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Clark P. Weldon

and

David H. Kroon, P.E.
Vice President of Engineering
CORRPRO Companies, Inc.

corrpro®

Corrpro Companies, Inc.
1090 Enterprise Drive
Medina, OH 44256
330.723.5082
WWW.CORRPRO.COM

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Construction and operation of offshore production facilities is tremendously expensive. The consequences of an offshore corrosion failure can be devastating. For these reasons, cathodic protection has become a universally applied technique for mitigating corrosion on marine pipeline and production facilities.

Marine pipelines are typically provided with cathodic protection by bracelet anodes of zinc or aluminum. Impressed current systems at platforms or onshore are also used, as well as hybrid systems which employ a combination of the two techniques. For marine structures, aluminum anodes are often attached to the jacket, although impressed current and hybrid systems are also common.

Whatever the method of applying cathodic protection, the primary concern is arresting corrosion. For cathodic protection to be effective in arresting corrosion, a properly planned program of monitoring, inspection and maintenance is essential.

The most widely accepted method of evaluating cathodic protection on pipelines and structures is through the use of potential measurements. Potential measurements on offshore pipelines have traditionally been recorded only at readily accessible locations such as platform risers, wellheads, and test stations located near shore. Divers can be used to take potential measurements on unburied pipelines, but this procedure is much too costly to use extensively.

Monitoring of pipeline cathodic protection only at platforms or shore installations provides limited information. It is possible that serious corrosion can be occurring on a pipeline even when potentials at a riser or test station satisfy the criteria for cathodic protection.

In many respects, the same is true for platforms. Potential measurements taken from the surface frequently do not reflect the significant data necessary for comprehensive evaluation of the cathodic protection system. In many cases, areas of low potential indicating lack of protection are highly localized at nodes, conductor bays or skirt pile guides. These anomalies would typically not be detected unless a detailed inspection and potential survey was performed.

Corrosion surveys and inspection of offshore platforms and pipelines are particularly important at this stage in development of our offshore petroleum resources. Many existing offshore platforms and pipelines are reaching the end of their cathodic protection system design lives. Decisions must be made as to if and/or when additional

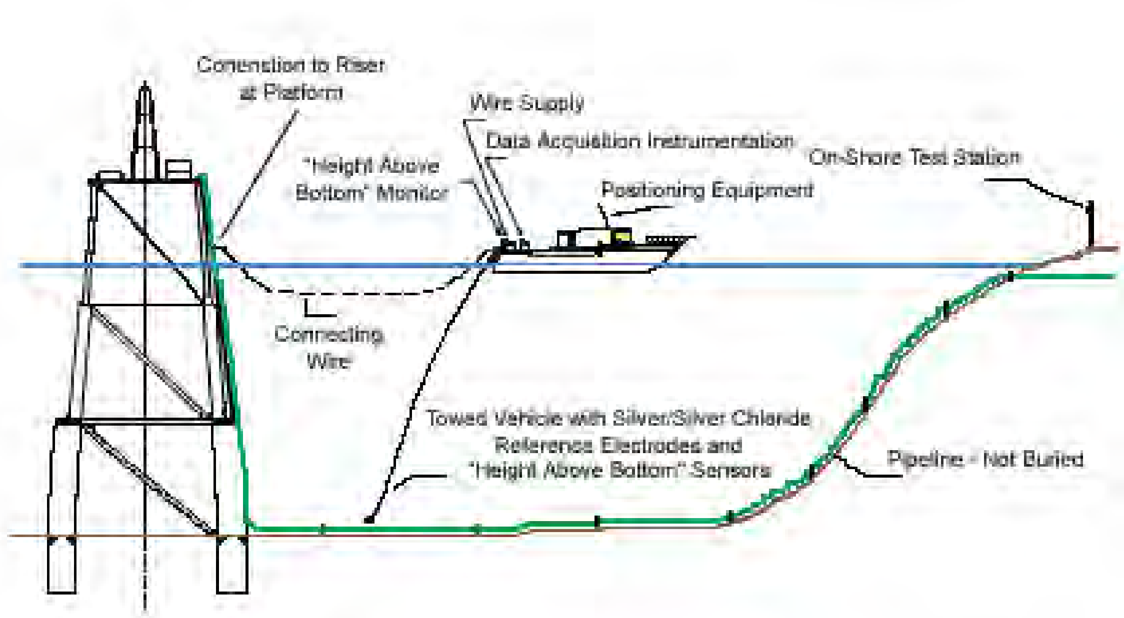


Figure 1 Towed Fish/Trailing Wire Survey

cathodic protection must be retrofitted to prevent corrosion failures. The data provided by corrosion surveys and inspection plays a key role in this decision making process.

The industry move into "deep" water has also had a tremendous impact on corrosion control practices. Deep water platforms and pipelines present new challenges for design, maintenance, inspection and retrofit of corrosion control systems. The advent of the remotely operated vehicle (ROV) has radically altered corrosion survey and inspection practices.

Probably the single most important development in the last several years with respect to offshore corrosion survey and inspection methods is the use of computers Computerization of survey data acquisition, processing and management has provided the means for development of all of the state of the art corrosion control techniques used today. These include close interval pipeline surveys, modeling of platform cathodic protection and inspection data management systems.

The purpose of this paper is to present an overview of corrosion control survey techniques in use today for monitoring and maintenance of offshore pipelines and platforms. The paper also includes a discussion of computerized inspection data management techniques.

Towed Vehicle/Trailing Wire Pipeline Survey

The Towed Vehicle/Trailing Wire potential survey is probably the most widely used method for monitoring cathodic protection levels along offshore pipelines. The survey is performed by making a test connection to the pipeline at an accessible location such as an offshore platform riser or onshore test station. Alternately, the survey may be performed with a test connection to a stationary electrode placed on the sea floor at a location where the pipeline potential is known. A silver/silver chloride reference electrode is towed above the pipeline from a vessel while maintaining the test connection. The pipe-to-electrolyte (P/E) potential is measured and recorded on board with a computerized data acquisition system. The potential is displayed on a video terminal and plotted on a graphics printer' (see Figure 1).

The pipeline is generally tracked by electronic positioning equipment in conjunction with as-built coordinates. Side scan sonar or marine magnetometers can be used, particularly when the accuracy of the as-built coordinates is in question, or is not available.

The foremost objective of this survey is to determine the general level of cathodic protection relative to the NACE. criterion of -800 millivolts to Ag/AgCl. Figure 2 shows a typical P/E potential profile. Study of the profile indicates adequate cathodic protection with the exception of approximately 4000 feet of pipeline centered at seven thousand feet from the platform. Potential values recorded on this section are more positive than the -800 millivolt criterion for cathodic protection. A depression in potential value of this magnitude is typically caused by either severe coating damage or anode depletion. The exact cause cannot be determined from the potential profile alone.[1]

The continuous towed vehicle survey can also provide information to determine magnitude and direction of long line currents, electrical interference, and current requirements.

The towed vehicle/trailing wire survey is used to determine the overall P/E potential profile and for location of major problem areas such as areas of coating damage or anode loss. The advantages are relatively low cost, when compared to submersible or diver assisted surveys, and simplicity of theory and operation. Additionally, this is the only technique which can be used economically on buried pipelines and under other conditions where visual or magnetic tracking with a diver or R.O.V. is difficult to impossible.

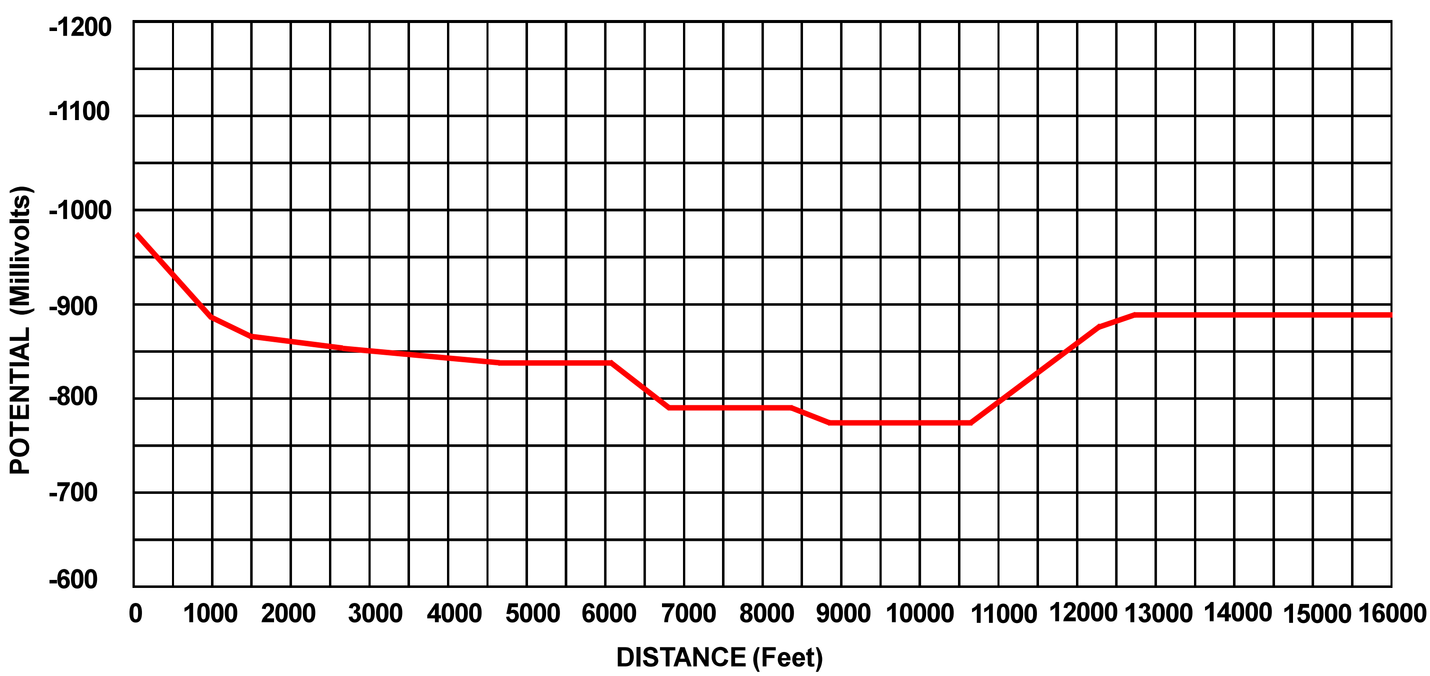
The primary disadvantage is lack of sensitivity to minor anomalies such as individual anode bracelets, small coating defects, and poorly insulated field joints. On a well polarized pipeline, anomalies such as these can be detected only when the reference electrode position is maintained at a distance of less than approximately two pipeline diameters from the pipeline.

Submersible/Trailing Wire Pipeline Survey

This technique uses the same principles as the towed vehicle survey, but a submersible is used to carry the reference electrode along the pipeline. Under normal circumstances, the reference electrode position can be maintained within a meter of the pipeline at all times. This makes it possible to detect features such as bracelet anodes and coating holidays that cannot be detected using the towed vehicle method.

Figure 3 illustrates the technique using an unmanned submersible (remotely operated vehicle) to carry the reference electrode. Note that the R.O.V. is only used as a vehicle for the reference electrode. All wire handling and data acquisition are performed on board the support vessel which is connected to the R.O.V. by a tether.[2]

Figure 2: P/E Potential Profile - Towed Fish Survey



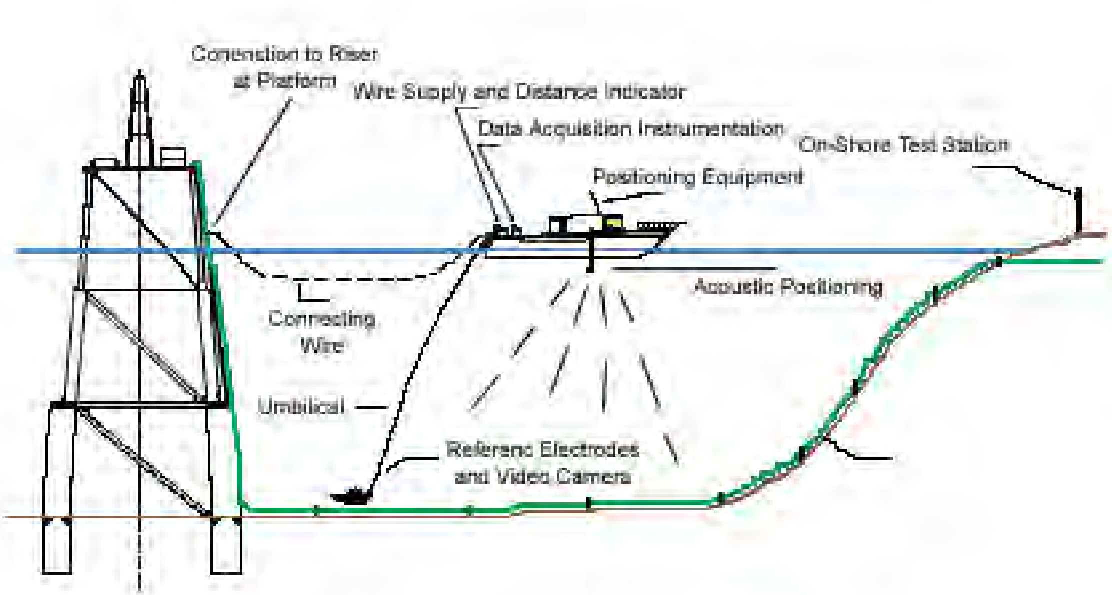


Figure 3 Unmanned Submersible Trailing Wire Survey

Reading location is typically determined using conventional electronic surface positioning (ship location) interfaced with underwater acoustic positioning (ROV location). Reference points such as anode bracelets, pipe joints, line crossings and risers serve as calibration points for the positioning systems. Position fixes are electronically entered into the cathodic protection survey data stream at fixed intervals and at anomalies. The survey data is later plotted versus pipeline stationing to provide a detailed continuous potential profile of a pipeline. This includes detection of individual bracelet anodes, coating holidays, and poorly coated or damaged field joint wraps. A short section of typical data is shown in Figure 4. Study of the data indicates the presence of two functioning bracelet anodes and two poorly coated field joints.

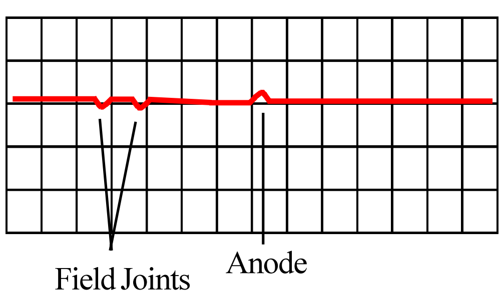


Figure 4: P/E Potential Profile-Submersible Assisted Survey

The primary advantage of the submersible technique is the increased sensitivity to minor changes in potential. The survey provides a detailed P/E potential profile, pinpoints the location of problem areas, and provides information concerning the cause of a problem. The submersible potential survey is ideally performed in conjunction with electric field gradient (cell-to-cell) measurements. This provides even greater resolution of anomalies and aids in the interpretation of the P/E potential data.

The primary disadvantage of the submersible survey is relatively high cost per pipeline mile. The cost of a submersible survey is approximately 7 to 10 times the cost of the towed vehicle survey on a per mile basis. For this reason, most submersible assisted cathodic protection surveys are performed in conjunction with other work requiring an ROV.

A particular disadvantage of the Submersible/Trailing Wire technique is that the use of a trailing wire during an ROV aided survey can be difficult. The survey progresses by maintaining the position of the survey support vessel above the ROV as the vehicle travels along the pipeline. This maneuver called "live boating" requires skillful interaction between the survey vessel captain, the navigators and the R.O.V. pilot. The trailing wire can further complicate this often delicate process particularly when weather conditions are poor.

Remote Electrode Submersible Survey

The most commonly used submersible aided survey is the remote electrode survey. This technique has been popular in the North Sea for nearly ten years and is commonly used as a component of many pipeline inspections or surveys.

The remote electrode submersible survey measures the potential between a Ag/AgCl electrode positioned just above the pipeline and a "remote" electrode located near the water's surface above the pipeline. This measurement is used in conjunction with direct contact P/E potential measurements at anodes and other accessible locations to produce a continuous P/E potential profile. A schematic of the remote reference electrode survey is shown in Figure 5.

At the start of a remote electrode survey, a direct contact P/E potential is measured at an accessible location such as a bracelet anode. Simultaneously, the potential between the electrode close to the pipe and the remote electrode mounted on the submersible umbilical is recorded. This establishes the fixed voltage offset between the pipe potential and remote earth The two electrodes are then moved down the pipeline and the potential between the electrodes is continuously recorded. The P/E potential at any particular point on the pipe is then the P/E potential recorded by direct contact, plus the voltage offset between the close and remote electrodes at the point of direct contact, minus the potential between the remote and close electrodes at the particular point.

The primary advantage of this method is its relative ease of operation. Unlike the trailing wire technique, the remote electrode method has little or no effect on the ROV "live boating" operation.

The primary disadvantage is that direct contact potential readings are required to establish the original voltage offset and to recalibrate the measurements at frequent intervals.

This is required because the remote cell is moving and is subject to some potential drift or variation over time. This requirement virtually excludes the use of the remote electrode survey on pipelines that are continuously buried over long distances, as is the case with many pipelines in the Gulf of Mexico.

Electric Field Gradient Survey

Electric field gradient (E.F.G.) measurements are usually made in conjunction with potential measurements obtamed using an R.O.V. E.F.G. measurements are made by measuring the potential of two electrodes placed at

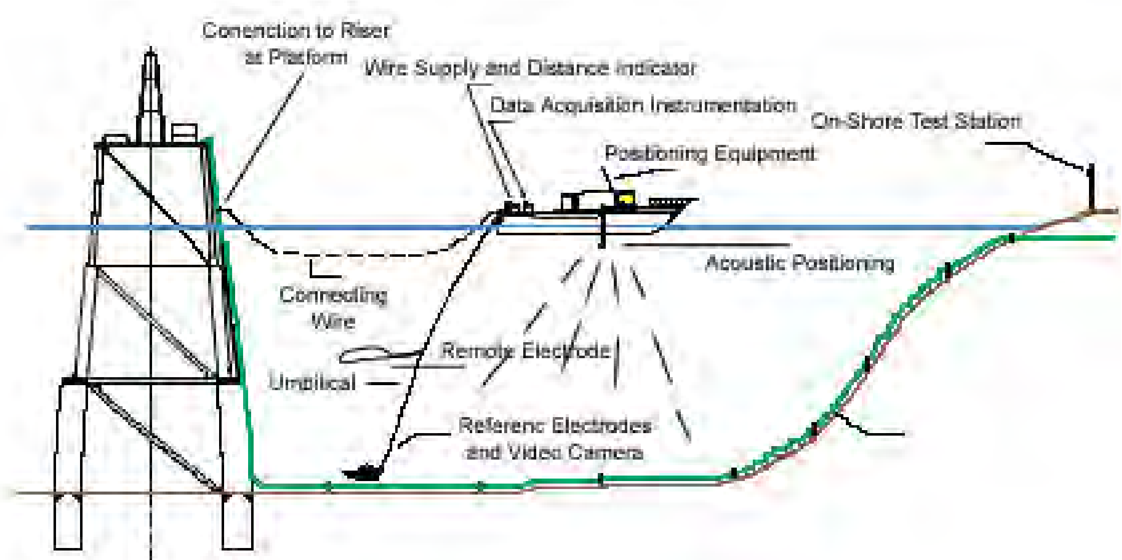


Figure 5: Remote Electrode Survey

a known distance apart in a plane perpendicular to the pipeline. This is typically accomplished by mounting two or more electrodes on a submersible, aligned so that they are normal to the pipeline, as the ROV proceeds along the pipeline. The electrodes may be spaced from a few inches apart to over two feet apart depending on the equipment.

One operator uses a rotating "T sensor" with two electrodes to measure EFG The sensor is rotated to eliminate errors caused by electrode potential drift over the course of a survey. The operator claims precision of up to 1 micro-volt/cm using this technique.[3]

Electric field gradient measurements are used to detect changes in current density and direction at all points along a pipeline. This allows detection of anomalies such as nonfunctioning anodes, coating holidays, and defective field joint wraps which may not be detected by P/E potential measurements. EFG also provides data useful for estimation of current densities associated with anodes (current output) and coating holidays. This information can be used to predict cathodic protection system life and for design of future pipeline cathodic protection systems. Please note, however, that due to the complex nature of the pipeline environment and the EFG measurement, accurate calculation of anode output is extremely difficult, if not impossible, using existing survey techniques. A number of variables must be considered in this calculation including electrolyte resistivity, degree of anode burial and anodesensor geometry. A study performed in 1982 of the various methods for offshore pipeline cathodic protection systems states that ".... calculations of anode currents from current density on electric field gradient measurements suffer from considerable errors such as those introduced when measuring the c.d/e.f.g., determining the sensor to anode distance and the direction of the measurement and furthermore estimating the symmetry of the electric field."[4]

E.F.G. measurements are extremely useful for determining location and relative severity of coating holidays, and for locating disfunctional anodes. The measurements can also provide a useful comparative estimate of anode outputs They do not provide highly reliable data for determining anode life or P/E potential. E.F.G. measurements are most valuable when used in conjunction with P/E potential surveys or with direct P/E potential readings taken at frequent intervals along pipelines.

Drop Line Platform Survey

The most commonly used method for monitoring cathodic protection levels on offshore platform jackets is to lower a weighted Ag/AgCl reference electrode from the platform deck and record structure-to-electrolyte potential values at uniform intervals from the water surface to the sea floor. This procedure is generally repeated at several representative locations on the platform jacket. Electrical connection to the structure is made above the water line. The electrical connection should be made to a welded structural member and should not be in the vicinity of welding activity.

The chief advantage of this method is simplicity and low cost. The primary disadvantage of the drop line is lack of ability to control reference electrode position relative to the structure. This makes accurate interpretation of potential measurements extremely difficult and prevents useful correlation of data with previous surveys on the same platform.

Guy Line Platform Survey

The guy line platform survey employs a tensioned guy wire which runs from the sea floor to the water surface inside the platform jacket. A reference electrode is attached to the guy wire and lowered to the bottom while potential measurements are taken at selected intervals. The advantage of this technique is that potential measurements are recorded at the same location during each cathodic protection survey. Useful correlation of data from successive surveys is therefore possible. The major limitation is that the reference electrode cannot be placed at specific locations, such as nodes or anodes. Despite this, the guy wire survey is an improvement over the drop line survey and can still be accomplished at a relatively low cost. This is particularly true on structures located in shallow water.

Diver/R.O.V. Assisted Platform Survey

This technique employs a diver or R.O.V. to position the reference electrode near the structure. The potential survey may be performed using one of two techniques. One technique involves use of a diver held voltmeter equipped with a sharp metallic probe and a Ag/AgCl reference electrode. The diver simply presses the contact probe against the structure and reads the digital display of the voltmeter. The potential reading is transmitted to the surface by audio link

The preferred method is to use an above water metallic connection to the structure and an above water measurement device. The diver or R.O.V. is used solely to place the reference electrode at the desired location while the potential measurement is recorded. This assures that a high resistance metallic contact is not affecting the potential measurement.

If an R.O.V. is used, potential is measured using a silver/silver chloride reference electrode mounted on the frame of the vehicle. The electrode is mounted in a position that allows the tip of the electrode to be placed directly against the structure in front of the video camera.

The primary purpose of the survey is to obtain a comprehensive potential profile of the platform. This is accomplished by recording potential values around each node and at all locations where cathodic protection current flow may be shielded or otherwise impeded, such as at conductor bell guides. Potential values are also recorded along representative structural members and conductors. Special attention is given to areas of the jacket such as the skirt pile guides, conductors, and boat docks

Representative anodes should be visually inspected and tested for operation by structure-to-electrode potential, electric field gradient, or both Where areas of lower than expected potential values are detected, more extensive testing is performed. This includes physical measurement of adjacent anodes, electric field gradient measurements and detailed visual inspection.

If low potential values are found over an entire depth zone, further testing and inspection is performed. When a visual inspection of the depth zone indicates that the low potential values are not caused by missing or depleted anodes or by metal unaccounted for in the cathodic protection design (e.g. debris, additional conductors), then environmental conditions must be considered. These include temperature, dissolved oxygen, salinity, and water currents. Each of these parameters can be measured from the surface to the sea floor to provide a complete profile with depth.

The primary advantage of using a diver or an ROV to perform a platform potential survey is that the electrode can be placed at known locations, thus allowing a detailed potential map of the structure to be obtained. This is the only method of assuring that cathodic protection is being achieved at all locations on the structure.

The choice of using divers or ROV's to perform the survey is primarily a function of water depth Generally, ROV's are more cost effective than divers for inspections in over 200 feet of water. Otherwise, divers and ROV's both have their attributes and drawbacks Divers are capable of performing many functions such as magnetic particle inspection, cleaning, debris removal and repairs far more effectively than ROV's . The primary advantage of ROV's besides increased depth capabilities, is as a relatively stable platform for video recording. This allows the viewer on the surface, who is hopefully an experienced corrosion engineer, to direct the corrosion survey by watching a video monitor. The placement of the electrode as well as any damage, corrosion or debris is recorded on videotape. In most cases, inspection data such as depth, time, data and potential is digitally superimposed on the videotape. This aids in post survey data processing, tape editing and reporting. Note that many operators are now using a combination of divers and ROV's for comprehensive inspections on major structures. ROV's are generally used for the detailed potential survey and visual inspections, followed by divers for marine growth removal, cleaning, NDT and debris removal.

Platform EFG/Current Density Survey

Several major operators, particularly in the North Sea, regularly employ EFG/Current Density measurements as a component of comprehensive ROV assisted jacket inspections. The E.F.G. measurements are used to calculate cathode current densities and anode outputs. This data is useful in diagnosing current distribution problems, estimating cathodic protection system life, and designing new and retrofit cathodic protection systems.

These measurements are particularly useful for design of cathodic protection for deep water structures. Many cathodic protection design parameters for deep water are not well understood, although research is currently being conducted. EFG/Current Density measurements on existing deep water structures provide valuable empirical information for future designs. This includes anode performance, polarization rates and current density requirements.

Due to the complex geometry of platform jackets, accurate and useful EFG measurements require the use of highly sophisticated EFG sensors. These EFG measurement systems must be able to detect changes in potential in the micro-volt range and have the means for determining the direction of current flow. Several ROV mounted systems are currently being used. These include the rotating T-sensor described earlier, and a sensor containing a concentric array of several reference electrodes all referenced to a common central electrode.

EFG measurements are generally recorded at representative anodes, nodes, conductors and pile guides. The data is later used to calculate current densities and anode outputs. In some cases, the EFG data is used along with potential data for calculation of current distribution using computer modeling techniques such as finite element and finite boundary analysis.

Computerized Inspection Data Management

During a comprehensive inspection of a platform jacket, vast amounts of pertinent data are collected. This may include cathodic protection potentials, EFG measurements and descriptions of marine growth, debris and structural damage. Additionally, hours of videotape are recorded. In the case of a diver assisted inspection, the data may include magnetic particle inspection and ultra sonic testing. Computerized data management systems have been developed to facilitate accurate and complete information recording, compilation, analysis and reporting.

Most information management systems use personal computers in conjunction with a relational data base system. Inspection information is generally entered into the computer on board the survey vessel as the inspection proceeds. This information must include time, date, videotape number and test point designation for correlation with drawings, logs and videotapes. Inspection points, such as nodes, are each assigned an alphanumeric designation based on depths and structural location. This uniquely identifies each inspection point in the data base for retrieval, editing and reporting.

Additional information that may be entered includes the following:

* Potentials
* EFG
* Debris-type, size
* Structural damage-type, description
* Corrosion-type, severity
* Scouring-bottom survey
* Marine Growth-thickness, type, % of coverage
* Work Description

This data is stored in the database for subsequent analysis and generation of inspection reports. These inspection reports are used for trend analysis, creation of repair work orders, corrosion data evaluation and maintenance scheduling and budgeting. An example of a typical report menu is as follows:

* Inspection Log
* Test Points not inspected
* Cathodic Protection Potentials outside limits
* Potential History
* Debris Survey
* Structural Damage Survey
* Strructure Inspection Summary
* Repair Status
* Photograph Log

More sophisticated data base management systems utilize CAD technology to graphically recreate the structure on the computer screen. These graphic capabilities are useful for detailed visual identification of anomalies such as cracks, repairs, or corrosion, as well as for sketches for bidding, data analysis and [5] creating reporting.

The ultimate aim of computerized data management systems is to aid the inspection manager in efficient planning and operation of inspections, and to allow rapid analysis and reporting of results. Use of these systems should increase as the importance of comprehensive inspection programs is recognized, and as acceptance and knowledge of computer technology continues to increase.

CONCLUSIONS

All of the survey methods have been used extensively and are constantly being modified and improved. The choice of the method, or a combination of methods, is dependent on a wide range of factors including water depth, water currents, location, depth of burial, size or length, cathodic protection system age, and cost. The requirements of each individual pipeline or structure will help dictate the method to be used. In general, the following guidelines are offered:

A. Pipeline

1. For measurement of overall P/E potential and location of major problem areas, the towed vehicle method is far and away the most economical, particularly for long pipelines. If problem areas are discovered using the towed vehicle method, then a submersible survey should be used to obtain detailed information on those sections.

2. For completely buried pipelines, the towed vehicle method is the most reliable for obtaining the P/E potential profile. Pipe tracking devices can be fitted to submersibles, but because of the separation between the electrode and pipe caused by burial, submersible assisted measurements may not be significantly more sensitive or accurate.

3. To obtain detailed information concerning relative output of anodes, size and location of coating flows, and integrity of field joint wraps, electric field gradient measurements are most effective, particularly when used in conjunction with either the submersible P/E potential survey or direct contact P/E potential readings. Calculations of P/E based on remote electrode measurements is also an acceptable method assuming that direct contact P/E potential measurements are made at frequent distance intervals. Calculations of P/E potential based on EFG measurements is the least desirable method of obtaining a P/E potential profile.

B. Structure

1. Drop line and guyline surveys provide general information on the potential levels of protected structures. The guyline is preferred since trends can be detected by comparison with surveys of prior years. Neither technique assures placement of the reference electrode in the most critical areas such as nodes.

2. Diver/ROV assisted surveys provide more detail for evaluating the effectiveness of cathodic protection systems. Potential readings can be taken in the critical areas such as nodes or conductor bays. Visual inspection assists in determining the cause of any problems detected. To prevent inaccurate measurements and the need for call backs, an experienced corrosion engineer should be present for on site data interpretation. This will ensure proper equipment calibration and additional investigation where initial measurements indicate potential problem areas. ROV assisted platform surveys are the most economical and effective for deep water platforms. In addition to structure-to-electrolyte potentials, EFG measurements can be recorded. The video monitor provides a permanent record of the measurements and location. Again, the use of experienced vehicle operators and corrosion engineers is necessary to achieve the best results.

3. Computerized information management systems are a valuable tool for the inspection manager. These systems, designed for use with personal computers, provide the basis for rapid and accurate data acquisition, analysis and reporting. The reports are designed to aid in inspection and repair budgeting, bidding and scheduling. The most advanced systems utilize CAD technology for graphic display of jacket components and inspection results. These systems can facilitate exact location of anomalies as well as provide sketches for bidding or reporting purposes.

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