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CATHODIC PROTECTION CURRENT REQUIREMENTS FOR ELECTRICAL GROUNDING MATERIALS

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ABSTRACT

Although cathodically protected pipelines are often connected directly to electrical ground in stations and plants, there is little information on the amount of current required to polarize various grounding materials such as copper, tinned copper, stainless steel, silicon iron, and galvanized steel. This paper presents results of short and long-term cathodic polarization tests on commercially available grounding materials buried in a low resistivity clay and a high resistivity sand. The results indicate that in the non-aerated clay all the grounding materials, that would normally be cathodic to steel, required the same or less current density than steel. In the more aerated sandy soil, the current requirements for all the cathodic materials as well as steel increased by at least 2 orders of magnitude with copper requiring an increase of 3 orders of magnitude. Packaged zinc and magnesium anodes were also included in the testing program since they are occasionally used as grounding electrodes for cathodically protected pipelines.

Keywords: electrical grounding, cathodic protection, current requirements, current density, current distribution, cathodic polarization, steel, copper, tinned copper, silicon iron, stainless steel, zinc ribbon, zinc anodes, magnesium anodes

INTRODUCTION

It has been estimated[1] that about 90% of utilities use copper as the primary grounding material which, when directly connected to ferrous structures, has been shown to accelerate corrosion of the ferrous structure due to the resulting galvanic couple. A 7-year driven ground rod test program[2] quantified the accelerating effect of corrosion on buried steel caused by ground rods made of copper, Ni-Resist, and stainless steel, at 19 test sites throughout the U.S. If a grounding system comprised of these materials is connected directly to cathodically protected piping, then the current required to maintain the protection criterion for steel piping could be more than if the grounding system were steel. In all cases the increase is significant when the pipeline facilities are well coated, as has been the practice for oil and gas piping for many years. It is not surprising that Husock[3] concluded "it would be best if the particular structure on which cathodic protection is to be applied, were completely isolated from any copper grounding system." In many cases however this is neither desirable nor practical, especially at pipeline stations.

If a grounding system is to be directly connected to a cathodically protected pipeline, an estimate of the cathodic protection current required to polarize the grounding system is needed. Unfortunately, there is no clear consensus in the literature as to the current density needed for the polarization of buried copper. Field tests conducted on a 15m length of copper cable by Bladholm and Kormendy[4] indicated that a current density of approximately 54μA/cm^2 was required to polarize the copper to –850mV$_{cse}$. Ghesquiere[5] conducted current requirement tests on a copper plate and a copper ground rod in 3,000 ohm-cm water and found the current densities to achieve a potential of –850mV$_{cse}$, were 8.6μA/cm^2 and 12.5μA/cm^2 respectively, compared to 2.2μA/cm^2) required by a steel plate in the same environment. The *"current density required to polarize the copper to an adequate potential necessary to protect a ferrous structure may be 10 to 20 times as high, on a per unit basis*", according to Kirkpatrick in a more recent article.[6]

A number of investigators have found that to just protect copper alone, a relatively modest current density is required, presumably because the potential of the copper does not have to be shifted to highly negative values as it does when connected to steel. Waters,[7] in cathodic protection studies on copper water piping, found that current densities in the range of 0.25μA/cm^2 to 4.4μA/cm^2 were required after a 9 month period in a variety of soils. A current density value of 0.32μA/cm^2 was used by Northern Virginia Electric Cooperative[8] to design cathodic protection systems to protect copper concentric neutral wires, but this value was found to be inadequate in some instances. Zastrow[9] used a 0.1V potential shift method to determine the current required to protect an underground bare concentric neutral which required an initial current density of 1.8μA/cm^2.

Because of the apparently high current requirements of copper, Ghesquiere[10] opted to use ground rods of anode grade zinc, in a gypsum/soil mixture, connected to an insulated copper grounding conductor. Schaefer[11] chose galvanized steel ground rods protected by zinc anodes as an alternative to copper in order to avoid the high current requirements of copper. Kirkpatrick[12] reports using zinc electrodes with insulated copper connecting cables as a grounding system in pipeline compressor stations in the early 1970's where the grounding system was bonded directly to the buried piping. He also reported on the use of galvanized steel rods and cable by the Rural Electrification Administration for many years.

Lawson,[13] as a result of field tests, inspections, and calculations, recommended the use of tinned copper instead of copper because it lowered the grid-to-soil potential by –0.2V, thereby reducing galvanic corrosion problems. Tinned copper was also utilized when galvanized cable was not readily available for a generating station grounding grid system,[14] and the authors commented that tinned coated copper would also reduce cathodic protection current requirements. Of course, steel ground rods are commonly used and their current density requirements would be similar as for bare steel portions of the coated piping.

In order to assess the current requirements of various grounding materials a research project (PR-262-9913) was sponsored by the Pipeline Corrosion Supervisory Committee of the Pipeline Research Council International. The tests were carried out between 1999-2000 at the National Research Council in Ottawa by Bruce Baldock and Shuyian Qian and the project was managed by Correng Consulting Service Inc.

FIELD TESTS

Grounding Materials

Current requirement tests were conducted on the following grounding materials: carbon steel, copper-clad steel, stainless steel, galvanized steel, tinned copper cable, zinc anode ribbon (bare and surrounded by sulfate rich backfill) and high potential magnesium surrounded by sulfate rich backfill. A new ground rod material, composed of high silicon cast iron, was also added to the testing program, since this material was being marketed for use in highly corrosive soils. All grounding materials were commercially available and were procured with similar diameters, so that when used in equal lengths, there would be no significant difference in surface area and resistance to earth. For the field tests, steel strip coupons used in a previous PRCI project[15] were included in the test matrix for comparison to the steel ground electrode. The dimensions and calculated surface areas for each of the grounding materials are listed in Table 1 and shown in Photo 1.

Test Arrangement

A 1.5m long sample of each grounding material was installed horizontally at about 1m depth around the perimeter of existing pipe samples in two different soil conditions as shown in the arrangement of Figure 1. One soil was clay (the native soil), having a resistivity of approximately of 1800 ohm-cm, which represented a relatively unaerated, and wet environment and the second was a well-drained sandy soil with a resistivity of about 90,000 ohm-cm that simulated a highly aerated condition.

Two AWG #12/7strand test leads were attached to one end of the specimen and the connection covered with a reinforced bitumen pad to insulate it from the soil. One test lead was run up the potential monitoring tube and the other was routed to a test station and interconnected to a common negative bus through a 0.1ohm shunt rated at 2A. Potential monitoring tubes were placed vertically over the mid-point of each ground rod specimen to facilitate the measurement of its potential with minimum voltage drop.

The test circuit schematic, shown in Figure 2, was identical for both the clay and sand sites. The test instrumentation, shown in Photo 2, was located in the test hut shown in Photo 3. The instrumentation consisted of a Corrosion Service field potentiostat and a Nilsson Model 820 current interrupter. The potentiostat had a maximum output of 500mA at 15V. All electrode potentials were measured using a Fluke Model 867B multimeter on the 1 G-ohm input resistance scale.

Test Procedure

A series of cathodic polarization scans was performed at each site with the controlling copper-copper sulphate reference electrode placed in the monitoring tube at the steel ground rod for all tests.

The test procedure was as follows:

(a) the corrosion potential of each grounding material specimen was measured before connecting the electrodes together in the shunt test station;

(b) the 5 grounding materials (labeled Group 'A'), whose corrosion potential was normally less anodic than galvanized steel (i.e. carbon steel, copper-clad steel, tinned copper, high silicon cast iron, and stainless steel) and a steel strip coupon were connected together in the shunt test station and, after 24 hours, the current magnitude and direction were measured for each material;

(c) the potential of each of the connected specimens was measured to a saturated copper-copper sulphate reference electrode (CSE) located on the surface of the ground above each specimen and in the respective monitoring tube;

(d) after 24 hours, the potentials and current for each grounding specimen in Group A were measured and the potentiostat set potential was increased –50mV;

(e) step (d) was repeated with the remaining grounding specimens (galvanized steel, zinc and magnesium) being connected into the circuit only when the ON potential of the Group A electrodes to the surface CSE was approximately the same as their respective corrosion potential measured in step (a). The cathodic polarization scan was stopped when $-1200\text{mV}_{\text{cse}}$ was attained or the current limit of the potentiostat was reached;

(f) all electrodes were disconnected and left to depolarize for a minimum of 72 hours before repeating this test procedure.

The results from these initial tests indicated that it was difficult to polarize the Group 'A' electrodes in the sand and therefore it was considered important to conduct current requirement tests over a longer time period than the 50mV/day rate typically used in the initial test. Long term tests were conducted at both the clay and sand sites by holding the Group 'A' electrodes at specific carbon steel set potentials for extended periods of time until the potentiostat current stabilized indicating that a steady state condition had been reached. Typically each individual test lasted from about one week to one month on each setting, with the sand site requiring the longest time.

TEST RESULTS

Initial Test Results in Sand Soil

At the sand site (well aerated and well drained soil), Figures 3 and 4 compare the cathodic current densities received by the individual ground rods as the set potential for the carbon steel ground rod was progressively increased electronegatively. Up to a set potential of about $-1000\text{mV}_{\text{cse}}$ the current densities for each of the Group 'A' electrodes were very similar, with the current densities ranging from 5-8 $\mu\text{A/cm}^2$.

The galvanized steel and bare zinc electrodes were connected to the Group 'A' electrodes when the 'ON' potential measured to a surface reference equaled or was more negative than the corrosion potentials of these materials. The set potential for the carbon steel is considerably less negative than the measured surface 'ON' potentials, because the surface potentials incorporate a large voltage drop, whereas the set potential is measured with respect to a reference placed in a soil tube immediately above the carbon steel ground rod. Figure 3 indicates that these zinc electrodes received a lower current density than the other electrodes up to a set potential of about $-1000\text{mV}_{\text{cse}}$ after which the current density was comparable to the Group 'A' electrodes.

The packaged zinc and magnesium anodes picked up considerably more current than any of the other electrodes, as illustrated in Figure 4. This is understandable since these anodic electrodes, surrounded in low resistivity backfill in the package, had resistances that were an order of magnitude less than the other electrodes. The packaged zinc electrode, no doubt due to its lower corrosion potential, typically received more than twice the current as the high potential magnesium anode.

Although the Group 'A' electrodes each received approximately the same amount of current, ostensibly because they had similar resistances, their cathodic polarization characteristics were quite different as indicated in Figure 5. Here the polarized potential of each electrode was measured as an 'instant-off' potential with the reference electrode placed inside the soil tube of each ground electrode, thus eliminating all earth voltage drops from the measurement. Copper did not polarize nearly as well as the other electrodes, and its polarized potential seemed to reach a maximum of $-500mV_{cse}$ at current densities in the range of $10\text{-}20\mu A/cm^2$ while the other electrodes were polarized to values typically 200mV more electronegative than copper in this current density range.

Initial Test Results in Clay Soil

Current distribution to the Group 'A' electrodes in the clay soil was relatively uniform for all but the tinned copper electrode, which received considerably more current. As the carbon steel set potential was increased, the galvanized steel and zinc electrodes were connected to the ground electrode array when the potentiostat reached a set point of $-1050mV_{cse}$ as shown in Figure 6. Because the resistances of these electrodes were similar to those of the Group 'A' electrodes, the current pick-up was similar, except for the tinned copper. When the polarized potentials of Group 'A' electrodes are compared to their current densities as denoted in Figure 7, it is apparent that the tinned copper electrode did not polarize as well as the other electrodes. The higher current density received by the tinned copper could be due to better charge transfer efficiency at the tin oxide/clay surface. However, tinned copper did not exhibit a higher current demand in the long-term tests. Unlike at the sand site, the copper electrode polarized as well as any of the other electrodes.

Long Term Test Results

Figure 8 shows the polarized (instant-off) potential of the Group 'A' and galvanized steel electrodes. Galvanized steel, which was included as a Group 'A' electrode in these tests because its natural corrosion potential in sand was in the $-600mV_{cse}$ range, required the least current density (approximately $1\mu A/cm^2$) to polarize more electronegative than −850mV. Stainless steel required $5\text{-}6\mu A/cm^2$ to polarize to the same criterion, while carbon steel, silicon iron, and tinned copper required about $20\mu A/cm^2$. Copper required the highest current density, estimated by extrapolation to be approximately $200\mu A/cm^2$.

At the clay site, the current requirements were significantly lower than in the sand and there was very little difference in the current requirements amongst the individual electrodes. The results, shown in Figure 9, indicate that the current density required to polarize the Group 'A' ground electrodes to $-850mV_{cse}$ was generally less than $0.2\mu A/cm^2$. Comparison of the long-term polarization data from the sand and clay soil indicates that the current density required to protect the grounding electrodes is more dependent on the soil conditions than on the type of electrode material, although the widest current density range among the materials was in the sand soil.

These two test conditions fairly represent the current density extremes that would be encountered in actual practice. The sand site, since it was well drained, was therefore well aerated, and the periodic rains would wash out any salts that might aid in forming calcareous deposits. The clay site, which was typical of the native soil conditions, provided a very deaerated environment, and judging by the high salt content in the ground water analysis, provided conditions that would favor the formation of calcareous deposits.

The current requirement extremes between the sand and clay soil are illustrated for the copper and carbon steel electrodes are illustrated in Figure 10.

CONCLUSIONS

Both laboratory and field cathodic polarization tests indicated that the current required to polarize the Group 'A' grounding electrodes to $-850mV_{cse}$, the recognized protection criterion for steel, is greater in aerated conditions compared to non-aerated conditions by about two orders of magnitude.

The long term polarization tests, which most closely simulate actual field conditions, revealed that the current requirements in the clay (non-aerated) soil at the carbon steel protective criterion was less than $0.2\mu A/cm^2$ for all Group 'A' electrodes. Moreover, the steel ground rod required as much or more than the other four materials, with copper requiring the least. These values are well below the $1\text{-}3\mu A/cm^2$ given for steel in the NACE reference book.[16] For non-aerated conditions therefore, the current requirements for copper clad steel, tinned copper, silicon iron, and stainless steel are essentially the same as for carbon steel.

Grounding system current demand can be minimized by using electrodes that are normally anodic to steel, such as galvanized steel, bare zinc anode ribbon, packaged zinc anodes, or magnesium anodes. In the case of the packaged anode materials, not only do they eliminate the need for extra cathodic protection current, but where the pipeline is reasonably well coated, they could provide the needed cathodic protection current for the station piping. The feasibility of doing so would depend on whether or not there were other structures, such as reinforced concrete and buried electrical conduit, also connected to the piping and grounding system. It further requires that the station grounding system is discrete, confined to the station area, and not connected to an extensive power distribution grounding system.

In the aerated soil, the steel ground rod required about $20\mu A/cm^2$ (considerably more than $1\text{-}3\mu A/cm^2$ indicated in the NACE reference book[17]) as did the silicon iron and tinned copper electrodes. The copper clad steel ground rod required about $200\mu A/cm^2$, while the stainless steel electrodes needed about $7\text{-}8\mu A/cm^2$. Galvanized steel, which was included in the long-term polarization tests with the Group 'A' electrodes because its corrosion potential in the high resistivity soil was about $-650mV_{cse}$, required only $1\text{-}2\mu A/cm^2$. Because of these high current density requirements, it would not be prudent to use copper clad steel grounding rods, and by inference, bare copper grounding conductors, in highly aerated soils. Moreover, to minimize the amount of cathodic protection current needed for grounding systems in high resistivity soil, galvanized steel or bare zinc would be the best choice. Interestingly, the use of packaged galvanic anodes may not be a good choice, since these materials, because of their low relative resistance to earth, receive a disproportionate amount of current. Although packaged anodes won't pick up cathodic protection current until their corrosion potentials are exceeded by the applied cathodic protection voltage, this occurs readily in high resistivity soils.

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REFERENCES

1. Sen, P.J., Steel Grounding, IEEE Industrial & Commercial Power Systems Technical Conference, Chicago, 1985, p.1.

2. Task Group T-10C-2a of NACE Technical Committee T-10C, Driven Ground Rod Test Program, Materials Performance, Sept. 1970, p.62-64.

3. Husock, B., The Effect of Electrical Grounding Systems on Underground Corrosion and Cathodic Protection, AIEE Transactions, Vol.79, 1960, p.8.

4. Bladholm, E.F., and Kormendy, L.J., Cathodic Protection and Isolation Solve Corrosion Problems of Subsurface Piping in Generating Stations, Materials Protection, Feb. 1963, p.23.

5. Ghesquiere, J.D., Cathodic Protection and Zinc Grounding in Industrial Plant Construction, Corrosion, Vol.17, March 1961, p.15-16.

6. Kirkpatrick, E.L., The Conflict Between Copper Grounding Systems and Cathodic Protection, Materials Performance, Sept. 1999, p.35.

7. Waters, D.M., Cathodic Protection to Protect Copper Pipelines from External Corrosion, NACE Corrosion'82 Conference, 1982, Paper #41, p.15.

8. Woodsmall, G.P. and Hollcroft, M.L., Cathodic Protection of Existing URD Systems, IEEE Conference Paper, 1986, p.3.

9. Zastrow, O.W., Estimating Cathodic Protection Requirements for Electric Cables in Contact with Soil, IEEE Conference Paper, 1986, p.3.

10. Ibid 7.

11. Schaefer, L.P., Electrical Grounding Systems and Corrosion, AIEE Transactions Vol.74, Part II - Applications and Industry, 1955, p.75-83.

12. Kirkpatrick, E.L., Alternatives to Copper Grounding in Sites Requiring Cathodic Protection, Materials Performance, Sept. 1986, p.18.

13. Lawson,V.R., Problems and Detection of Line Anchor and Substation Ground Grid Corrosion, IEEE Conference Paper, 1986, p.12.

14. Collins, J.H. and Thalmann, E.H., Cathodic Protection at Steam-Electric Generating Stations, Corrosion, Vol.8, Sept. 1952, p.320.

15. Gummow, R.A. et al, Coating Quality Test Methods for Directionally Drilled Pipe, PRCI Contract # 262-9738, Final Report, Sept 1998.

16. NACE Corrosion Engineer's Reference Book, NACE, 1980, p.61.

17. Ibid 16.

Table 1: Dimensions & Surface Areas of Grounding Electrodes

Grounding Electrode	Dimensions (mm)	Surface Area (sq.m.)
Carbon Steel Rod	1525 lg x 20 dia	0.0958
Copper Clad Steel Rod	1525 lg x 17 dia	0.0814
Tinned Copper Cable	1525 lg x 15 dia	0.0718
Galvanized Steel Rod	1525 lg x 20 dia	0.0958
Silicon Iron Rod	1525 lg x 27 dia	0.1293
Stainless Steel Rod	1525 lg x 20 dia	0.0958
Zinc Ribbon Anode Bare	1525 lg x 17 wide x 22 high	0.0848
Zinc Ribbon Anode + Sulfates	1423 lg x 17 wide x 22 high	0.0791
Magnesium Anode + Sulfates	1422 lg x 21.3 dia	0.0951

Photo 1: Grounding Materials Included in the Tests

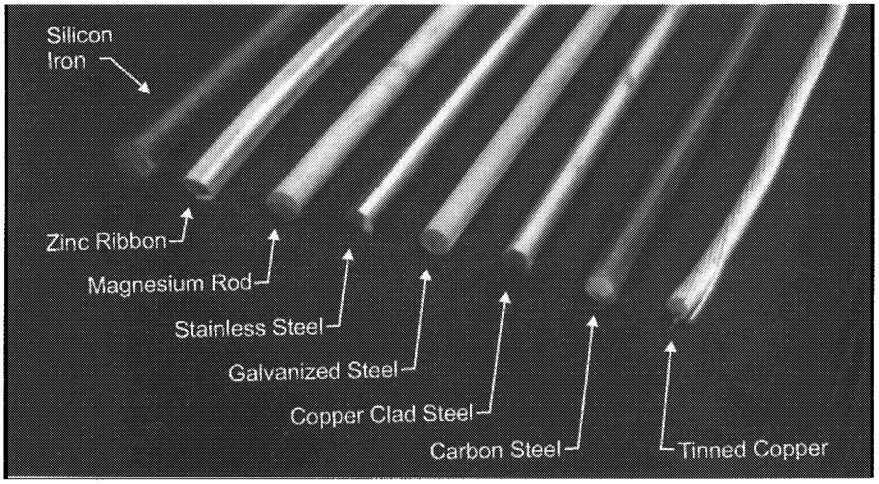

Photo 2: View of Instrumentation

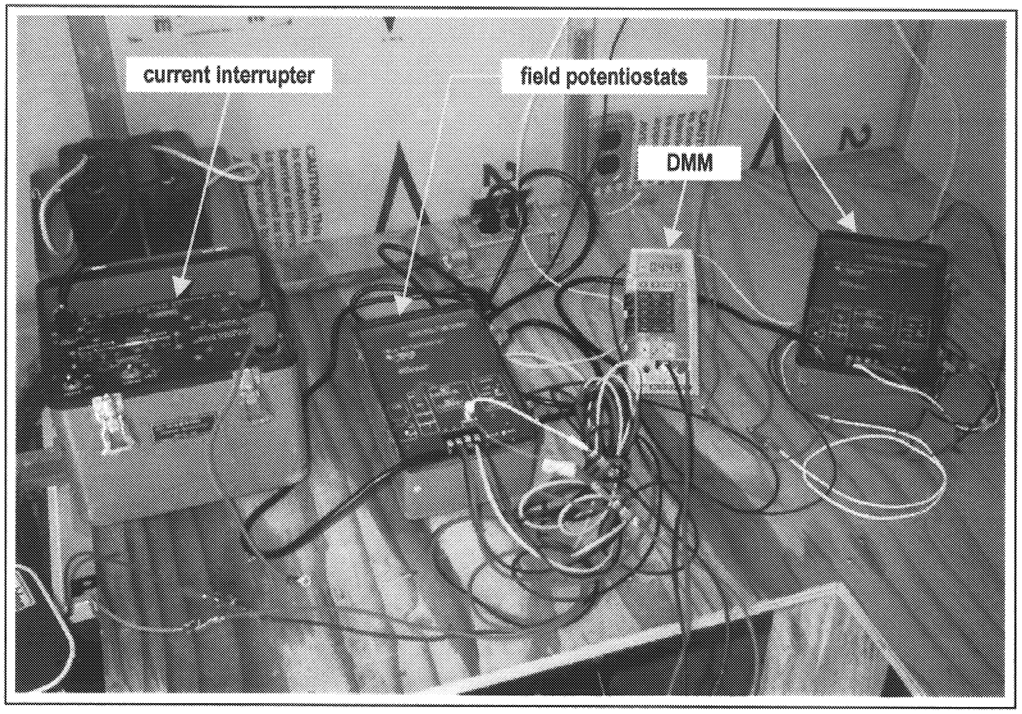

Photo 3: View of Test Site and Instrumentation Hut

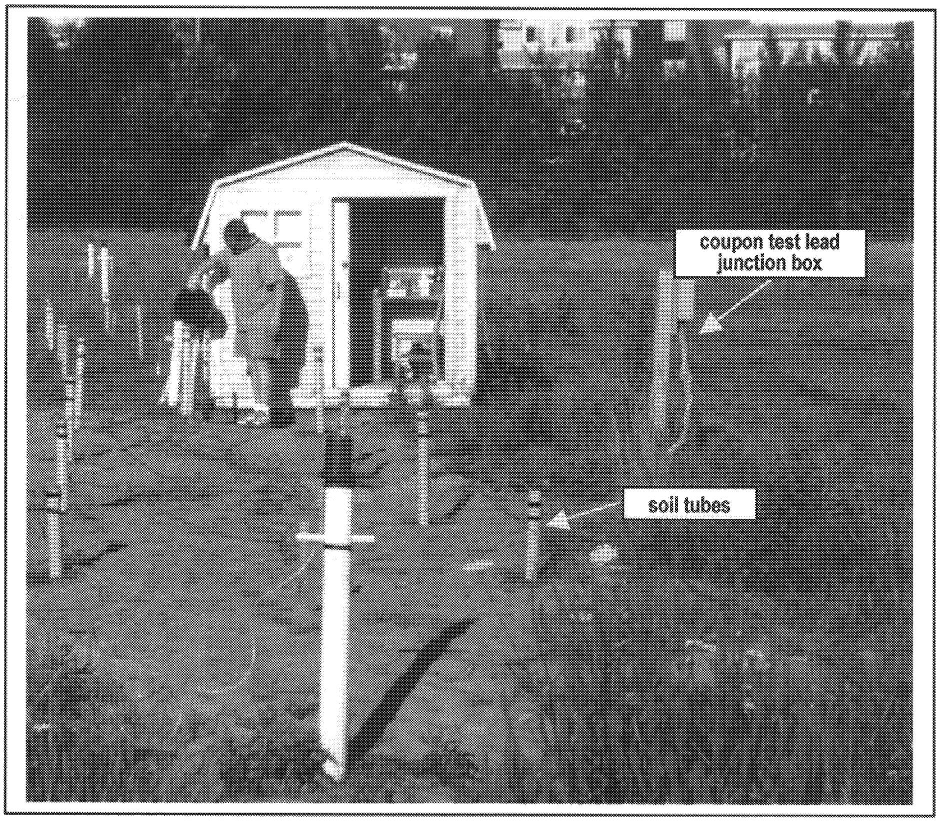

Figure 1: Typical Ground Rod Test Site Layout for Both Sites

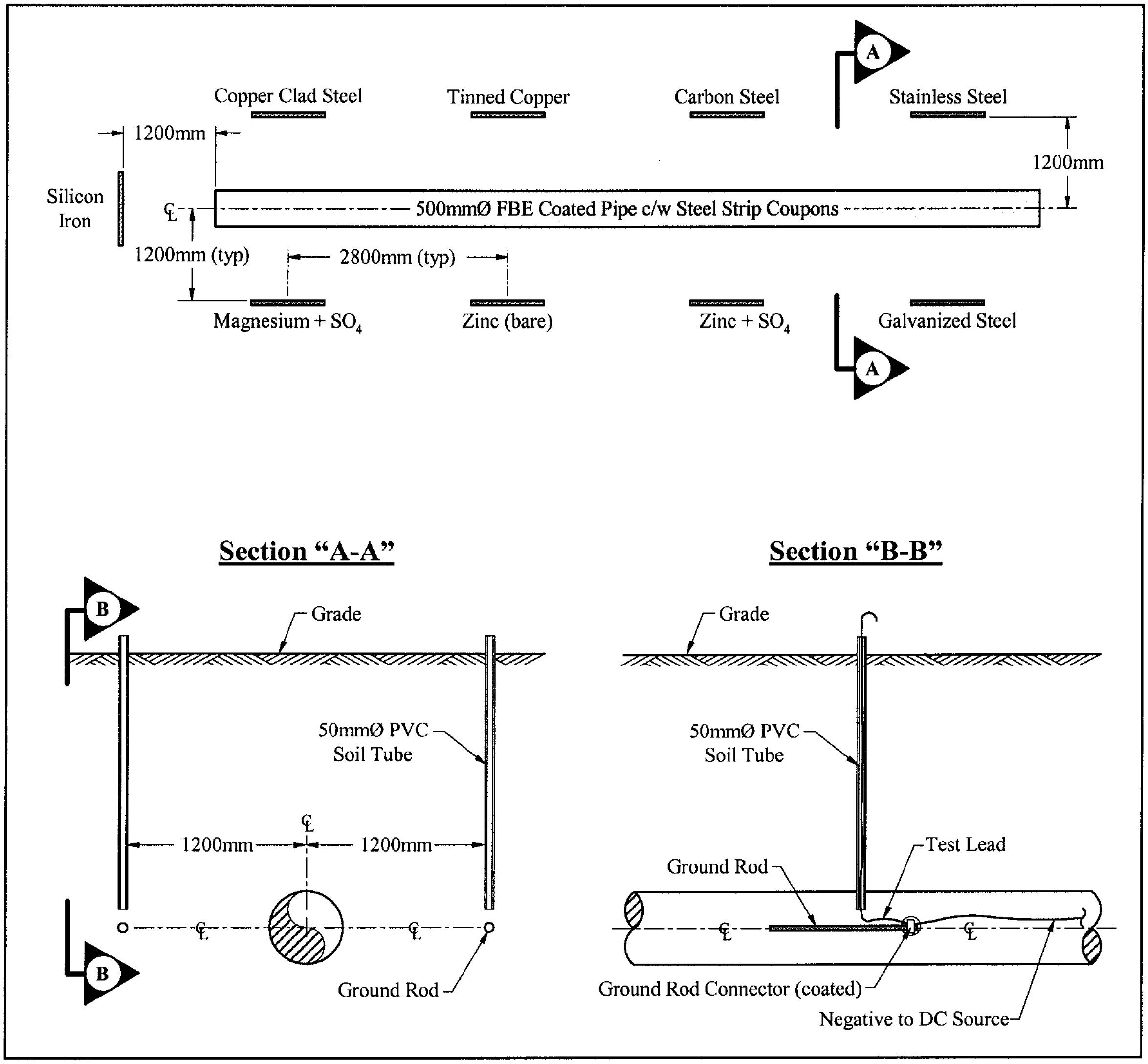

Figure 2: Electrical Schematic of Field Test Arrangement

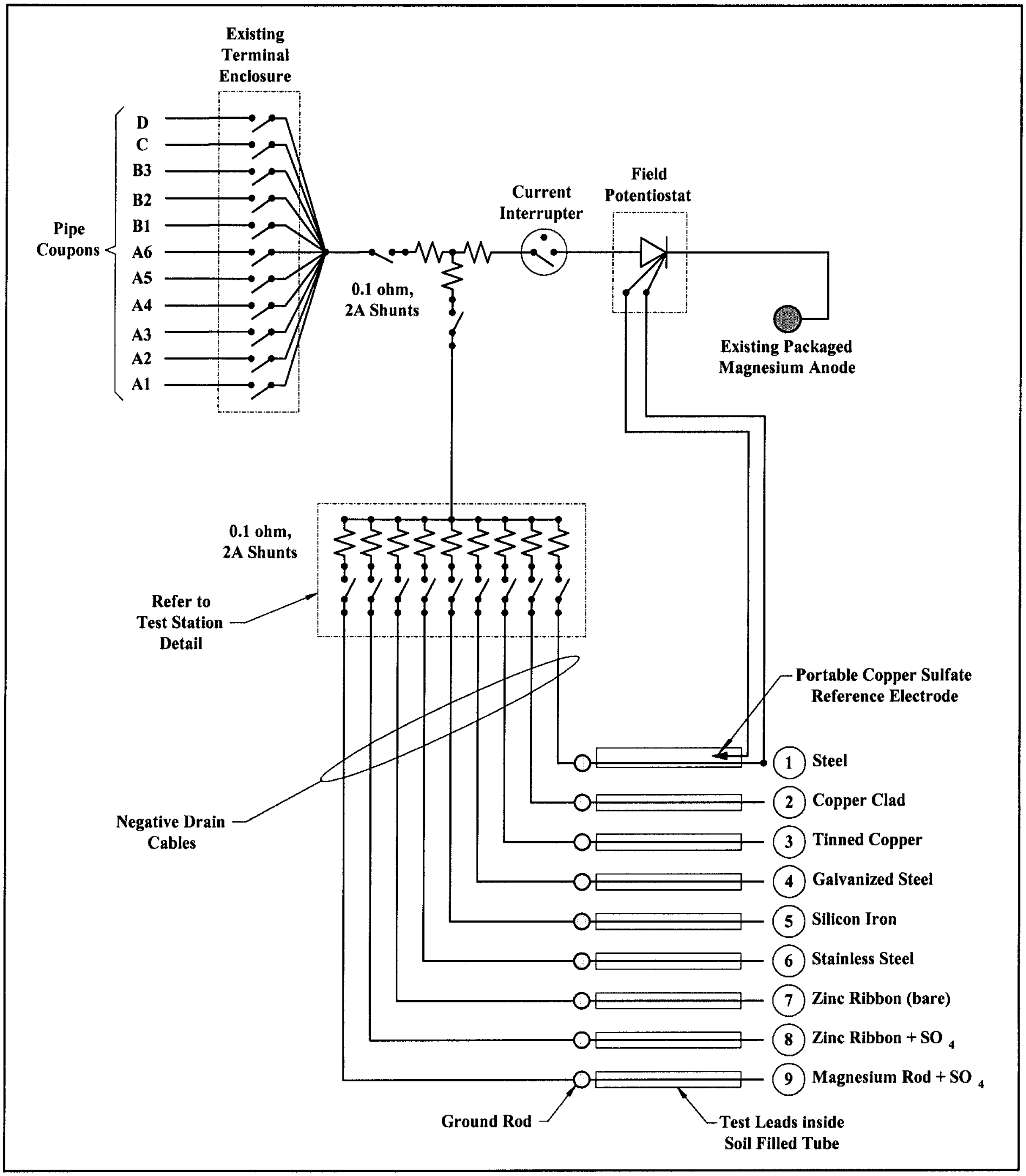

Figure 3: Current Distribution in Sand between All Grounding Electrodes Except for the Packaged Galvanic Anodes

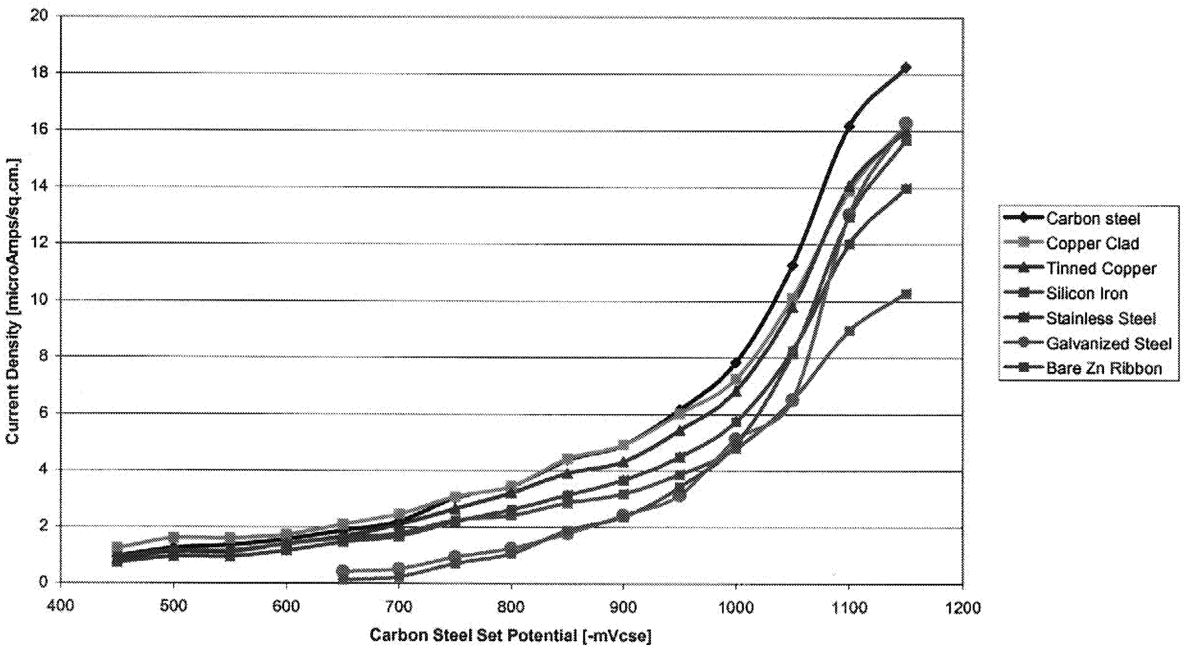

Figure 4: Current Distribution between All Grounding Electrodes and Galvanic Anodes in Sand Soil

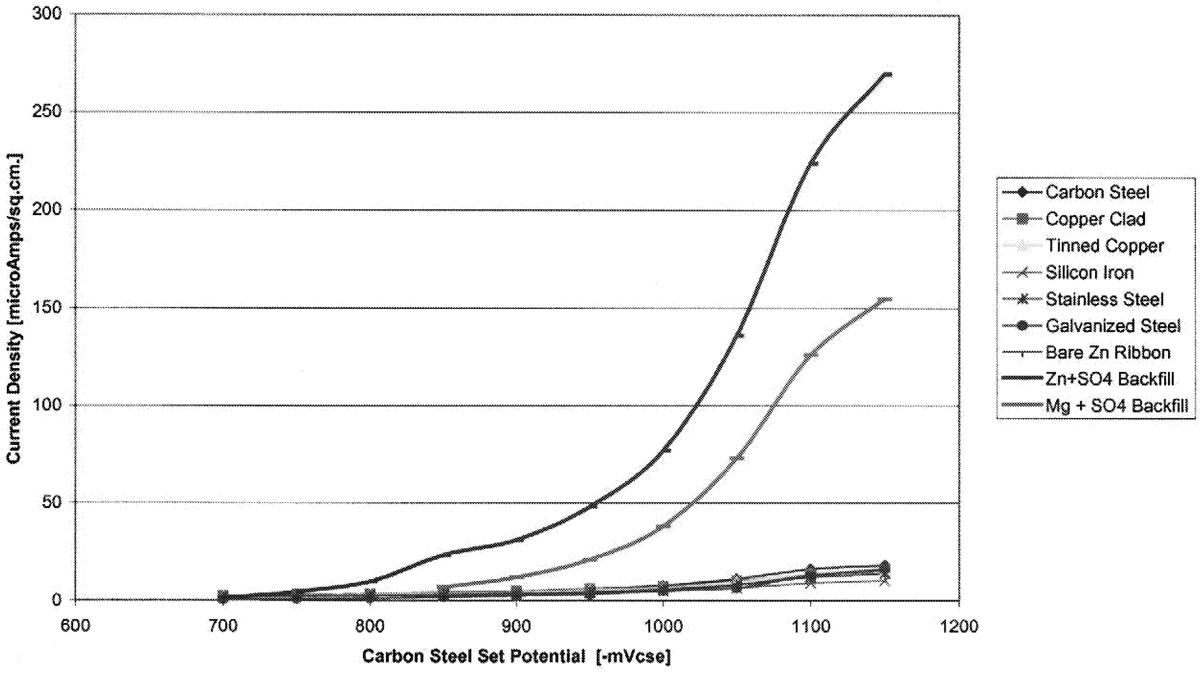

Figure 5: Polarization Curves for Individual Grounding Electrodes of Group 'A' in Sand Soil

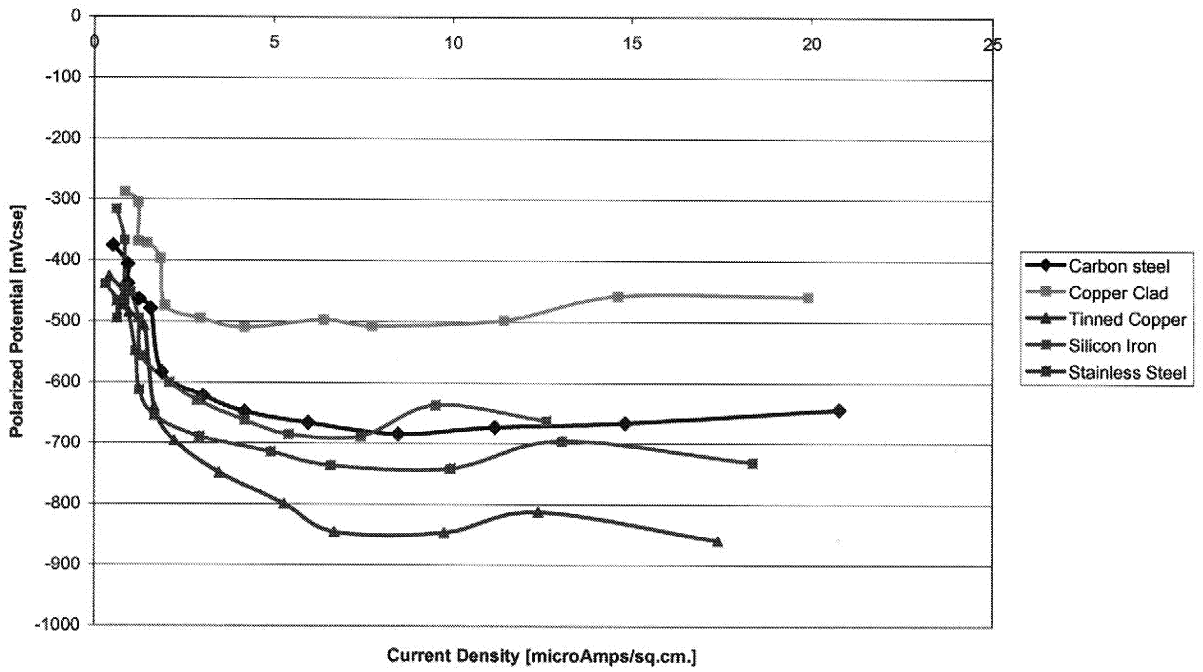

Figure 6: Current Distribution between all Grounding Electrodes Except Magnesium Anode in Clay Soil

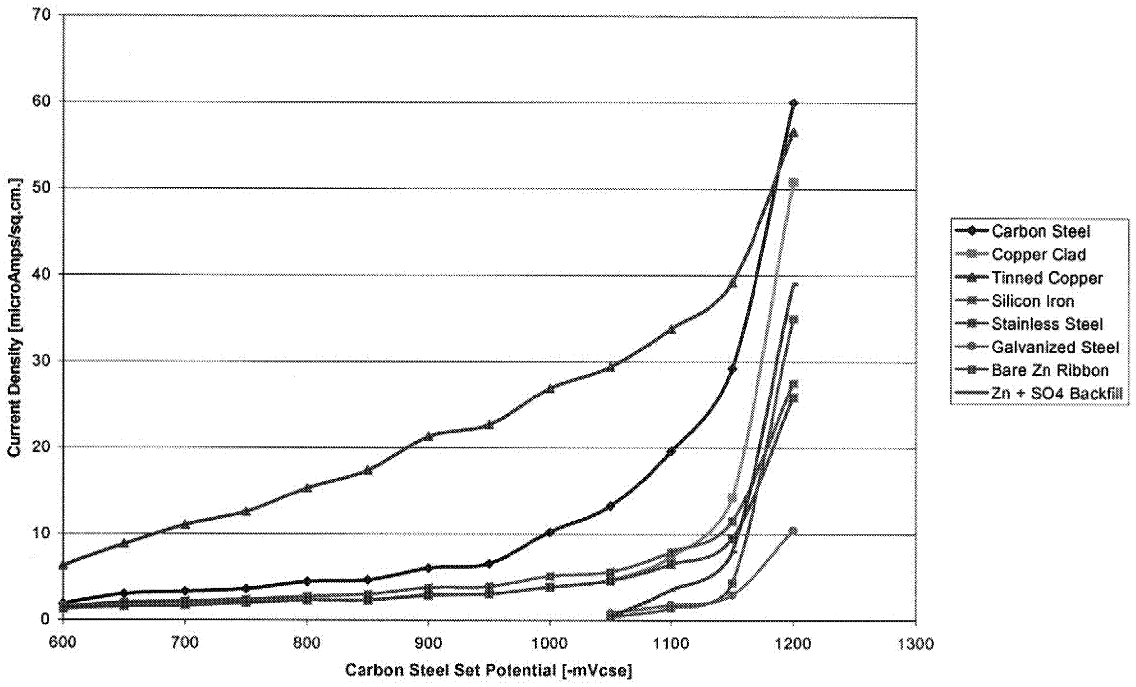

Figure 7 Polarization Curves for Group 'A' Grounding Electrodes in Clay Soil

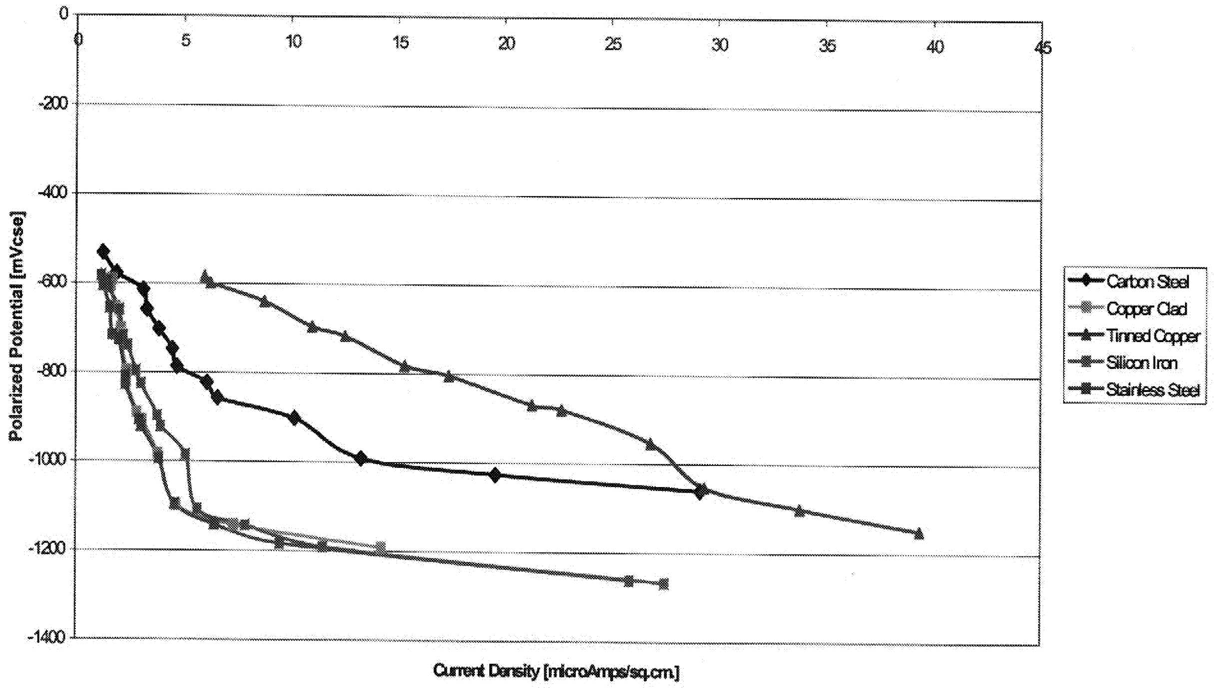

Figure 8: Polarized Potential versus Current Density for Group 'A' Grounding Electrodes and Galvanized Steel in Sand from Long Term Test Results

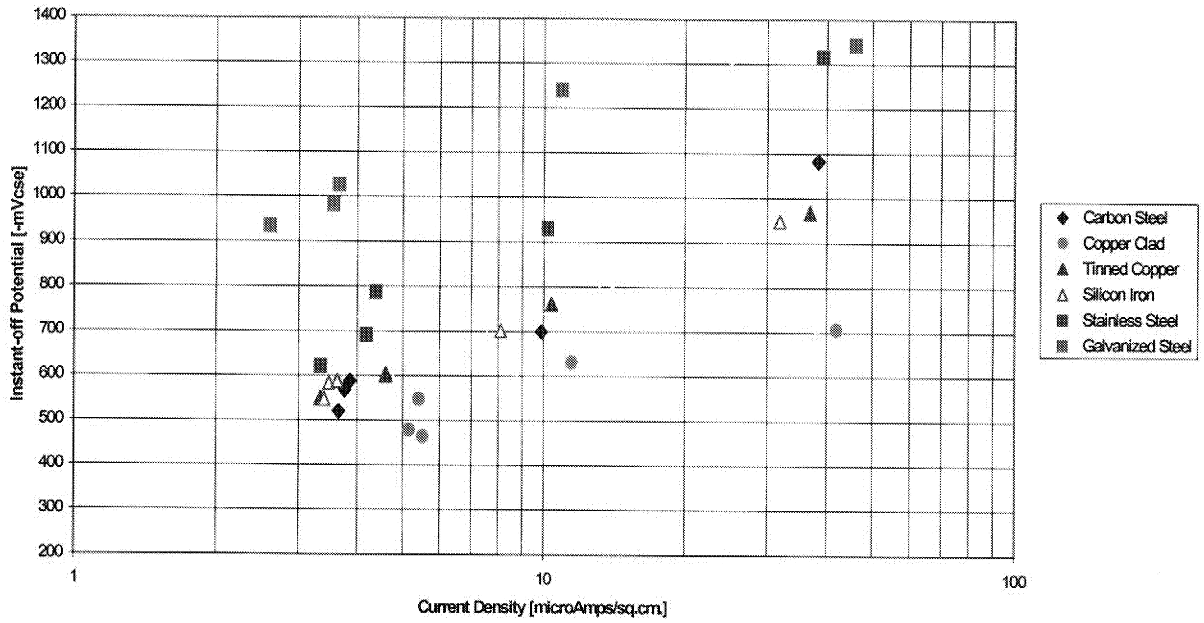

Figure 9: Instant-off Potential versus Current Density for Group 'A' Grounding Electrodes in Clay from Long Term Test Results

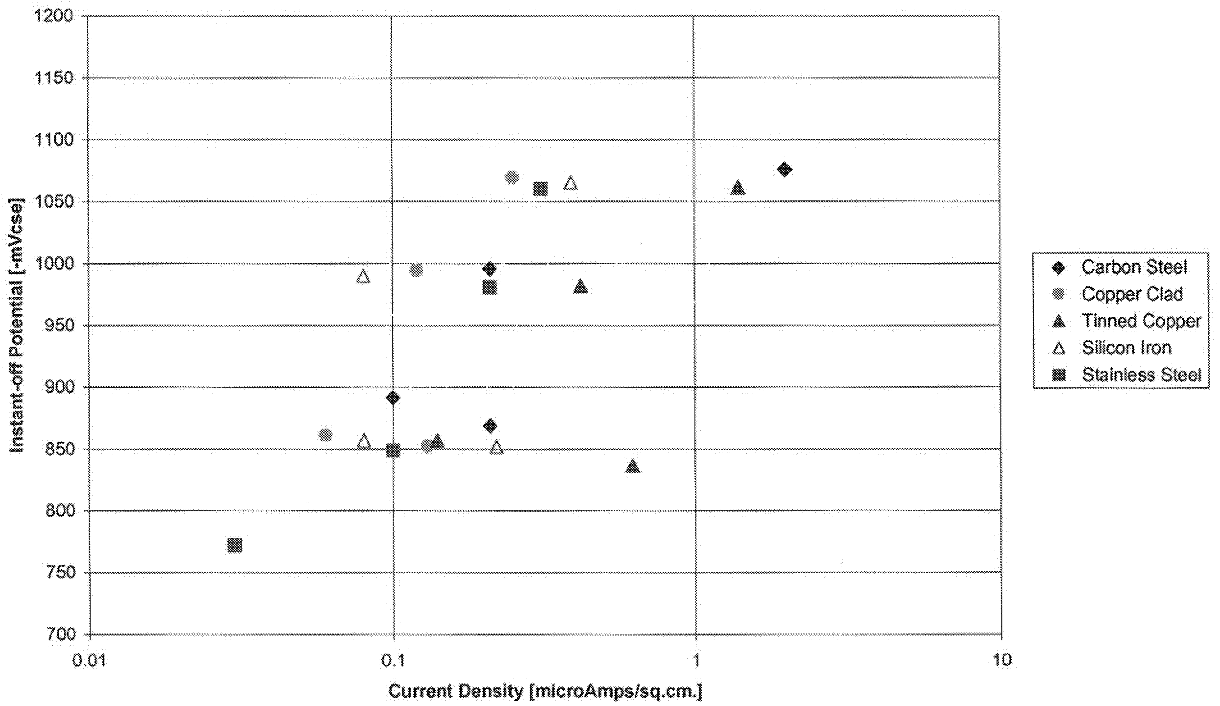

Figure 10: Instant-off Potential versus Current Density for Carbon Steel & Copper Electrodes in Sand and Clay Soil from Long Term Polarization Test Results