

[54] **METHOD AND APPARATUS FOR CATHODIC PROTECTION**

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[51] Int. Cl. **C23f 13/00**

[58] Field of Search **204/147, 196**

[56] **References Cited**

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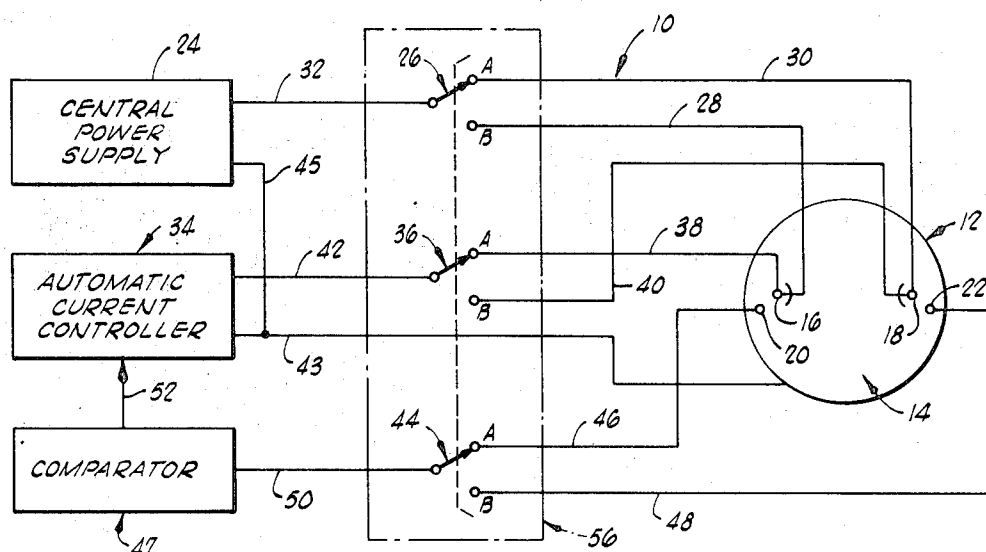
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[57] **ABSTRACT**

An improved apparatus and method for cathodically protecting surfaces exposed to a corrosive environment utilizing a predetermined number of anodes, each anode being connected to a power source adapted to supply a predetermined polarizing current thereto, and each anode being connected to a current controller adapted to supply an adjustingly, controlled polarizing current thereto. The polarizing current supplied by the current controller to any one anode is adjustingly controlled in response to the anode potential of that one anode with respect to the protected surface, the cathodic protection system being adapted to sequentially provide electrical continuity between each anode and the current controller and between the remaining anodes and the power source in such a manner that polarization of the system is obtained and maintained utilizing a minimum overall power consumption and in a manner maintaining a predetermined polarization over substantially the entire area of the protected surface.

7 Claims, 3 Drawing Figures



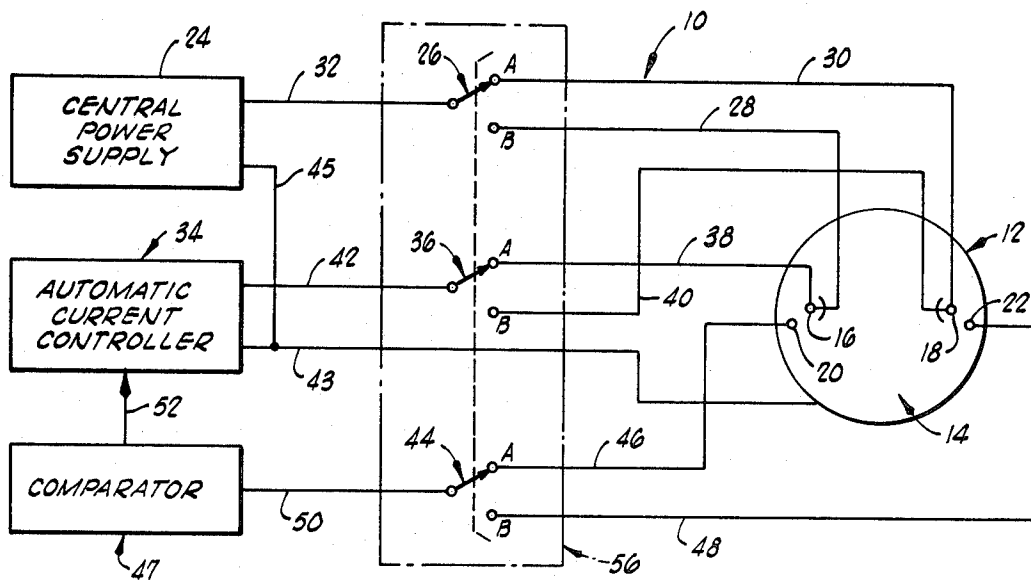


FIG. 1

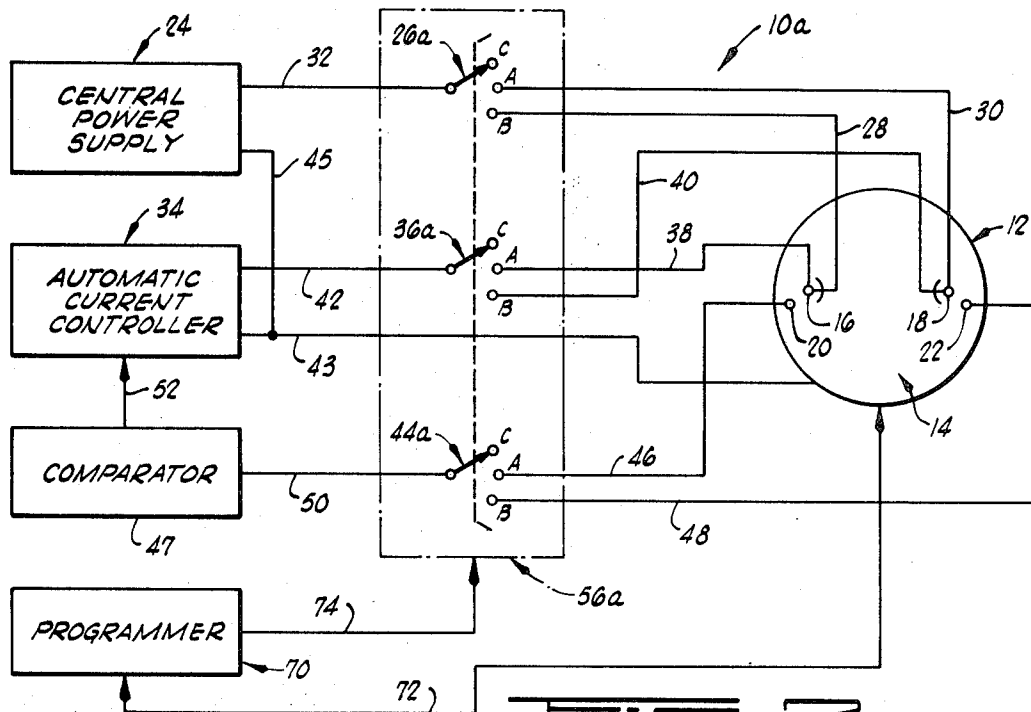
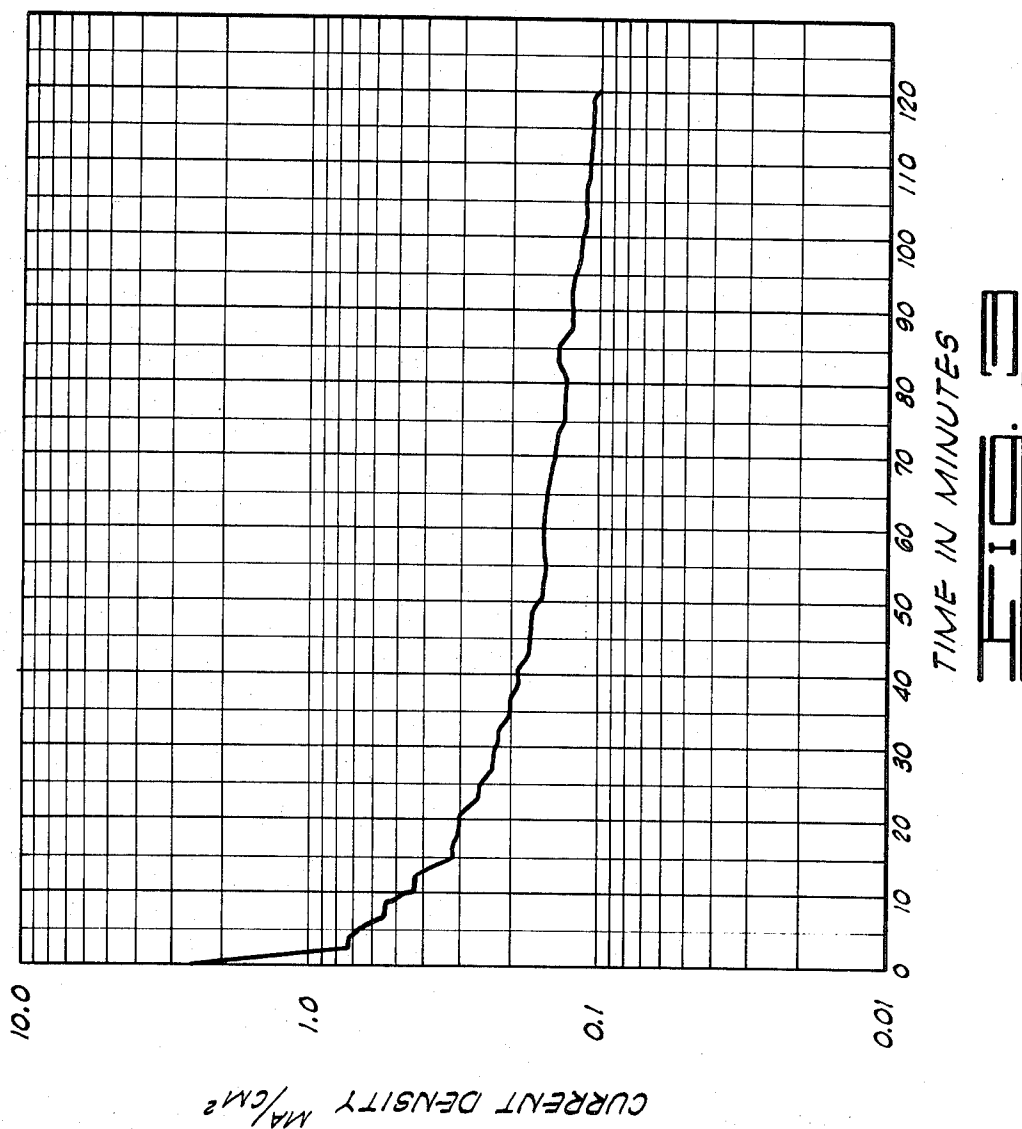


FIG. 2

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METHOD AND APPARATUS FOR CATHODIC PROTECTION

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates generally to improvements in cathodic protection systems and, more particularly, but not by way of limitation, to a cathodic protection apparatus utilizing a predetermined number of anodes wherein the polarizing current is supplied to each anode sequentially by a power source and a current controller.

2. Description of the Prior Art

In the past, cathodic protection apparatus has been proposed wherein the current or power supply to the power electrode or, in other words, the anode, was controlled to some extent via a reference half-cell, control circuitry. In some of the systems of a nature mentioned above, the power supply to the anode was placed or switched to an "on" or an "off" position as a function of information supplied via the reference half-cell. In some other systems of this general nature, the polarizing current was adjusted to some degree and in some manner as a function of the information supplied via the reference electrode.

In the past, the above mentioned systems have provided adequate solutions to various problems in the art of cathodic protection, however, it has been found that when attempting to protect particularly large or geometrically complex structures, most of these systems have been proven inadequate from an overall protection, control apparatus investment, and operating cost viewpoint. The cathodic protection systems proposed in the past have generally been found to utilize or consume a large total amount of power to obtain and maintain a particular polarization, and in some other instances these cathodic protection systems have been found inadequate to provide a desired protection over the entire area of the surface being protected.

SUMMARY OF THE INVENTION

The present invention contemplates a cathodic protection apparatus for obtaining and maintaining a predetermined polarization of a protected surface in a corrosive environment, having a predetermined number of anodes adapted to cooperate with the protected surface which is maintained cathodic, in such a manner that the predetermined polarization is obtained and maintained utilizing a minimum total power consumption and such that a predetermined polarization is established and maintained over substantially the entire area of the protected surface. Each anode is disposed at a predetermined position with respect to the protected surface, and each anode is adapted to cooperatively establish an anode potential between each anode and the protected surface. A power supply is connected to each anode and is adapted to provide a predetermined polarizing current to the anodes connected thereto. The cathodic protection apparatus includes a potential control which is adapted to selectively indicate the anode potential of each anode, and to provide an output control signal proportional to one of the anode potentials compared to a predetermined set potential. A current controller is connected to each anode and is adapted to provide an adjustingly, controlled polarizing current to each anode connected thereto. The current

controller is also connected to a portion of the potential control, and is adapted to receive the output control signal from the potential control. The current controller adjustingly controls the polarizing current provided by the current controller in response to the output signal of the potential control. A switching control is interposed between each anode and the power supply and between each anode and the current controller. The switching control is adapted to selectively and sequentially provide electrical continuity between one of the anodes and the current controller and electrical continuity between the remaining of the anodes and the power supply, such that sequentially, the current controller provides controlled polarizing current to one of the anodes and the power supply provides polarizing current to the remaining anodes.

An object of the invention is to provide a cathodic protection apparatus for protecting a surface exposed to a corrosive environment utilizing a minimum total power consumption.

Another object of the invention is to provide a cathodic protection apparatus for protecting surfaces exposed to a corrosive environment wherein a predetermined polarization is controllingly maintained over substantially the entire area of the protected surface.

One other object of the invention is to provide a cathodic protection apparatus for protecting surfaces exposed to a corrosive environment which utilizes a minimum number of protection units.

A further object of the invention is to provide a cathodic protection apparatus for protecting relatively large surface areas exposed to a corrosive environment.

A still further object of the invention is to provide a cathodic protection apparatus for protecting surfaces exposed to a corrosive environment wherein the protected surface has a relatively complex geometrical shape.

One other object of the invention is to provide a cathodic protection apparatus for protecting surfaces exposed to a corrosive environment which is economical in construction and operation.

Other objects and advantages of the invention will be evident from the following detailed description when read in conjunction with the accompanying drawings which illustrate various embodiments of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic-diagrammatical view of a cathodic protection apparatus constructed in accordance with the invention.

FIG. 2 is a schematic-diagrammatical view of a modified cathodic protection apparatus, similar to the cathodic protection apparatus of FIG. 1.

FIG. 3 is a graph showing Current Density (MA/CM²) versus Time (minutes) relating to a particular test specimen cathodically protected in accordance with the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to the drawings in general and to FIG. 1 in particular, shown schematically and diagrammatically therein is a cathodic protection apparatus or system 10 adapted to cathodically protect a surface, designated in

FIG. 1 by the general reference 12, and referred to below as the protected surface 12. An electro-chemical type of cathodic protection basically relates to a system whereby an electric current is supplied to an anode immersed in an electrolyte and to a surface which is to be protected, wherein the protected surface potential is maintained cathodic, thereby reducing the corrosive effect of the electrolyte on the protected surface. Cathodic protection of this general type is well known in the art, and a detailed description thereof is not necessary herein.

More particularly, the cathodic protection apparatus 10 is adapted to obtain and maintain polarization within a predetermined range over substantially the entire area of the protected surface 12 in contact with a corrosive fluid or environment, referred to sometimes below as an electrolyte and designated in FIG. 1 by the general reference 14.

The term polarization is known in the art generally as a condition wherein corrosion is controlled by use of an electric current to oppose the electrolytic tendency of a metal to corrode (replace lost electrons).

It should be particularly noted that the protected surface 12 has been shown diagrammatically in FIG. 1 as having a circular shape merely for illustrative purposes, and for the purpose of clarity of description. It should therefore, be noted that the cathodic protection apparatus 10 of the present invention is particularly useful for cathodically protecting large surface areas, surfaces having an irregular geometrical configuration or, in general, surfaces wherein the anode potential required to maintain a predetermined current density varies with respect to different positions on the protected surface 12, as will be made apparent below.

The cathodic protection apparatus 10 includes a predetermined number of power electrodes and, more particularly, as shown in FIG. 1, two power electrodes 16 and 18, referred to below as the anodes 16 and 18, are disposed in the electrolyte 14. It should be noted, that in a particular application utilizing the cathodic protection system of the present invention, more anodes may be required, and the two anodes 16 and 18 are shown in FIG. 1 merely for illustrative purposes. The factors considered in determining the precise number of anodes to be utilized in a particular application will be described more fully below.

The anodes 16 and 18 are spaced a predetermined distance apart or, more particularly, the anodes 16 and 18 are disposed at predetermined positions with respect to the protected surface 12. The spacing of the anodes 16 and 18 over the protected surface 12 and the number of anodes utilized in a particular cathodic protection system will depend on such considerations as, for example, the material to be protected, that is the composition of the protected surface 12, the "throwing power" of the anodes, the geometry or geometrical configuration of the protected surface, the corrosivity of the particular electrolyte 14 and the temperature of the electrolyte 14.

It is well known in the art that an anode operating in a particular cathodic protection system has a determinable "throwing power" with respect to the particular cathodic protection system. The term "throwing power" is generally used in the art to indicate the ability of a given electrode or anode to cover or to maintain

and hold polarized a given surface area in contact with a particular electrolyte or corrosive environment.

In the cathodic protection apparatus 10, the anodes 16 and 18 are disposed with respect to the protected surface 12 such that the throwing power of each anode 16 and 18 cooperates to establish and maintain a predetermined polarization over substantially the entire area of the protected surface 12. For example, the anodes 16 and 18 may be disposed such that the throwing power of the anode 16 slightly overlaps the throwing power of the anode 18, and thus the two anodes 16 and 18 cooperate to protect the entire area of the protected surface 12 in contact with the electrolyte 14.

In most instances, sufficient empirical data is available to determine the spacing or placement of the anodes over the protected surface. In other instances, however, it may be necessary to establish the empirical data with respect to a particular cathodic protection system in order to determine the spacing in accordance with the above described cooperation. The determination of the number of anodes and the determination of the spacing of the anodes in a particular application, as described above, will be made more apparent below.

The cathodic protection apparatus 10, as shown in FIG. 1, also includes a predetermined number of reference electrodes, each reference electrode being disposed in the electrolyte 14, and one of the reference electrodes being disposed and adapted to cooperate with one of the anodes 16 or 18 in the operation of the cathodic protection apparatus 10. The reference electrodes are constructed of a material which is located in the e.m.f. table at a lower or more noble position than the material of the protected surface 12, and may be, for example, a calomel electrode when cooperating or being utilized in a system wherein the protected surface 12 is a stainless steel.

More particularly, as shown in FIG. 1, two reference electrodes 20 and 22 are disposed in the electrolyte 14. The reference electrode 20 is disposed with respect to the protected surface 12 and with respect to the anode 16 to indicate the anode potential of the anode 16 with respect to the protected surface 12, and to cooperate to control the polarizing current being provided to the anode 16 during one portion of the operation of the cathodic protection apparatus 10, as will be described in more detail below. The reference electrode 22, as shown in FIG. 1, is disposed with respect to the protected surface 12 and with respect to the anode 18 to indicate the potential of the anode 18 with respect to the protected surface 12, and to cooperate in the cathodic protection apparatus 10 to control the polarizing current being provided to the anode 18 during one portion of the operation of the cathodic protection apparatus 10, as will be described in more detail below.

Each anode 16 and 18 is electrically connected to the positive side of a power source or, more particularly as shown in FIG. 1, a central power supply 24 via a two-position switch 26. The positions of the switch 26 are designated in FIG. 1 as A and B and, as shown in FIG. 1, the switch 26 has been positioned in the A position thereof.

The anode 16 is connected to the B-position of the switch 26 via a conductor 28, and the anode 18 is connected to the A-position of the switch 26 via a conduc-

tor 30. The switch 26 is connected to the positive side of the central power supply 24 via a conductor 32.

In the A-position of the switch 26, as shown in FIG. 1, the switch 26 functions to provide electrical continuity between the anode 18 and the positive output side of the central power supply 24 via the conductors 30 and 32. In this position of the switch 26, there is no electrical continuity between the anode 16 and the central power supply 24, for reasons to be made more apparent below.

It is apparent from FIG. 1, that when the switch 26 is moved or positioned in the B-position thereof, the switch 26 will establish electrical continuity between the positive side of the central power supply 24 and the anode 16 via the conductors 28 and 32, and the anode 18 will not be in electrical communication with the central power supply 24, for reasons which will be made apparent below. The central power supply 24, is adapted to provide a predetermined amount of polarizing current to the anode 16 or 18 connected thereto or, in other words, in electrical continuity therewith. It is apparent from the above, that the power supply 24 will more particularly provide polarizing current to the anode 16 or 18, depending upon the position of the switch 26. Power supplies of this general nature are well known in the art and no further description is required herein.

Each anode 16 and 18 is also electrically connected to the positive output side of an automatic current controller 34 via a two-position switch 36. The two positions of the switch 36 are designated in FIG. 1 as A and B and, as shown in FIG. 1, the switch 36 has been moved or switched to the A-position thereof. As shown in FIG. 1, the anode 16 is electrically connected to the A-position of the switch 36 via a conductor 38, and the anode 18 is electrically connected to the B-position of the switch 36 via a conductor 40. The switch 36 is electrically connected to the positive output side of the automatic current controller 34 via a conductor 42.

It is apparent from FIG. 1, that in the A-position of the switch 36, as shown in FIG. 1, the switch 36 functions to provide electrical continuity between the anode 16 and the positive output side of the automatic current controller 34 via the conductors 38 and 42. In this position of the switch 36, the anode 18 is not in electrical communication with the automatic current controller 34.

It is also apparent from FIG. 1, that when the switch 36 has been moved to the B-position thereof, the switch 36 will function to provide electrical continuity between the anode 18 and the automatic current controller 34 via the conductors 40 and 42. In the B-position of the switch 36, the anode 16 will not be in electrical communication with automatic current controller 34, for reasons which will be made more apparent below.

The automatic current controller 34 is adapted to provide an adjustably, controlled polarizing current to the anode connected thereto or, in other words, to the anode 16 or 18 in electrical continuity therewith. More particularly, the polarizing current provided by the automatic current controller 34 is adjustably controlled in response to a control signal received by the automatic current controller 34, in a manner to be more fully described below. Current controllers adapted to

provide an adjustably controlled current output in response to a control signal are well known in the art and therefore a detailed description is not required herein.

As shown in FIG. 1, the negative side of the automatic current controller 34 is electrically connected to the protected surface 12 via a conductor 43, and the negative side of the central power supply 24 is also electrically connected to the protected surface 12 via a conductor 45 which is connected to the conductor 43. The central power supply 24 and the automatic current controller 34 are thus connected to the protected surface 12 in such a manner as to maintain the protected surface 12 cathodic.

As shown in FIG. 1, each reference electrode 20 and 22 is in electrical communication with a comparator 47 via a two-positioned switch 44. The two positions of the switch 44 are designated in FIG. 1 as A and B and, as shown in FIG. 1, the switch 44 is in the A-position thereof.

The reference electrode 20 is electrically connected to the A-position of the switch 44 via a conductor 46 and the reference electrode 22 is electrically connected to the B-position of the switch 44 via a conductor 48. The switch 44 is electrically connected to the comparator 47 via a conductor 50.

It is apparent from the foregoing in FIG. 1, that in the A-position of the switch 44, as shown in FIG. 1, the switch 44 functions to provide electrical continuity between the reference electrode 20 and the comparator 47 via the conductors 46 and 50. In this position of the switch 44, the reference electrode 22 is not in electrical communication with the comparator 47.

It is also apparent from FIG. 1, that in the B-position of the switch 44, the switch 44 functions to provide electrical continuity between the reference electrode 22 and the comparator 47 via the conductors 48 and 50. In the B-position of the switch 44, the reference electrode 20 is not in electrical communication with the comparator 47, for reasons which will become apparent below.

As mentioned before, the reference electrodes 20 and 22 are each adapted and positioned to indicate the anode potential of one of the anodes 16 or 18, more particularly, the reference electrodes 20 and 22 are adapted and positioned such that the potential of each reference electrode 20 and 22 with respect to the protected surface 12 is indicative of the potential of the anode 16 or 18 with respect to the protected surface 12. The comparator 47 is thus adapted to compare the potential of one of the reference electrodes 20 or 22, depending upon the position of the switch 44 with a predetermined set potential, and to produce an output control signal 52 which is proportional to such comparison or, in other words, indicative of such comparison.

The automatic current controller 34 is adapted to receive the output control signal 52 from the comparator 47, as indicated in FIG. 1, and to adjustably control the polarizing current provided by the automatic current controller 34 in response to the output control signal 52.

In actual practice, the comparator 47 and the automatic current controller 34 may, in some instances, comprise a unitary current control unit which is com-

monly referred to in the art as a "potentiostat." Potentiostats adapted to automatically adjust the current output therefrom in response to a particular reference or control signal supplied thereto are well known in the art and further detailed description is not required herein.

As diagrammatically indicated in FIG. 1, the switches 25, 36 and 44 are interconnected or ganged in such a manner that the switches 26, 36 and 44 are each simultaneously positioned in the respective A-position or in the respective B-position thereof. Also as shown in FIG. 1, the switches 26, 36 and 44, in a preferred form, comprise a unitary switching control unit, indicated in FIG. 1 by the general reference 56. From the foregoing, it is apparent that the switching control unit 56 is interposed between each anode 16 and 18 and the power supply 24, between each anode 16 and 18 and the automatic current controller 34, and between each reference electrode 20 and 22 and the comparator 47. The switching control unit 56 is particularly adapted to selectively and sequentially provide, for a predetermined period of time, electrical continuity between selected ones of the anodes and the automatic current controller 34 and electrical continuity between the remaining anodes and the power supply 24, such that sequentially the automatic current controller 34 provides controlled polarizing current to some of the anodes and the power supply 24 provides polarizing current to the remaining anodes, as will be described more fully below. In other words and in a preferred form, the switching control unit 56 is adapted to sequentially switch or move each switch 26, 36 and 44 to the respective A-position or B-position thereof at predetermined time intervals, for reasons which will become more apparent below.

The switching control unit 56 may, for example, be adapted to maintain the switches 26, 36 and 44 in the A-position for a preselected period of two minutes and at the end of that time move the switches 26, 36, and 44 to the B-position thereof. The switching control unit 56, for example, might then hold the switches 26, 36 and 44 in the B-positions thereof for a period of 2 minutes and at the end of that time move the switches 26, 36 and 44 back to the A-positions thereof. The particular time interval or switching period established for the switching control unit 56 with respect to a particular cathodic protection apparatus 10 will depend to some extent on the size of the surface area being protected by the cathodic protection apparatus 10, the required polarization, the number of anodes utilized in the particular cathodic protection system, and the composition and other parameters of the electrolyte 14. In view of the detailed description of the cathodic protection apparatus 10 contained herein, the determination of the switching period for a particular application will be apparent to those skilled in the art.

It should be specifically noted that the switches 26, 36 and 44 have been diagrammatically shown in FIG. 1 as being mechanically operated merely for the purpose of clarity of description and, in a preferred form, the switches 26, 36 and 44 would be adapted such that they would be electrically or electronically operated. Electrical or electronic switching units adapted to function in a manner as generally described above and as will be more particularly described below are well known in

the art and further detailed description is not required herein.

It should also be noted that there are various systems and apparatus available which are adapted to indicate the anode potential of a particular anode in a cathodic protection system, and to subsequently provide an output signal proportional to a comparison of that anode potential with a predetermined set potential. The utilization of the reference electrodes 20 and 22 and the comparator 47, as shown in FIG. 1, is indicative of a preferred form. Therefore, the comparator 47 and the reference electrodes 20 and 22 are sometimes referred to below as a potential control.

OPERATION OF FIG. 1

As mentioned before, the cathodic protection apparatus 10, as shown in FIG. 1, is adapted to cathodically protect the surface 12 utilizing a minimum total power consumption, and in a manner maintaining polarization within a predetermined range over substantially the entire area of the protected surface 12.

During the initial start-up of the cathodic protection apparatus 10, shown in FIG. 1, the switching control unit 56 is in, what may be referred to as an initial switching position, wherein the switches 26, 36 and 44 are in the A-position. In this position, the anode 18 is receiving polarizing current from the central power supply 24 via the switch 26.

The power supply 24 is particularly adapted to supply a minimum polarizing current to any particular electrode and, more particularly, as shown in FIG. 1, to provide a minimum polarizing current to the anode 18 in the A-position of the switches 26, 36 and 44. The polarizing current provided by the power supply 24 should be sufficient to maintain the potential of the anode 18 within a predetermined minimum-polarization range for a particular application such that the automatic current controller 34 can provide sufficient polarizing current to the anode 18 to bring the overall potential of the anode 18 up to a predetermined potential during the time period when the switches 26, 36 and 44 are moved to the B-position.

During the initial start-up and in the A-position of the switching control unit 56, the anode 16 is being provided polarizing current by the automatic current controller 34 via the switch 36, and the reference electrode 20 is in electrical communication with the comparator 47. In this position, the reference electrode 20 will of course be registering or measuring a minimum or, more particularly, a "zero" potential. Thus, in this position, the output control signal 52 of the comparator 47 will indicate to the automatic current controller 34 that a maximum polarizing current is to be supplied to the anode 16 via the switch 36.

It should be noted that the initial current to establish polarization in the cathodic protection system 10 is generally higher than the polarizing current required to maintain polarization. Therefore, the polarizing current output of the automatic current controller 34 to the anode 16 will be at a maximum during the initial start-up of the cathodic protection apparatus 10. It should also be noted that the reference electrode 20 is continuously providing the anode potential indication to the comparator 47 and the control signal output 52 of the comparator 47 will thus vary in response thereto,

thereby varying the polarizing current output of the automatic current controller 34 in accordance therewith.

After a predetermined period of time, the switching control unit 56 will move the switches 26, 36 and 44 to the B-position thereof. In the B-position of the switches 26, 36 and 44, the central power supply 24 will be providing polarizing current to the anode 16 via the switch 26 and the automatic current controller 34 will be providing polarizing current to anode 18 via the switch 36. The polarizing current being provided by the automatic current controller 34 to the anode 18 will be adjustingly, controlled in response to output of control signal 52 of the comparator 47 cooperating with the reference electrode 22, in a manner similar to that described before with respect to the anode 16 and the reference electrode 20.

After the predetermined polarization of the cathodic protection apparatus 10 has been established, the power supply 24 and the automatic current controller 34 will cooperate to maintain the cathodic protection apparatus 10 within a predetermined polarization range, or in other words to cathodically protect the surface 12, in a manner similar to that described above with respect to the start-up operation of the cathodic protection apparatus 10. Thus, during the operation of the cathodic protection apparatus 10, when the switches 26, 36 and 44 are in the A-position, the power supply 24 will be providing a minimum polarizing current to the anode 18 and the automatic current controller 34 will be providing an adjustingly, controlled polarizing current to the anode 16, that is adjustingly controlled with reference to the output control signal 52 of the comparator 47 cooperating with the reference electrode 20. In the B-position of the switches 26, 36 and 44 of the switching control unit 56, the power supply 24 will be providing a minimum polarizing current to the anode 16 and the automatic current controller 34 will be providing an adjustingly, controlled polarizing current to the anode 18, that is adjustingly controlled with reference to the output control signal 52 of the comparator 47 cooperating with the reference electrode 22.

It is apparent from the foregoing and from FIG. 1, that the reference electrode 20 functions to provide a reference anode potential measurement to the comparator 47 when the switches 26, 36 and 44 are in the A-position thereof, and the reference electrode 22 functions to provide a reference anode potential measurement to the comparator 47 when the switches 26, 36 and 44 are in the B-position thereof. Thus the switch 44 sequentially and selectively provides electrical continuity between the comparator 47 and the reference electrode 20 or 22.

It has been found that in cathodic protection systems utilizing only one power anode and one reference electrode, that the power anode may consume substantially more total power output than necessary to maintain the particular desired, polarization. It has also been found that, in some instances, utilizing a single power anode and a single reference electrode that the predetermined potential at which the power anode is maintained may be insufficient to provide the cathodic protection required by the system or, in other words, to maintain the particular cathodic protection system within a predetermined polarization. This of course results in an

overall increased operating cost and, in some instances, an increased corrosion rate with respect to particular areas of the protected surface.

The utilization of a predetermined number of power electrodes or anodes and a predetermined number of cooperating reference electrodes, in a manner as described above, permits the entire cathodic protection system to be maintained within a predetermined range utilizing less total power consumption and assures that all areas of the protected surface are maintained within that polarization range, thereby effectively reducing and controlling corrosion.

The above is particularly important when considering the utilization of a cathodic protection apparatus to protect tanks, having a relatively large surface area in contact with a corrosive fluid, wherein the various parameters of the corrosive fluid in the tank may significantly vary throughout the tank due to the large volumetric area occupied by the corrosive fluid. Thus, it is apparent from the foregoing that in such a tank, for example, the temperature of the corrosive fluid or the corrosive environment could vary considerably from one portion of the tank with respect to another portion of the tank, thus requiring more polarizing current to be provided at one area and less polarizing current to be provided at another area.

The cathodic protection apparatus 10 of the present invention thus establishes and maintains a predetermined polarization over the entire area protected surface 12 in such a manner that the polarizing current to each predetermined area of the protected surface 12 is maintained at a minimum and yet is sufficient to cathodically protect that portion of the protected surface 12. It should be particularly noted that the term "total power consumption" of the cathodic protection apparatus refers more specifically to the power consumed by the central power supply 24 and the automatic current controller 34 in establishing and maintaining the predetermined polarization.

It should also be noted that the utilization of a predetermined number of power anodes and predetermined number of associated reference electrodes cooperating therewith, in a manner as described above, becomes important in attempting to cathodically protect surfaces having an irregular or relatively complex geometrical shape. The various parameters of the corrosive fluid, in such an instance, and the polarizing current required to establish and maintain particular areas of the surface within a predetermined polarization range may vary considerably.

The graph shown in FIG. 3 is a plot of current density, measured in milliamps per centimeter squared, versus time, measured in minutes, for a particular experimental utilization of the cathodic protection apparatus 10, as described before. In this particular experiment, the test specimen was annealed 1020 carbon steel with a surface area of 22 square centimeters. The electrolyte utilized was a merchant grade H_3PO_4 (75 percent by weight) at a temperature of 24° centigrade. The reference electrode was a saturated calomel cell (SCE). The time interval or time period for the switching control unit 56 was set to sequentially switch the switches 26, 36, and 44 between the A-position and the B-position at 2-minute time intervals.

It is apparent from FIG. 3 that the current density required to maintain polarization within a predetermined range decreased over a period of time, the larger amount of polarization current being required to initially establish polarization. More particular, and as shown in FIG. 3, in approximately 120 minutes the current density required to maintain the test specimen (the carbon steel) cathodically protected was approximately 0.1 milliamps per square centimeter, whereas the current density required to establish polarization varied from approximately 2.0 to 0.15 milliamps per square centimeter in approximately 60 minutes. In this example, the corrosion rate was determined to be approximately 1.2 mpg, whereas normally the corrosion for unprotected steel is between 500 and 600 mpg.

From the foregoing it is apparent that the total polarizing current, that is the current provided by the central power supply 24 and the automatic current controller 34, to maintain a predetermined polarization decreased over a period of time. Thus, in this example, the total power consumed by the cathodic protection system 10 was substantially reduced over a period of time, since the current density required to maintain the predetermined polarization decreased during that period of time.

It should also be noted that the switching control unit 56 cooperates with the central power supply 24 and the automatic current controller 34, as described above, in a manner such that a large number of anodes are effectively and efficiently controlled by the single unit combination. Thus, the cathode protection apparatus 10 is also adapted to control a large number of anodes utilizing a reduced number of protection units.

DESCRIPTION OF FIG. 2

The cathodic protection apparatus 10a, shown in FIG. 2, is constructed similar to the cathodic protection apparatus 10, described before. One of the differences between the cathodic protection apparatus 10a and the cathodic protection apparatus 10 is that each switch 26a, 36a, and 44a of the switching control unit 56a is a three-positioned switch, having a third position designated in FIG. 2 by the letter or switch position C.

As shown in FIG. 2, when the switching control unit 56a has been actuated to move the switches 26a, 36a, and 44a to the C-position thereof, the central power supply 24 and the automatic current controller 34 are not in electrical communication with either the anode 16 nor the anode 18. In other words, the C-position of the switching control unit 56a represents a switch position wherein polarizing current is not being provided via the central power supply 24 nor the automatic current controller 34.

As shown in FIG. 2, a programmer 70 is disposed between the switching control unit 56a and the protected surface 12. More particularly, and as illustrated in FIG. 2, the programmer 70 is adapted to sense various parameters relating to the protected surface 12 or the electrolyte 14 via a sensing conductor 72 and to provide an actuating control signal 74 to the switching control unit 56a. The control signal 74 is responsive to the particular sensing control signal 72 being supplied to the programmer 70, as will be made more apparent below.

As diagrammatically indicated in FIG. 2 and in a preferred form, the programmer 70 is adapted to control the switching sequence of the switching control unit 56a. More particularly, the programmer is adapted to control the cycle time or period of the switching control unit 56a, that is the particular period of time in which the switching control unit 56a will maintain the switches 26a, 36a, and 44a in the A-position, the B-position or the C-position thereof.

Since the particular amount of polarizing current required to be provided to a particular anode at a given time and in a particular cathodic protection system to maintain the system polarized depends upon such parameters as, for example, the temperature of the electrolyte 14, as mentioned before. The programmer 70, in that instance, can be more particularly adapted such that the sensing signal 72 is responsive to the temperature of the electrolyte 14. The output control signal 74 of the programmer 70, in that example, would set the cycle time or switching period of the switching control unit 56a in accordance with the measured temperature of the electrolyte 14.

As shown in FIG. 2, the C-position of the switches 26a, 36a, and 44a essentially represents an "off" position, the sensing signal 72 might be adapted to sense the presence of the electrolyte within the protected surface 12 and the programmer 70 might then be adapted to cooperate with the switching control unit 56a to move the switches 26a, 36a, and 44a therein to the A-position and to automatically begin the cycle sequencing of the switching control unit 56a, in a manner similar to that described before.

From the foregoing it will be apparent to those skilled in the art, that in particular cathodic protection systems, the programmer 70 could be adapted to sense any particular controlling parameter or parameters in that system and to control the switching cycle of the switching control unit 56a in response to such a sensing signal. It will also be apparent to those skilled in the art, that although the C-position of the switches 26a, 36a, and 44a, as shown in FIG. 2, is essentially an "off" position, that in a particular cathodic protection system, the C-position of the switching control unit 56a could represent a switch position wherein the central power supply 24 was providing polarizing current to both anodes 16 and 18.

OPERATION OF FIG. 2

The cathodic protection apparatus 10a, shown in FIG. 2, will operate substantially similar to the cathodic protection apparatus 10, described before. One of the salient differences in the operation of the cathodic protection apparatus 10a, is that the switching period of the switching control unit 56a is controllably varied in response to the control signal 74 from the programmer 70. Since the programmer 70 is adapted to receive a sensing signal 72 which is responsive to various parameters of the cathodic protection system 10a, it is apparent that the cathodic protection apparatus 10a provides a more complete automatic control, which may be more effective or desirable in some applications.

It will be apparent from the foregoing, that the cathodic protection apparatus 10a retains all of the advantages of the cathodic protection apparatus 10,

described before, and yet provides an additional control feature which may operate in an overall cathodic protection system to still further reduce the total power consumption and yet maintain the predetermined polarization.

As mentioned before, the two anodes 16 and 18 have been shown merely for illustrative purposes and, in a particular cathodic protection system, as contemplated by the present invention, more anodes may be utilized. The precise number of additional anodes and the placement of such additional anodes with respect to the protected surface will be apparent to those skilled in the art from the above detailed description.

Changes may be made in the construction and arrangement of the parts or the elements of the various embodiments as disclosed herein without departing from the spirit and scope of the invention as defined in the following claims.

What is claimed is:

1. A cathodic protection apparatus for obtaining and maintaining polarization of a protected surface in a corrosive environment, the protected surface being maintained cathodic, comprising:

a plurality of anode means, each anode means being disposed at a predetermined position with respect to the protected surface;

a current controller means adapted to selectively provide an adjustingly controlled, polarizing current to one of said anode means;

a power supply means adapted to selectively provide a predetermined polarizing current to the remaining of said anode means;

a reference electrode means mounted in the vicinity of each of said anode means and generating an electrical control signal corresponding to the passivation condition of said protected surface, said current controller means being adapted to receive said electrical control signal and to adjustingly control the polarizing current provided by the current controller in response thereto; and

a switch means in electrical communication with said plurality of anode means, said power supply means, said current controller means and said reference electrode means, whereby said switch means is adapted to selectively and sequentially provide electrical continuity between said remaining anode means and said power supply means and to provide electrical continuity between said one anode means, said reference electrode means in the vicinity of said one anode means and said current controller means.

2. A system of claim 1 in which the reference electrode means is located within the area of the throwing power of its corresponding anode means for which the

passivation condition is being measured.

3. A system of claim 1 in which the plurality of anode means, controller means and switch means are placed and cooperate such that the passivation condition encompasses substantially the entire area of the surface being protected in the corrosive environment.

4. A system of claim 1 in which the controller means and switching means are adapted to operate in a cyclic manner with the period of time for each step in the cycle being adjusted according to a predetermined program.

5. A system of claim 1 in which the controller means and switching means are adapted to operate in a cyclic manner with the period of time for each step in the cycle and the overall cycle being adjusted in response to a control signal indicative of parameters of the passivation system.

6. The apparatus of claim 1 which is adapted to maintain a minimum overall power consumption and passivation condition for a large complex surface in a corrosive environment.

7. A method of protecting a surface by obtaining and maintaining polarization of the surface in a corrosive environment to maintain the surface cathodic with a minimum overall power consumption and passivation condition comprising:

disposing a plurality of anode means at a predetermined position with respect to the protected surface;

adapting a current controller means to selectively and adjustingly provide and control a polarizing current to one of said anode means;

adapting a power supply means to selectively provide a predetermined polarizing current to the remaining of said anode means;

mounting a reference electrode means in the vicinity of each of said anode means and generating an electrical control signal corresponding to the passivation condition of said protected surface;

adapting said current controller means to receive said electrical control signal and to adjustingly control the polarizing current provided by the current controller means in response thereto; and

connecting by a switch means said plurality of anode means, said power supply means, said current controller means and said reference electrode means, whereby said switch means selectively and sequentially provides electrical continuity between said remaining anode means and said power supply means and provides electrical continuity between said one anode means, said reference electrode means in the vicinity of said one anode means and said current controller means.

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