NEW IMPRESSED CURRENT CATHODIC PROTECTION SYSTEM FOR SHIPS' HULLS

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ABSTRACT

After a brief description of the principles of impressed current protection, this article reviews the current designs for external underwater hull protection against corrosion. It highlights some of the problems encountered, assesses the available design methods, and describes a new system.

Steel is generally used in the construction of ships hulls unless for other considerations a non-metallic material is necessary. Generally, the hull is coated, this being necessary for anti-fouling purposes as well as to prevent corrosion. The 'paints' used for this coating have improved tremendously over the past 20 years but it is still not possible to guarantee a totally impervious protective coating.

A cathodic protection system is consequently provided which will protect the hull where flaws or holes in the coating occur and in the event of severe paint damage or stripping. Additionally the formation of a galvanic cell between the bronze propellers and the steel hulls and the consequent corrosion of the hull in the vicinity requires a cathodic protection system to oppose this natural cell action.

By preventing or reducing the corrosion a smoother hull surface can be maintained thus reducing fuel consumption. Longer intervals between dockings become possible and routine repair and maintenance are reduced.

Impressed current cathodic protection systems were first used in the R.N. in the mid 1960s. Some redesign of the control unit has occurred since then but no fundamental change of design philosophy has been adopted.

Theory

Corrosion is an electrochemical reaction involving metals, chemicals and water which combine to form cells capable of generating electricity. When dissimilar metals are present in an electrolyte and joined by an external circuit a cell is formed; one metal becomes anodic and the other cathodic, and current will flow between them. For example, the bronze propellers and the steel hull form a cell because they are joined by the propeller shaft and bearings.

In principle a single metal immersed in an electrolyte should be all at one potential, but the whole of the surface will divide itself into anodic and cathodic areas, thus setting up local corrosion cells over its surface. This is attributed to varying chemical, electrical, mechanical or thermal conditions prevailing in the metal or environment.

The current flow or rate of corrosion will depend on the relative areas of metal exposed, the electrolyte, and the driving potential. Every metal has a freely corroding potential which can be measured in sea water with respect to a standard reference cell. A list of these potentials is given in TABLE I where the metals are arranged in decreasing order of activity.

TABLE I—*Potentials of selected metals in sea water at 25°C, with respect to a silver/silver chloride reference*

Metal	*Potential* volts
anodic end	
Magnesium	−1·52
Zinc	−1·05
Aluminium	−0·82
Mild Steel	−0·62
Lead	−0·48
Bronze	−0·22
Silver	0
Platinum	+0·18
cathodic end	

Notes: 1. Materials at the upper end of the Table will sacrifice to protect those below them (e.g. zinc will sacrifice to protect mild steel or bronze and steel will sacrifice to protect bronze).
2. These open circuit potentials will vary with temperature, flow and composition of the sea water.
3. Variation is also caused by heat treatment, welds, roughness, rolling, forging and structure of the material.

Cathodic Protection

If the potential of the anodic and cathodic areas can be made the same, polarization* is accomplished. At the polarization point, the potential difference on the structure has been nullified and the self-generated corrosion currents cease to flow.

Impressed current cathodic protection introduces a third electrode which is made anodic by an applied or impressed external voltage. The voltage is increased until the current flowing into the metal structure equalizes the potential of the anodic and cathodic areas and polarization is achieved.

Means of determining whether or not the metal structure is corroding or receiving protection is obtained by fitting a standard reference electrode or half cell. The metal structure and the reference electrode immersed in a common electrolyte form a galvanic cell whose voltage is the algebraic difference of the half cell potentials. The standard reference electrode normally used is of the silver/silver chloride type. For steel, the freely corroding potential with respect to silver/silver chloride is approximately −600 mV; polarizing it to −800 mV will provide almost complete protection under most conditions. It is this value of potential which is measured by the standard reference electrode and may be used to control the impressed current. If the potential is taken below the fully protected level, hydrogen

*The word polarization, when used in an electrolytic context, is defined as the change in the potential of the protected surface as a result of current flow into it.

evolution at the metal surface will occur causing bubbling and damage to the coating. If the potential is significantly below the optimum level, hydrogen embrittlement of the steel may take place. The potential of the protected surface therefore needs to be precisely controlled and over-protection avoided.

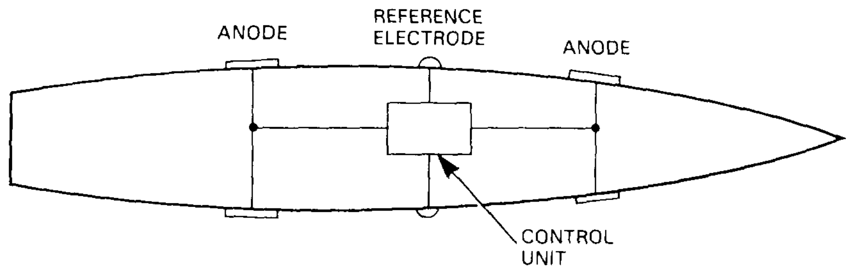

FIG. 1—TYPICAL IMPRESSED CURRENT CATHODIC PROTECTION SYSTEM

Impressed Current Control

A typical four anode system controlled from two reference electrodes is shown in FIG. 1. The four anodes are connected in parallel and the cables between control unit and anodes are balanced for equal resistance so that the anodes in parallel share the output current equally. Usually only one of the reference electrodes is used to control the system. Consequently the hull potential is measured at one point and the positions of the anodes are relied upon to distribute the correct impressed current to give the same potential everywhere on the wetted surface of the hull.

FIG. 2 is a simplified block diagram of the control system used in most R.N. ships. The desired hull potential can be manually preset in the reference voltage circuit. The reference electrode measures the actual hull potential and this potential is compared with the pre-set desired value. Any error is amplified and fed to the thyristor circuit to adjust the output current to the anodes. The control is automatic in so far as the impressed current delivered by the anodes is continually adjusted in response to any variation of the hull potential.

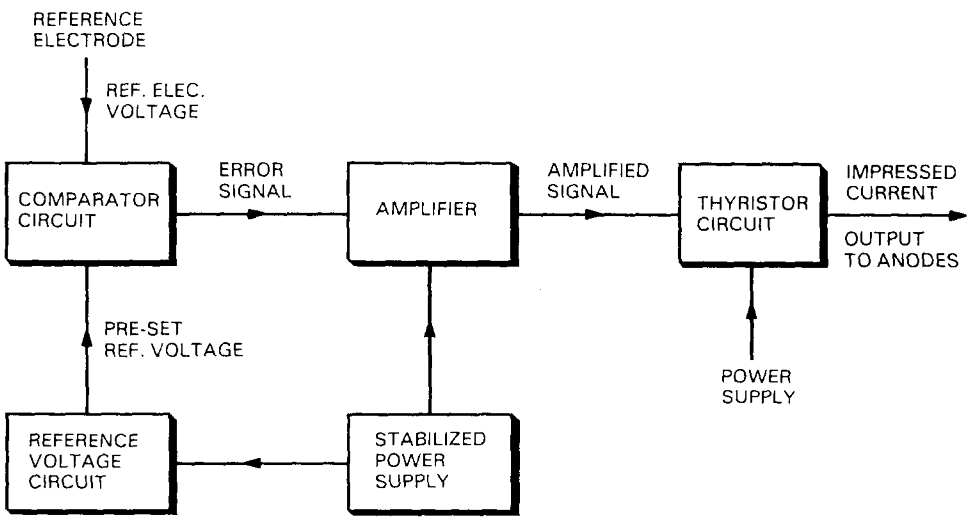

FIG. 2—IMPRESSED CURRENT CONTROL SYSTEM

Existing Equipments

Three different impressed current control equipments were designed for naval service in the 1960s and are still in use.

The equipment fitted in VALIANT Class submarines uses a different method of control to the others. Here, instead of thyristors, a saturable reactor or transductor (variable a.c. impedance) provides the means of adjusting the impressed current output to the anodes. The sensing technique is the same as that already described, but in this case the amplified error signal is fed to the control winding of the transductor to adjust its impedance and thus its output.

At about the same time, LEANDER frigates were being fitted with a system utilizing a thyristor-controlled output. The equipment consists of a control panel with up to three output channels. Each channel controls the output of a separate transformer/rectifier cubicle and each cubicle controls a group of up to six anodes. This design enables the equipment to be tailored to any size of ship.

In 1972, for Type 21 frigates and subsequent ship classes, the LEANDER control equipment was re-engineered to take advantage of the latest developments in components and circuit techniques, with consequent savings in space and cost. The large smoothing choke in the output line of the earlier equipment was omitted but a facility for connecting an external choke was provided. Thyristor control of output is retained. This equipment can only supply four anodes, which is sufficient for all except the very largest ships where two or more equipments would be fitted in master/slave arrangement. The complete equipment is contained in one cubicle and the control system incorporates a trip circuit which operates under certain sustained fault conditions.

This equipment is still being used for ships of current design. For the stretched versions of the Type 22 and Type 42, five and six anode systems respectively were required. Although the master/slave arrangement using two similar cubicles was the obvious choice, for expediency and cheapness a marine version of a commercial equipment was introduced as the slave. This hybrid system has not been entirely satisfactory and it has not fully resolved the problem for which it was intended, i.e. to improve the impressed current distribution to the stern and thus bring the hull potential in this area to the fully protected level.

Problems

The bare bronze propellers close to the steel hull form a galvanic cell; steel is anodic to bronze and thus the hull corrodes. In ships with controllable pitch propellers the situation is aggravated by the larger areas of bronze. Because the propellers are of bare metal which is a better conductor than coated steel the impressed current tends to be drawn to the bronze leaving the steel unprotected. Coating the bronze would alleviate the problem but none of the coatings or processes tried have been successful. An alternative is to insulate the propeller from the shaft.

This corrosion is additional to that resulting from the formation of anodic and cathodic areas on the steel. Account has to be taken of both these effects when designing the cathodic protection system. It has been found, however, that in most ships the potential of the steel in the stern area has not been maintained at the level required for complete protection. If the present cathodic protection system is adjusted to bring the hull potential of the stern area to the fully protected level, overprotection occurs forward since all anodes are connected in parallel and provide equal currents. Whilst longer periods between dockings are possible with a fully protected hull, if corrosion does take place it can quickly become severe and extensive damage will result before docking is due.

A more recent problem has been the interference with certain sonar displays. The impressed current is derived from a 3 phase, 60 Hz, rectified, thyristor-controlled a.c. source and 180 Hz spikes have been picked up by the sonar detectors.

Equipments whose design is more than 20 years old contain components which are now difficult or impossible to obtain, causing support and maintenance problems.

Cathodic Protection System Design

In the past no scientific method appears to have been used for designing impressed current cathodic protection systems, the British Standard Code of Practice[1] being relied upon, together with practical experience. The total impressed current required was derived from current density figures and the wetted surface area of the hull to be protected. The number of standard anodes of known maximum output was thus determined. The current density figures required to give full protection for steel and bronze were determined by experiment in the early days and these have continued to be used. The crux of the design is in determining the positions of anodes and reference electrodes to give a uniform protection potential over the whole wetted surface. These positions have been determined largely by experience.

The feasibility of mathematical and scale modelling has been investigated. There are several numerical programs available that could be applied to corrosion protection. Problems with size and complexity of the model arise with the application of finite element analysis particularly in areas of complex geometry such as around the propellers. The alternative numerical method, known as boundary element analysis, avoids many of these problems and is the more promising technique. The mathematical model allows a cathodic protection system to be simulated and the potential levels achieved over the surface to be examined. It should then be possible to adjust the model until the optimum protection is obtained and to translate the results into the full size system. Scale modelling is feasible in principle but there are significant practical difficulties in carrying it out.

Consideration of the problems encountered in the past led MOD to the conclusion that cathodic protection should be applied to hulls in zones with separate reference electrodes for independent control. By adjustment of the individual zones it should be possible to achieve a more uniform protection along the length of the hull. With the present system, under-protection at the stern is quite common whilst the remainder of the hull is fully protected. Consequently, with separately controlled cathodic protection systems—one for the stern area and another for the remainder—it is likely that they could be suitably adjusted to bring the stern to the required potential without unduly affecting the remainder of the hull.

Some improvement in hull potential at the stern has been achieved by rearrangement of the cathodic protection system in a stretched Type 42 where the hybrid master/slave control system exists. Although individual control of the different areas is not possible in this system, the slave output can be adjusted to some extent, with respect to the master output. Simple scale modelling experiments have been carried out by RNEC Manadon which have validated the concept of zone control.

Trials have been carried out to measure the cathodic protection output voltage and current spectrum, and a filter unit designed to suppress the sonar interference. These filters are being fitted in the anode output lines in certain existing systems.

New Impressed Current Cathodic Protection System

The new concept for cathodic protection is thus to divide the hull into zones each with its own control system, reference electrodes and anodes. A new control cubicle is under development and can be constructed to drive two, four or six anodes, controlled by up to three pairs of reference electrodes.

A standard system will most likely comprise a six anode control cubicle with two pairs of reference electrodes separately controlling two zones of the hull. The aft zone will contain two anodes and two reference electrodes on the undercut, and the forward zone will have four anodes and two reference electrodes.

A typical six-anode system controlled by two pairs of reference electrodes is shown in FIG. 3. The six anodes are connected to individual power units and the two pairs of reference electrodes are connected to two control modules. The power units and control modules are housed in one six-anode cubicle in this instance. Alternative packaging could be arranged, e.g. two and four power units housed in separate cubicles with the control modules housed in either cubicle. Balancing of the resistances of the anode leads is unnecessary with the new system.

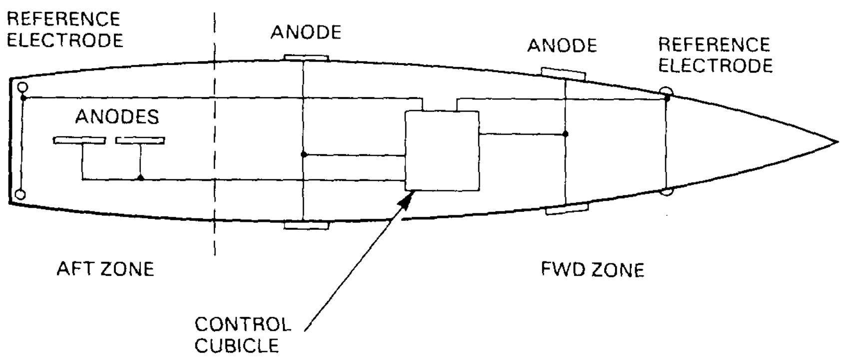

FIG. 3—TYPICAL NEW IMPRESSED CURRENT CATHODIC PROTECTION SYSTEM

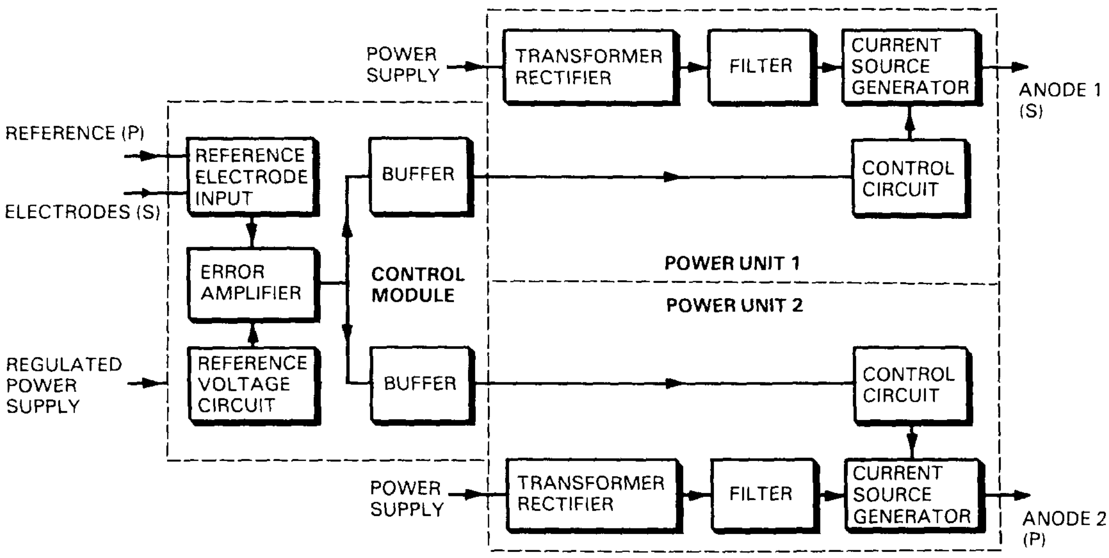

FIG. 4—NEW IMPRESSED CURRENT CONTROL SYSTEM

A simplified block diagram of the new control system is shown in FIG. 4. As in the existing equipments, the desired hull potential is set manually and the actual hull potential, as measured by a reference electrode, is compared with the set value and any error is amplified and fed to the power unit. Instead of the thyristor output control used in existing equipments, a series regulator is used in this case to adjust the impressed current output to individual anodes which are controlled in pairs. A prototype equipment is illustrated in FIG. 5.

Account has been taken of the need to provide a much smoother output than hitherto in order to avoid interference problems with other external underwater sensors, and appropriate filter networks have been built into each power unit. The control system normally operates from either the port or starboard reference electrode. Should the active reference electrode become defective, automatic change-over to the alternative electrode takes place. Alarm/trip and warning circuits are incorporated to detect fault conditions including over- and under-protection. Data logger outputs of the parameters normally logged manually each day by ship's staff have been provided for connection to an automatic data logger.

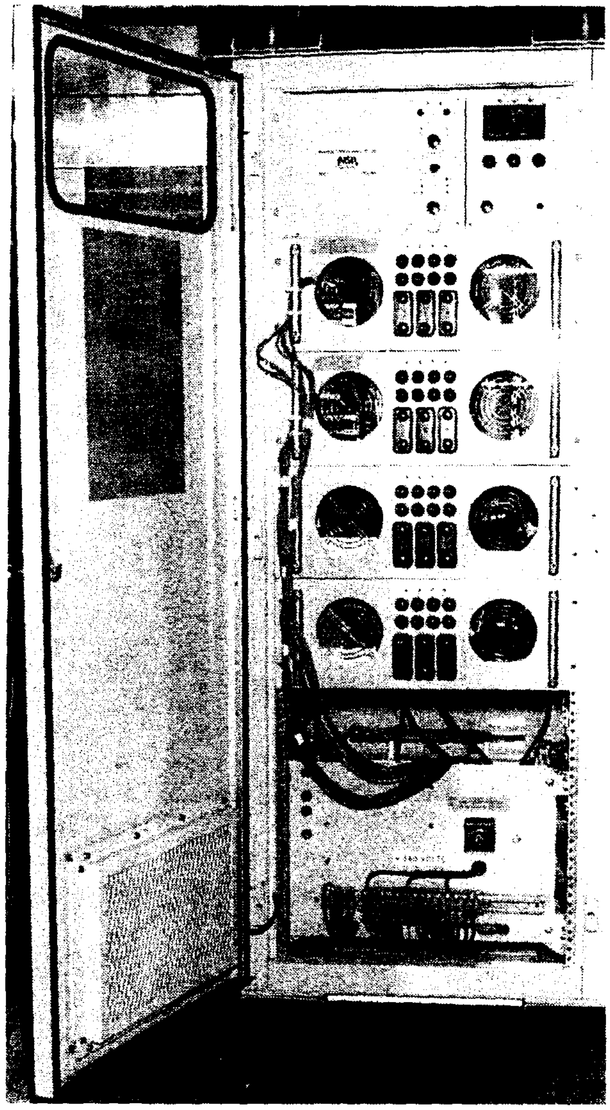

FIG. 5—FOUR-ANODE PROTOTYPE OF NEW CATHODIC PROTECTION EQUIPMENT

Conclusions

It should be possible for future impressed current cathodic protection systems to be designed with the aid of a mathematical model, enabling the optimum positions and numbers of anodes to be determined. The equipment that has been developed meets the present and foreseeable requirements and can be made to suit any size of ship. These, together with the concept of zone control, will ensure more even current distribution and better control of hull potential over the whole wetted surface area.

The monitoring and data logger output facilities can help ship's staff analyse fault conditions and relieve them of the task of manually recording daily readings. The smoothed output will be important as more sensitive sensors are introduced and should avoid the need to switch off the cathodic protection system for unacceptably long periods.

All these features are aimed at making the cathodic protection system more efficient and achieving the purpose for which it is fitted, viz. preventing corrosion of the underwater materials, maintaining a smoother hull surface to reduce fuel consumption, permitting longer periods between dockings, and reducing repair and maintenance routines.

Epilogue

The current policy of competitive procurement results in equipments being introduced into the Fleet which do not have all the desirable features. Cathodic protection systems will therefore be encountered which do not contain all the features described in this article.

Acknowledgement

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Reference

1. British Standards Institution code of practice for cathodic protection. CP 1021. 1973.