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THEORETICAL CONSIDERATIONS IN THE CATHODIC PROTECTION OF WIRE ROPE

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ABSTRACT

A theoretical discussion of the problem of current distribution along a wire rope cathode is discussed. A curve has been estimated from these considerations which shows the current distribution factor for 1 1/4 inch wire rope for several anode potentials. The conclusions drawn from this study show that it is impossible to protect several thousand feet of bare wire rope from a central anode location, but that many thousand feet of even imperfectly coated wire rope could easily be provided cathodic protection from a central location.

PROBLEM STATUS

This is an interim report; work on this problem is continuing.

AUTHORIZATION

NRL PROB. NO. M04-02

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THEORETICAL

The length of wire rope which can feasibly be cathodically protected from a single anode array can be calculated by the methods of PRITULA (1) and MORGAN (2).

In determining the effect of cathodic protection on a wire rope, two main factors control the current to the unpolarized rope - the metallic resistance (r) per unit length of rope, and the coating conductance (g) in mhos per unit length. Bare rope is a special case of the general problem where the conductance (g) must be calculated from the relationship for the electrolytic resistance of long anodes (3). Cathodic protection is applied to the rope from a single point. This causes a potential change across the coating of E_x volts at point x (Fig. 1). The current flowing in the metallic circuit at this point is I_x and this current causes a change in E_x of δE_x because of the IR drop in the rope. The differential equations for this system can be established as follows:

$$\delta E_x = I_x \cdot r \cdot \delta x \qquad \text{Eq. (1)}$$

$$\delta I_x = E_x \cdot g \cdot \delta x \qquad \text{Eq. (2)}$$

Combining $$\frac{\partial^2 E_x}{\partial x^2} = r \cdot g \cdot E_x \qquad \text{Eq. (3)}$$

This equation (3) has a solution,

$$E_x = A \cosh ax + B \sinh ax \qquad \text{Eq. (4)}$$

where $a = \sqrt{rg}$

Applying boundary conditions, and defining E_a as the potential of the rope at the point of connection of the anode,

$$E_a = E_m \cosh al \qquad \text{Eq. (5)}$$

where E_m is the minimum potential change on the rope for protection. Now by derivation from equation (1),

$$I_a = \frac{a}{r} E_m \sinh al \qquad \text{Eq. (6)}$$

where I_a is the total current required by the cathodic protection system.

Now if the rope under consideration had an infinitestimal metallic resistance,

$$I_a = g \cdot E_m \cdot l \qquad \text{Eq. (7)}$$

The ratio of (6) to (7) will give the relative current increase to protect a rope with an appreciable metallic resistance. If we define this as a current spread factor, X, then a value of X of 16 would mean that 16 times as much current would be required to protect the rope under consideration as would be required for a rope with no metallic resistance.

$$X = \frac{\sinh al}{al}, \text{ where } a = \sqrt{rg}, \text{ and}$$

$$l = \text{length of rope} \qquad \text{Eq. (8)}$$

PRACTICAL CALCULATIONS

From Reference (4), the total area of a 1 1/4 inch wire core 6 x 37 wire rope is 0.758 square inches. This corresponds to a metallic resistance (r) of 8.6×10^{-5} ohms-foot^{-1}. For bare rope, the other necessary parameter (g) must be estimated from Dwight's Formula (3). As Dwight's formula applies only to cylinders, it is necessary to find the cylinder equivalent in electrolytic resistance to the wire rope. By graphical methods, it was determined that the 1 1/4 inch wire rope is equal in effective circumference to a cylinder with diameter of 1.69 inch.

The Dwight formula for the electrolytic resistance of a cylinder,

$$R = \frac{\rho}{2\pi L}\left(\ln \frac{2L}{D} - 1\right), \text{ where } L = \text{length of cylinder,}$$

$$\text{and } D = \text{diameter of cyclinder,}$$

may be reduced to the form,

$$R = \frac{0.1044}{L}(\ln L - 1.654) \qquad \text{where } L = \text{length in feet,}$$

$$\text{and } R = \text{resistance in ohms,}$$

for a 1 1/4 inch diameter wire rope in 20 ohm - cm sea water. The parameter, g or electrolytic conductance per linear foot unfortunately varies with the length of rope, but a reasonable approximation may be calculated from the above relationship. The best average value is 1.5 mhos/linear foot for the electrolytic resistance of a bare 1 1/4 inch wire rope in 20 ohm-cm sea water. For coated rope, somewhat more precise values of g are obtainable. From data in BURNS and BRADLEY (4) it can be calculated g for a "fair" organic coating is 4×10^{-3} mhos/linear foot, for a "poor" coating, 4×10^{-2} mhos/linear foot, and for a "very poor" coating 4×10^{-1} mhos/linear foot.

We may now calculate two parameters of interest. First, we may calculate from Eq. 8 the parameter defined as the current spread factor, X. This is the ratio of current required to protect a wire rope to the current required to protect an idealized wire rope with zero metallic resistance. As this is a ratio, we have made no assumptions concerning the polarization characteristics of the rope; as a penalty for avoiding this assumption we are unable to make any estimate of absolute order of current required to protect the rope.

Secondly, we may use Equation 5 to calculate the distance along the rope to which current will be driven by any of several anodes. Here we must make several simplifying assumptions. We assume that the rope is entirely unpolarized, and that to obtain a modicum of cathodic protection, at least 50 millivolts of driving voltage will be required. There will be two *main* sources of error in these assumptions; Because of polarization of the wire rope, current will be thrown further along the rope than we have calculated. This is because the total current will be less, and the IR drop in the rope will thus be less than in the case with no polarization.

The second source of error is the implied assumption that the current to the rope will be limited entirely by the electrolytic resistance to the rope and the driving voltage available. In any practical case, the geometry and electrolytic resistance of the anode array will also be a limiting factor. This error will be a positive error and tend to balance the negative error due to ignoring polarization effects.

On Fig. 2 has been plotted the current spread factor X for 1 1/4 wire rope as a function of the length of rope from the anode connection point. Also plotted on this figure are the Limit of Cathodic Protection lines for zinc anodes, magnesium anodes, and an impressed current system with a driving voltage of 5.0 volts. The potential of the unprotected rope is assumed to be 0.65 volt to silver/silver chloride. The current spread factor X has been plotted for bare rope, and ropes with coatings of 150 ohm/sq. inch, 1500 ohms/sq. inch, and 15,000 ohms/sq. inch respectively.

SUMMARY AND CONCLUSIONS

A mathematical treatment for the cathodic protection of wire rope has been reported. From this treatment, practical information has been developed for 1 1/4 inch wire rope. From this treatment, several main conclusions may be drawn:

1. Bare rope can not be protected for over a few hundred feet from the anode connection point. This point may, however, be considerably removed from the physical location of the anode.

2. Increasing the driving voltage is a relatively ineffective means of increasing the length of rope protected.

3. Organic coatings are an extremely efficient way of increasing the spread of cathodic protection. A coating rated only "fair" in terms of marine paint would enable the design of a system to protect several thousand feet of rope from one anode array. Such an array could be designed with a life of many years.

4. It is recommended that the use of wire rope factory coated with such materials as polyvinyl chloride be investigated for use where replacement of the rope is impractical, and that such rope be used in conjunction with cathodic protection.

ACKNOWLEDGMENT

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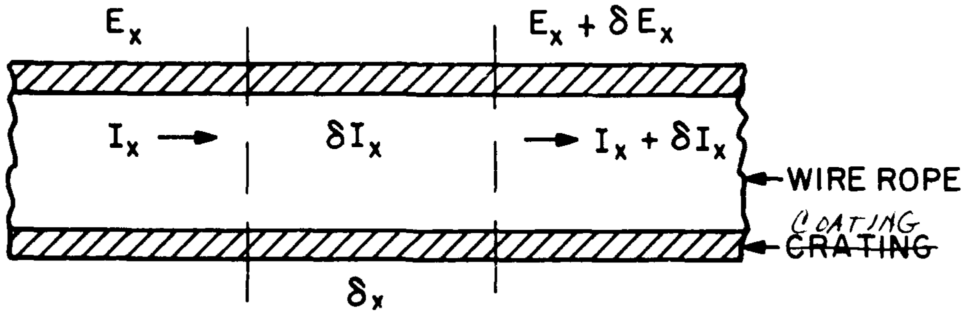

Fig. 1 - Longitudinal section through a coated wire rope under cathodic protection

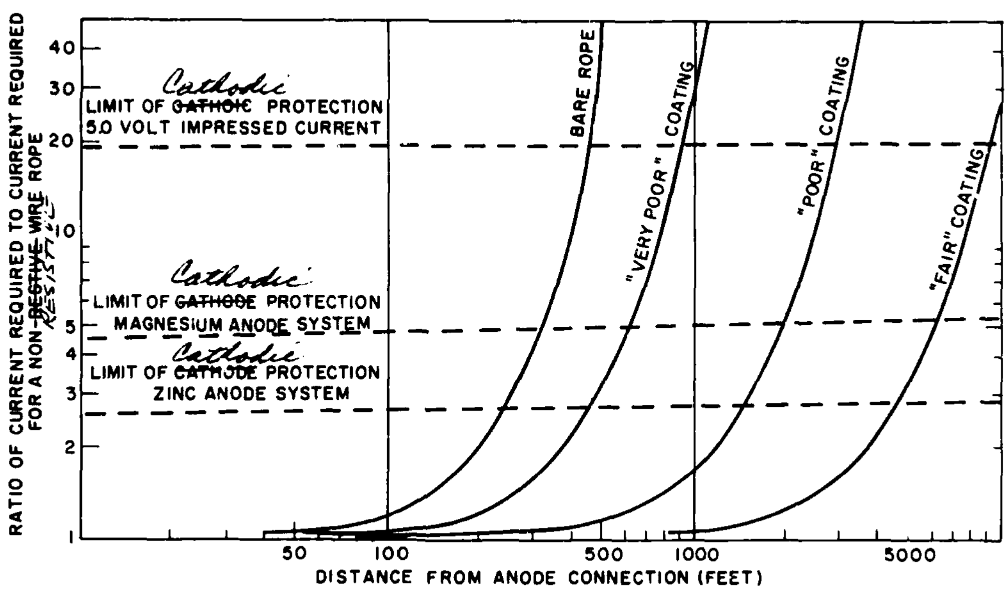

Fig. 2 - Theoretical considerations for the cathodic protection of bare and coated 1-1/4 inch wire rope