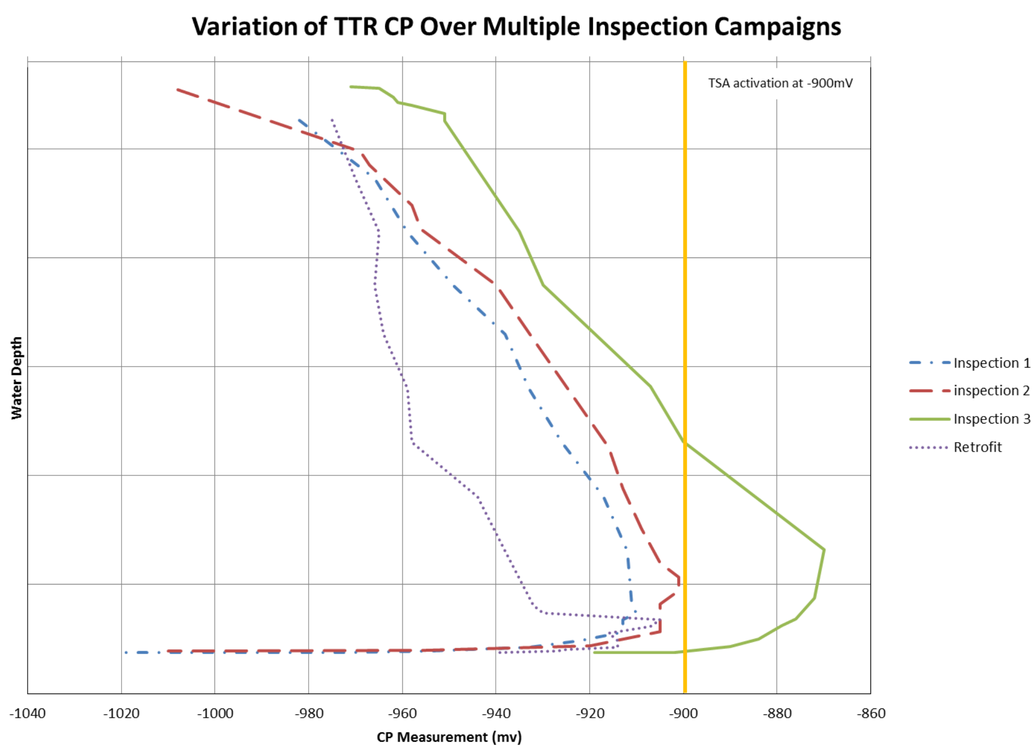

Figure 2: Example CP Results for TTR

ANODE OPTIMIZATION

Optimization of anode configuration, sizing, shape, and layout is crucial to maximize the effectiveness and life expectancy of the CP system. Considerations in optimizing anode design and layout include the following:

- Rapid polarization
- Reducing excess anode weight
- Ease of installation
- Minimizing interference with equipment fabrication, installation, and maintenance or monitoring (ROV operations)
- Minimizing mutual anode interference
- Assuring uniform anode consumption
- Maximizing anode utilization or efficiency
- Uniform current distribution

Anode Sizing

In general, anode sizing and shape should be developed based on an analysis of design requirements for anode mass and initial or final current output. Ideally, the anode requirement for current output and mass should be similar to minimize excess anode mass and maximize polarization capacity. Anode size and core configuration should reflect consideration of space limitations, mutual anode interference, and avoiding interference or clashing with equipment installation, operation or maintenance. In general anode sizing should be as large as feasible while satisfying the previously listed considerations. Where feasible, anodes for an individual structure should be the same size and type to minimize differential anode consumption. Major non-electrically continuous subcomponents of larger structures such as yokes, mudmats, and piping support structures of pipeline end terminations should each be equipped with dedicated anodes to eliminate the requirement for electrical bonding between components. Bonds can be damaged or be loosened during facility installation and lead to loss of CP during service life.

Anode Layout

In addition to the anode shape and size, the anode layout should be optimized to create an efficient CP system. When determining possible anode layouts, anodes should be evenly spaced over a structure to provide uniform current distribution. This is particularly important on uncoated structures where current requirements are much higher. In particular, current distribution should be carefully considered on uncoated structures with complicated geometries, where cathodic shielding may be an issue. For most subsea structures which are well coated, cathodic shielding and current distribution in general are not critical issues.

A larger issue for anode layouts on subsea structures is mutual interference between adjacent anodes. Specifically, interference between closely spaced, geometrically parallel anodes can greatly reduce anode current output. Parallel arrays of closely spaced anodes should be avoided. When possible, placing anodes end to end, perpendicular, or staggered allows for a lesser impact on anode current output. If closely spaced parallel anodes cannot be avoided due to space limitations, calculations should be performed to assess anode current output to assure that CP design requirements for total initial and final current output are satisfied. An example of a parallel anode array is shown in Figure 3 on a mudmat. An example of anodes rearranged into end to end, perpendicular, and staggered configurations are shown in Figure 4, Figure 5, and Figure 6, respectively, to show layouts where anode interference is not a concern.

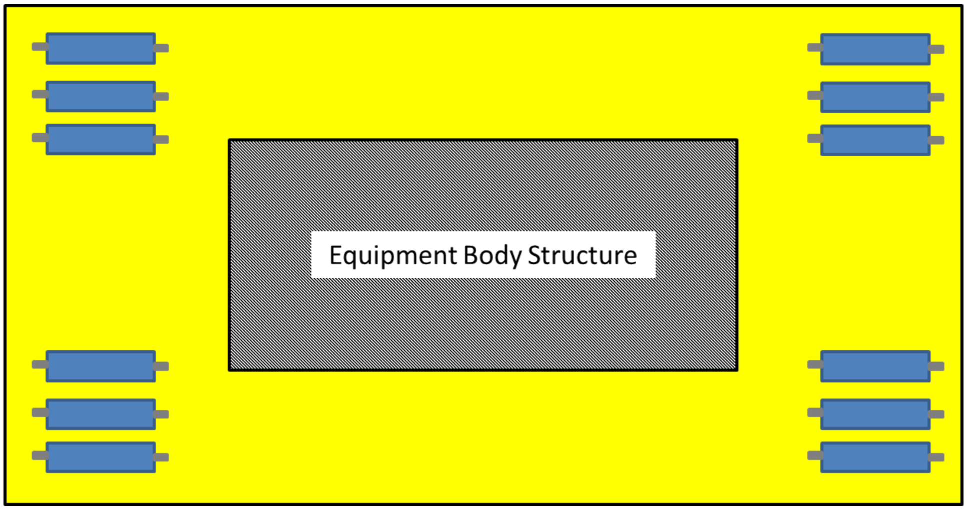

Figure 3: Example Mudmat Anode Layout with Parallel Arrays (Not Preferred)

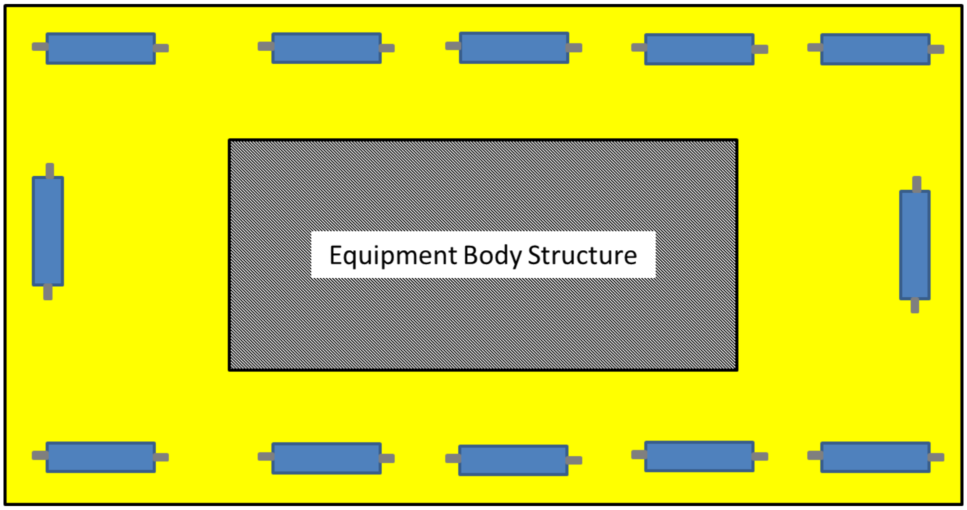

Figure 4: Example Mudmat Anode Layout with End to End Anodes (Preferred)

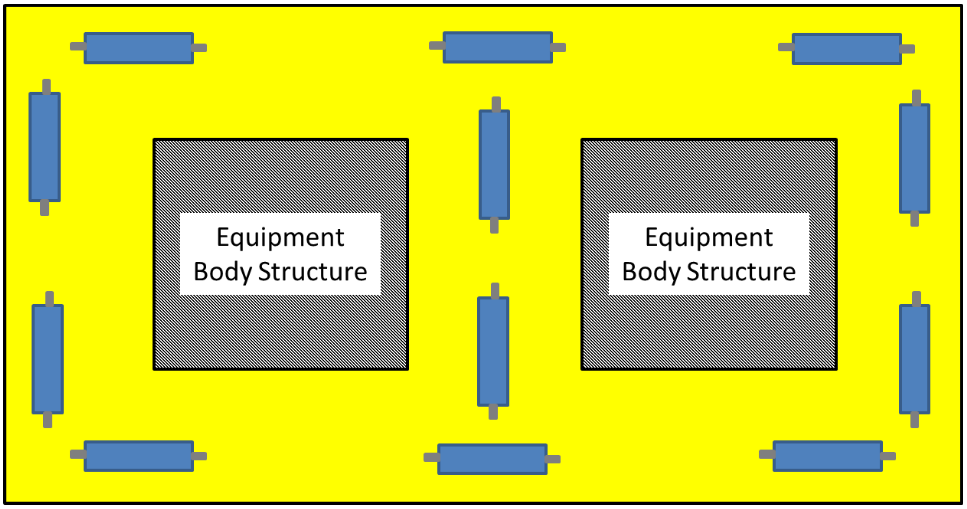

Figure 5: Example Mudmat Anode Layout with Perpendicular Anodes (Preferred)

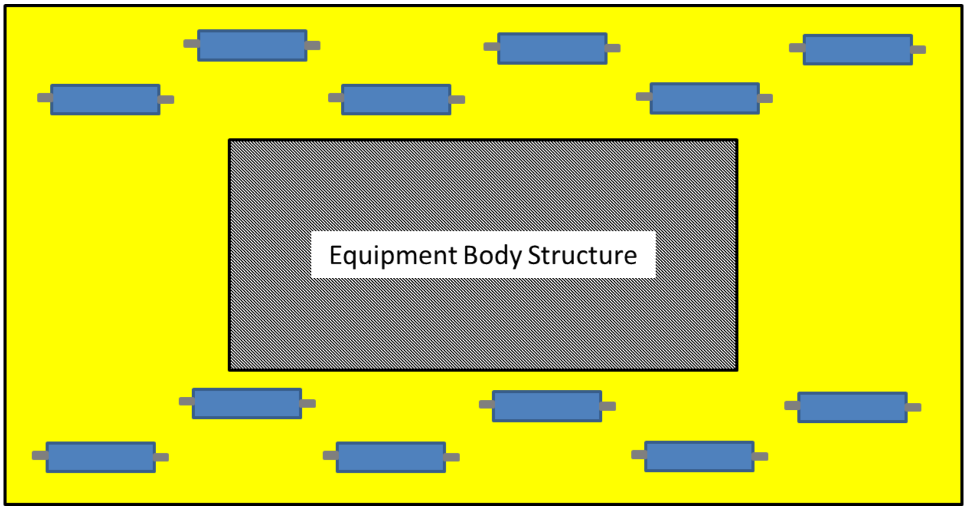

Figure 6: Example Mudmat Anode Layout with Staggered Anodes (Preferred)

Case Study – Subsea Tree Anode Layout

Subsea trees are key subsea equipment within a subsea field development and typically have large surface areas both coated and uncoated. Depending on tree design, space for attachment of anodes may be restricted due to limited frame space and overall congestion. Tree CP designs typically include the requirements of the associated well casing which constitutes a large current drain, further complicating anode placement.

A subsea tree had large anode requirements due to a 30 year service life, elevated temperature piping, numerous current drains such as uncoated tubing and fittings, a well casing, and cold, high resistivity seawater. Due to congestion in certain areas of the structure, anodes were crowded into multiple anode arrays of closely spaced parallel anodes. In less congested areas of the structure, anodes were well spaced resulting in little mutual anode interference. Calculations of current output were performed for the arrays of closely spaced anodes and for adequately spaced anodes. Results of the calculations showed that the current demand from the tree would result in premature depletion of the adequately spaced anodes, leaving anodes in closely spaced arrays largely unconsumed due to mutual interference. The closely spaced anodes would then not have the current output capacity to provide CP to the tree over the remaining service life. The solution was to design and install a sacrificial anode sled to be retrofitted after the tree installation.

BASELINE CATHODIC PROTECTION SURVEY

Once fully installed, a subsea development acts as one large CP system, where typically all components are electrically continuous. A baseline CP survey is the important final step in CP system verification for a subsea field. The baseline survey provides confirmation that the system has polarized and is providing protection to the subsea equipment. Additionally, the baseline CP survey helps to identify any potential areas of discontinuity or other anomalies that may have resulted from deficiencies in design or from the installation process; as well as, baseline CP potentials for each subsea component for future CP health monitoring. It is typically recommended that a baseline CP survey is completed within the first year of operation after subsea equipment has been installed. This provides time for the system to fully polarize.

Cathodic Protection Inspection

During a CP inspection it is important to capture the relevant details to assess the health of the CP system. The CP measurements must meet the acceptable criteria for the material, typically more negative than -800mV to an Ag/AgCl/seawater reference electrode. Observation of the condition of the anodes is also important in assessing whether the anodes are functioning properly and often to estimate degree of depletion relative to service life. The condition of an anode or anodes can also provide insights into current drain from anodes on one structure to another electrically continuous structure.

Case Study – Anode Activity

A subsea field had a baseline inspection completed, which included a CP survey to confirm functionality of the system. It was noted during the survey that the flush mount anodes on a subsea distribution unit (SDU) equipment body had been largely consumed over a very short service life. The CP measurements on the SDU body confirmed that adequate CP was being provided.

Concern was raised that the SDU anodes were being consumed so early in the CP system service life. Examination of the field layout showed that the SDU was connected through flying leads to two subsea trees, each equipped with a sacrificial anode CP system. A subsequent visual inspection showed that tree anodes were being consumed at a rate generally consistent with the tree service life. The premature depletion of the SDU anodes was determined to be caused by the large differential in anode size between the small SDU anodes and the much larger tree anodes. Since the SDU and trees are electrically continuous, the anodes on both structures are working together to protect both the SDU and the trees. This results in the small SDU anodes being consumed quickly, since they are helping to protect a much larger structure than designed for. Fortunately, as the smaller anodes are consumed, the larger anodes on the tree will provide protective current to the SDU with no net loss of CP system service life. This situation is common in subsea fields due to the large variation in anode sizing, and is often the cause of unwarranted concern over premature consumption of smaller anodes. If all CP individual systems comprising a field wide system are adequately designed for the field life, premature consumption of smaller anodes becomes a “cosmetic” concern instead of a true integrity concern. This can be confirmed by performing a CP design audit to confirm that connecting structures are equipped with adequate CP systems and by performing periodic CP potential surveys over the subsea developments service life

CONCLUSIONS

CP systems are used along with coatings on all subsea facilities as a preventative measure against external corrosion. Through design, verification, inspection, and remediation of CP systems there are important lessons to be shared. Experience including case studies from CP design verification audits, electrical continuity testing, anode sizing and layout, and the importance of an integrated CP system has been shared in this paper.

Incorporating these lessons with a robust CP design can help prevent asset integrity issues caused by external corrosion during the life of a subsea development. CP design verification audits are a useful tool to assure independent equipment CP designs are compliant with project requirements and applicable industry standards, as well as to confirm CP functionality as a fully integrated unit across the subsea asset. Electrical continuity should be confirmed during FAT testing on all non-welded connections including all bolted, hinged, or mated connections using instruments capable of measuring to the accuracy level required. Anode sizing and anode layout should be reviewed to ensure an optimal CP design and adequate spacing to prevent interference issues. Finally, once a system has been installed, a baseline CP survey should be performed to confirm fitness for service, establish baseline potentials, and to identify anomalies or deficiencies that may require remediation or ongoing monitoring during periodic subsea inspections.

REFERENCES

1. DNVGL RP-B401 (edition June 2017), “Cathodic Protection Design”.

2. DNV RP-F103 (edition October 2010), “Cathodic Protection of Submarine Pipelines by Galvanic Anodes”.