

# Coating integrity effects on impressed current cathodic protection system parameters

V.G. DeGiorgi,<sup>a</sup> C.P. Hamilton<sup>b</sup>

<sup>a</sup>*Mechanics of Materials Branch, Code 6382, Naval Research Laboratory, Washington, DC 20375, USA*

<sup>b</sup>*George Washington University, Department of Defense Science and Engineering Summer Apprenticeship Program, Washington, DC 20052, USA*

## Abstract

A computational study of the changes in electrical current requirements due to damage to the corrosion preventative coating on the propellers of a U. S. Navy ship is performed. Coating damage is modeled using effective coating efficiency. The boundary element model used has been previously validated by comparison with physical scale modeling experimental results. Trends for higher current demand and lower potential at key locations with increasing levels of damage are presented. The ability to quickly define operating parameters for arbitrary damage levels using boundary element computer models is demonstrated.

## 1 Introduction

Coatings are often used in conjunction with impressed current cathodic protection (ICCP) systems to minimize the effect of corrosion on marine structures. In general, the presence of a coating reduces the current required by an ICCP system. The integrity of the coating is one of the

factors which influences the amount of current reduction possible. One of the difficulties in designing a combined coating and ICCP system is that coatings deteriorate with time. In many instances the degree of coating deterioration can only be determined by inspection after removal from service. This has lead to one approach for system design which ignores the existence of the coating in the design of the companion ICCP system. The ICCP system is designed to provide corrosion protection in the event of complete coating failure. While this ensures that sufficient power is available for the worse case condition it may also result in an expensive over-design of the system. A better design may be achieved by considering intermediate levels of damage in the design of the power supplies and other system components. In addition, a knowledge of the relationship between required power and damage level may be used as an in-service indication of coating integrity.

Computational modeling has become an established design tool in structural engineering and other disciplines. Computational techniques, with emphasis on finite element and boundary element methods, and their application to corrosion systems are summarized in review articles by Zamani et al [1] and Munn [2]. The purpose of this study is to demonstrate the capability and versatility of computational modeling by determining current demand required for corrosion protection for increased levels of damage to the protective coating applied to the propellers of a surface ship.

## 2 Scope of Work

The purpose of this computational study is to determine the effects of coating degradation on ICCP system performance, specifically on current demand and the recorded voltage levels at key locations on the structure. The ICCP system studied is an existing system installed on the CG-66, a U. S. Navy destroyer. It is assumed that a perfect ground exists between the ICCP system and the propellers. The paint configuration considered "is based on that of a freshly painted ship: docking blocks, equal to approximately 1% of the hull surface, are the only exposed steel on the hull This paint condition is combined with varying level of damage

to the propellers' protective coating. The bare propeller condition has been completed as part of the validation analysis for the boundary element model [3].

Dynamic, or ship under way, conditions are considered. In general, dynamic conditions require a higher current demand than static, or ship at rest or in dock, conditions.

### 3 Ship Geometry

The ship hull and ICCP system analyzed are shown in schematic form in Figure 1. The ship has dual rudders and

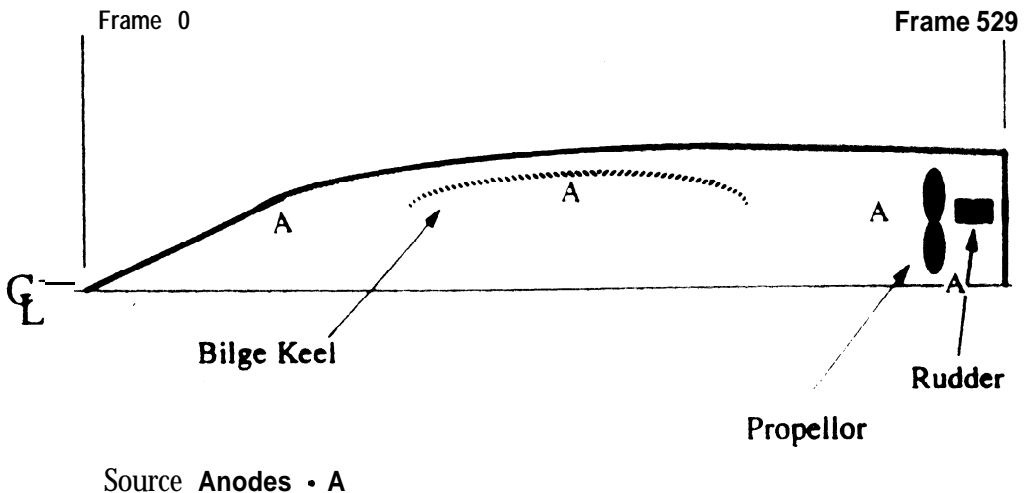


Figure 1. Schematic of Ship Hull and ICCP System

propellers. The ICCP system analyzed consists of 3 pairs of symmetrically placed anodes and a centerline anode in the aft section of the hull, two power supplies and two reference cells. Reference cells are control sensors for the ICCP system. The fore and mid-section anodes are connected to the first power supply and use the forward placed reference cell. The remaining anodes are connected to the second power supply. ICCP system symmetry and geometric symmetry of the hull allow for half of the ship to be modeled. The hull section below the design waterline is modeled.

## 4 Computational Model

The boundary element model created for the analysis (Figure 2) consists of 1596 hybrid quadratic elements fabricated of 6916 mesh points. Quadrilateral elements which have a linear representation of the solution variables, electrical potential and current density, and a quadratic geometric representation are used. These are standard elements in the commercial code used. A solution of the boundary element model requires approximately 2 hours of computer processing time on a CRAY-YMP supercomputer. This boundary element mesh had been previously validated by comparison with experimental results [3].

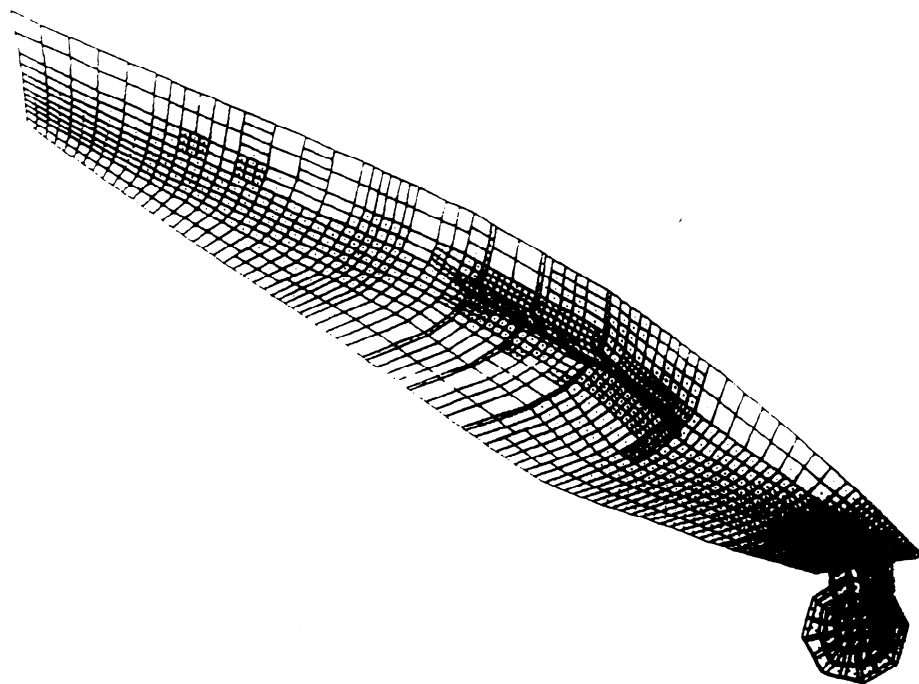


Figure 2. Boundary Element Mesh

The impressed current anodes are explicitly included in the boundary element model. The source anodes have finite areas and fixed locations. Anodes connected to the same zone are prescribed identical voltages as part of the defined boundary conditions.

Coating damage may be modeled either as an effective reduction in the efficiency of the coating or as discrete breaks in the coating which expose the base metal

to the electrolyte. In this analysis, propeller coating damage is **modeled** using effective coating efficiency. In determining an effective coating efficiency, the polarization curve is scaled by an effective surface area. For example, a 90% coating efficiency corresponds to 10% exposed metal. The current required to protect an area is defined as 10% of the current needed to protect the same area of bare metal.

Three basic materials are used in the boundary element model. These are steel, nickel-aluminum-bronze (NAB) and a corrosion preventative coating. Nonlinear material polarization responses are used for steel, NAB and the modified NAB corresponding to the defined damage levels. The coating is defined as a perfect insulator. The hull, with the exception of the docking blocks, is defined to be undamaged coating. The docking blocks are assigned the properties of bare steel. The propellers are assigned NAB or modified NAB properties depending on the damage level to be **modeled**. Aging effects associated with time in service are not included in the analysis. All surfaces are assumed to be free of calcareous deposits. The polarization responses of steel and NAB are as determined from large scale testing in which instrumented metal plates were towed at various speeds in natural seawater [4].

The seawater in the model is defined with a constant resistivity of 20 Ohms-cm.

The total current supplied to each zone is calculated from the boundary element computational results. In this analysis, each power zone is defined as being powered by an external power supply which is sufficient for the current demands.

## 5 Computational Analysis

A commercial boundary element program [S] was used to solve the **LaPlace** governing equations for the defined ship structure. Impressed current anodes are defined by assigned voltage values. The solution of interest corresponds to a potential of 0.85 Volts **Ag/AgCl** at the reference cell locations. The effects of coating damage is simulated by analysis of five coating damage levels ranging from perfectly coated (zero damage) to completely bare (100% damage) propellers. Intermediate levels of coating

damage considered were 1%, 5% and 10% of the propellers' surface area. An effective coating efficiency approach was taken in modeling the current demand of the damaged propellers.

## 6 Analysis Results

Results examined for this evaluation include the current required to maintain 0.85 Volts Ag/AgCl at both reference cells, the voltage along the lower surface of the rudder and the voltage at the lower tip of the propellers. The total current required for achieving the target reference cell reading are shown in Tables 1 and 2.

Table 1. Electrical Current Requirements (Amps)

Percent Damage:	0	1	5	10	100
Forward System	4.2	4.4	5.0	5.7	22.3
Aft System	10.8	11.0	11.8	12.6	31.7
<b>TOTAL</b>	<b>15.0</b>	<b>15.4</b>	<b>16.8</b>	<b>18.4</b>	<b>64.0</b>

Table 2. Electrical Current Requirements (Amps)

Percent Damage:	0	1	5	10	100
Docking Blocks	15.0	13.5	12.4	11.0	13.7
Propellers	-0-	1.9	4.4	7.4	50.3
<b>TOTAL</b>	<b>15.0</b>	<b>15.4</b>	<b>16.8</b>	<b>18.4</b>	<b>64.0</b>

The current necessary increases with increasing levels of damage to the propeller coating. The increase in current is shared by both forward and aft systems. This indicates that even though the increase in damage is concentrated in the aft section, the system responds globally with both forward and aft power sources are affected.

The level of corrosion protection provided to the rudder is affected by the level of damage to the propellers' coating. The rudder, as represented by the lower surface of the rudder, has potentials above the target value of 0.85 Volts Ag/AgCl for zero to 5% propeller coating damage. At 10% propeller coating damage the potential readings fall

below the target potential' as shown in Table 3. The computed value for a bare propeller compares favorably with the value reported from physical scale modeling experiments.

Table 3. Potential at Lower Surface of Rudders  
Voltage (Ag/AgCl)

Percent Damage:	0	1	5	10	100
Computer Model	0.89	0.89	0.86	0.82	0.81
Experiment [6]	--	--	--	--	0.83

The level of corrosion protection to the propeller is affected by the amount of damage to the propeller coating. The propeller coating damage is modeled as small holidays, or breaks in the coating, which are evenly distributed over the entire surface area of the propellers. Results from this analysis are only appropriate when the damage mechanism is such that this is a realistic model of the coating damage. A trend of decreasing potential with increasing damage is shown in Table 4.

Table 4. Potential at Lower Surface of Propellers  
Voltage (Ag/AgCl)

Percent Damage:	0	1	5	10	100
Computer Model	0.89	0.88	0.85	0.81	0.68
Experiment [6]	--	--	--	--	0.71

In the case of bare propellers, the calculated potential reading at the lower tip of the propeller compares favorably to the reported value from physical scale model experiments.

## 7 Summary

The power requirements for corrosion protection using an existing ICCP system for intermediate levels of propeller coating damage has been determined using boundary element techniques. The boundary element model and