INITIAL CORROSION SURVEY OF THE BAY AREA RAPID TRANSIT SYSTEM

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The 75-mile (120-km) Bay Area Rapid Transit System has a dc traction power supply that uses the continuously welded steel running rails for its negative current return. The rails are mounted on insulating fasteners to minimize leakage current. However, high values of stray current have been measured during the initial operation of the system. Testing has demonstrated that the negative return grounding at traction substations and its interconnection with other grounding has been the major cause of stray earth currents. An alternate method of negative return grounding through diodes has been tested and is being installed. The diodes block exchange currents, but allow leakage and fault current return to the traction rectifiers.

•THE BAY AREA Rapid Transit (BART) System, like many other direct-current traction systems, uses its tracks for negative return of traction current. Since these 4 rails extend for 75 miles (120 km) and are physically close to the earth, they can be the source of stray earth currents (1). Such stray currents are a major cause of electrolysis of buried metals in the vicinity of direct-current traction systems (4). This paper discusses the nature of the BART system earth current problem and what is being done to solve it.

DESCRIPTION OF ELECTRIFICATION SYSTEM

The running rail negative return consists of the 4 main-line steel rails that are continuously welded and bonded at 1,000-ft (305-m) intervals. This circuit element has a resistance of about 2.5 mΩ/1,000 ft (8.2 mΩ/km) of track. The rails are insulated from the earth and structures except at traction substations. The rail insulation is provided by the rail mounting. Insulating pads and clips are used to mount the rails on concrete ties, and special insulating fasteners are used to mount the rails on the concrete surfaces of aerial structures and subway inverts. Wood ties and ballast are used for rail support at switches and through seismic zones.

The 37-traction power substations are located where loading and voltage drop dictate. The BART system is center fed, so most substations are located adjacent to passenger stations. These traction substations are supplied from twin 34.5-kV cables. Transformer rectifiers at the substations convert the 34.5-kV, 3-phase, 60-Hz energy to 1,000-dc energy. The circuit to the transit vehicles is made by a 1,000-V third rail, sliding contact shoes on the cars, car wheels, and the track negative return. As noted before, the traction rectifier negative is grounded at each substation.

The twin 34.5-kV cables are fed at 7 points by the local electric utility company. At grade, the cables are direct buried and lead covered. On aerial structures and in tunnels, the cables are in 2 nitrogen-filled pipes.

The 75 miles (120 km) of main-line double track are supported on several types of structure, all of which can be damaged by stray current electrolysis. About 20 miles (32 km) are in tunnel, 27 miles (43 km) are in aerial structures, 24 miles (39 km) are at grade on exclusively occupied right-of-way, and 3.6 miles (5.8 km) are in the Trans-Bay Tube. In addition to the main line, there are 3 storage yards in the East Bay.

Publication of this paper sponsored by Committee on Corrosion.

The vehicles are powered by 4 chopper-controlled dc traction motors. Each car draws about 1,000-A current at the start and about 200-A current at full speed. The vehicles are equipped with regenerative breaking so that a decelerating train can feed energy to a nearby accelerating train. This latter feature conserves part of the energy that would otherwise heat the breaking resistors.

TESTING AND MODIFICATIONS

Each traction rectifier is equipped with 2 shunts: 1 measures total rectifier current and 1 in the rectifier ground connection measures current over paths other than the rail negative return. Initial measurements made with a single train operating and only part of the line energized showed 10 to 20 percent of the local rectifier current in the ground connection. These are extremely high leakage current values, and further investigation has shown that the greatest part of the current is caused by connections of the substation ground mat to other structures and not by leakage from the rails.

For instance, a conduit connected to a traction substation ground mat at one time carried hundreds of amperes. Passenger station lighting and equipment power is supplied by a 480-V utility service, which is separate from the traction service. In this case the conduit connected the traction substation ground mat to the passenger station ground mat, which was connected to a water main with a faulty dielectric union. Where possible, we are eliminating connections between the traction substation grounds and passenger station service grounds.

We made initial coordinated tests with the local gas supply utility. Its gas mains cross and parallel the BART system right-of-way. In at least one case, in the test area, a main is within 10 ft (3 m) of a traction substation ground mat. For these tests a single train was cycled over the A-line segment. The time and location of train starts were recorded onboard while chart recorders monitored potentials and current flow on gas pipes and at traction substations. Two tests were made: 1 with traction substation negative return ground connections in place and 1 with these ground connections opened. With ground connections in place, current flow between traction substation ground mats was recorded. With ground connections open, voltages between rails and ground were recorded. Analysis of the charts enabled us to determine current paths, and the tests showed that lifting the traction rectifier's connections to ground markedly reduced stray current carried on the gas lines.

Current pickup on a gas main revealed grounded connections at a switch on the aerial structure. Investigation revealed contacts of the running rail fasteners and the restraining rail fasteners at the switch. The restraining rail fasteners, which mount a rail outboard of the running rail for containment of car wheels in case of derailment, are, of course, tied to the reinforcing steel. Contacts between running rail and restraining rail fasteners have been eliminated on the system.

The current exchanges between traction substation ground mats of as high as 15 percent of current supplied to the train seemed surprisingly high given the ground mat resistances and the open circuit rail drop voltages. The 34.5-kV cable pipes provide a path for these exchange currents. These pipes are grounded at the traction substations and are supported on the tunnel liners and aerial structures. Analysis and testing of the aerial structure case show that these pipes carry the exchange currents. These conclusions apply to the pipes wherever they are found on the system.

The aerial girders are isolated from other structures to withstand seismic forces. One end of the girder has a horizontal pin in a plastic sleeve, and the other end is mounted in vertical dowels in plastic sleeves. Elastomeric pads between vertical and horizontal joint surfaces provide a degree of electrical isolation between girders and between girders and support columns. The 34.5-kV pipes are hung from the girders and anchored and grounded at every fifth column. Figure 1 shows the circuit.

The pipes and their ground connections every 300 ft (91 m) form an extended ground conductor whose calculated resistance (2) is equivalent to the 4-rail negative return circuit.

The driving voltage for the substation ground current exchanges, as for all stray traction current, is the voltage drop in the running rail negative return. The traction

Figure 1. Solidly grounded substations.

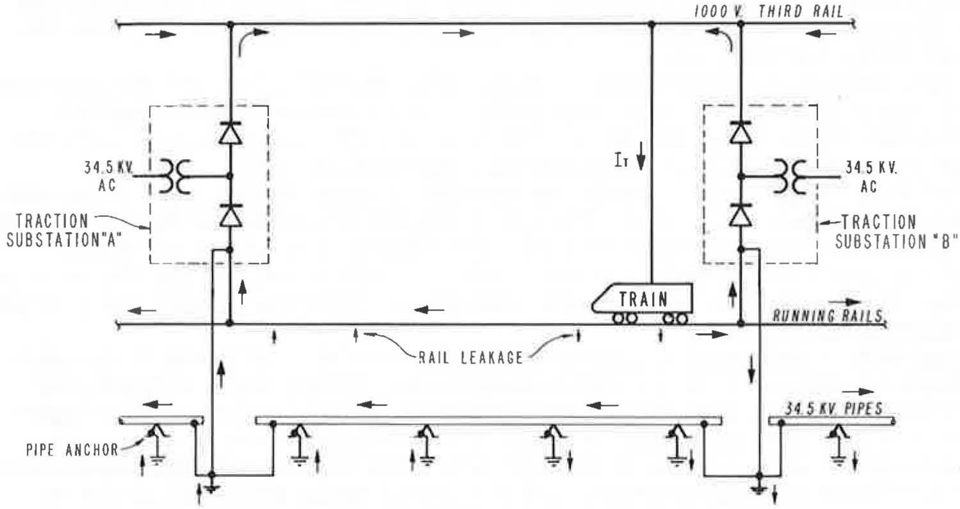
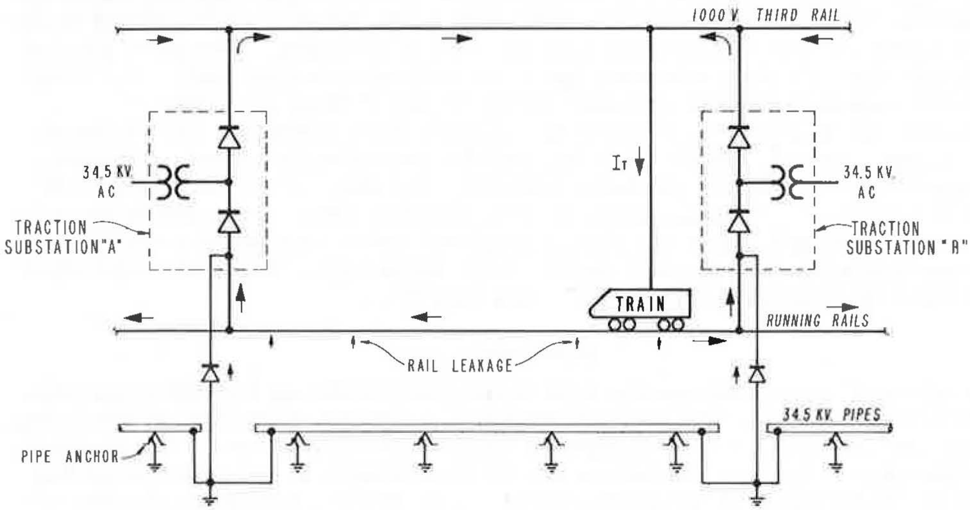


Figure 2. Diode-grounded substations.



power system is designed so that about 30 percent of an accelerating train's power requirement is supplied from the 2 substations adjacent to the substation with maximum loading. Our tests indicate that half of this current or about 15 percent does take the ground path between substations.

Since the extended circuit elements, running rails, 34.5-kV pipes, and the earth are connected only at the substations, a break in the negative return ground connection should eliminate the exchange currents. This is exactly what was observed in the test with traction substation negative return ground connections opened.

The rail drop voltages will of course appear at these open connections. These voltages exist between rails and ground. When the rails are grounded, the voltages appear between the rail grounds and remote ground. The voltages also appear between the passenger station platforms and the running rails, if platform and rail are not connected. Any attempt to bond rails and platform will transfer the potentials to other and perhaps more hazardous locations.

The magnitude of these rail-to-ground voltages is from 10 to 30 V with the present 4-car revenue operation. If the ground connections are opened, these voltages may double; but the values are still comparable to those measured in other transit properties. We used field data and a network analyzer to develop a clearer picture of the distributed negative return circuit characteristics. This study showed that under certain fault conditions the voltage between rail and ground can be quite high, and it is necessary to consider touch potentials and provide for safety.

As a consequence of this study, we tested diode grounding. Figure 2 shows this technique. The diodes in the negative return ground connection permit fault current and rail leakage current to return to the substation, but block exchange currents over the ground mat connections. Our tests indicate that the ground currents should be reduced by several orders of magnitude with this type of grounding. The stray current would then be due to leakage over rail fasteners and inadvertent grounds. The latter have proved easy to locate and eliminate during testing of diode grounding.

Of course, we still have the problem of rail to platform voltages. Our platforms are reinforced concrete, and the steel has not been intentionally bonded. The measured resistances between the platform surfaces and ground are as low as 100 Ω/ft^2 (92.9 Ω/m^2) when wet. This insulation level is marginal when one considers the voltages that may develop between car side and platform under some system conditions. We are now testing membrane surfaces for the platform edge. These surfaces would provide both slip resistance and electrical isolation (3).

SUMMARY

High values of stray earth current have been measured during the initial operation of the dc traction system. The tract negative current return is mounted on insulating fasteners, so little leakage is expected or measured from this source. The negative return grounding at traction substations and its interconnection with other grounding has been the major cause of the earth currents. An alternate method of negative return grounding through diodes has been tested and is being installed.

ACKNOWLEDGMENT

This project was performed with assistance from the U.S. Department of Transportation. The contents of this report reflect the views of the author, who is responsible for the facts and the accuracy of the data presented. The contents do not necessarily reflect the official views or policies of the Bay Area Rapid Transit District or the Urban Mass Transportation Administration. The author wishes to acknowledge the work and contributions of R. H. Miller, D. R. Stanley, O. Kramer, and E. F. Wargin, members of the staff at the Bay Area Rapid Transit District.

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