AC Propulsion-Good Medicine, But What Are the Side Effects?

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ABSTRACT

The introduction of alternating current (ac) propulsion systems, although providing many benefits, may carry with it some unexpected negative side effects caused by the introduction of a new emitter of electromagnetic interference to the current transit environment. Methods for measuring the susceptibility envelopes of the many signaling subsystem receptors present in the transit system are examined. Techniques for measuring susceptibility in the field and in the laboratory are discussed; these include noise burst tests, interruption of track signal tests, and phase relationship tests. Failure modes presented include both operational reliability and safety failures. The measurement of conductive and inductive emissions from a new European transit system that uses ac propulsion has been accomplished. The preliminary results of this testing are presented.

The advantages of alternating current (ac) propulsion in rail rapid transit system applications make it attractive to large, established transit authorities as well at to new systems. It promises improved reliability, reduced operating costs, and reduced maintenance costs. The ac propulsion systems would be designed to run on existing rail lines by using on-board inverters to convert the direct current (dc) traction power to ac to drive squirrel-cage motors. New ac-powered cars could be phased into the operating fleet of a transit authority and could operate in the current environment of existing dc-powered transit vehicles and signaling systems.

With these benefits may come some hidden problems. It is known from past experience that whenever new technology is introduced into an existing system, its early operating history will reveal unexpected negative side effects that must be overcome before the full realization of the promised benefits.

The electromagnetic interference and compatibility project, which is being run by UMTA and the Transportation Systems Center (TSC), has been assigned the task of identifying the possible side effects of operating ac propulsion vehicles on existing rail transit systems. The three primary subsystems that must be considered when examining electromagnetic compatibility in rail rapid transit systems are propulsion, signaling, and traction power. Other ancillary subsystems that should also receive some attention include vehicle air conditioning, lighting, and communications.

As new technology is developed and is applied to one subsystem, the effects of this technology will have an impact on the balance that exists in the current system. For example, the introduction of a chopper-controlled propulsion system to replace cam controllers can cause harmonic interference that may breach the susceptibility envelope of the existing signaling system. Countermeasures must then be taken to restore the operational reliability and safety of the transit system.

The introduction of ac propulsion involves the introduction of a new emitter source. Therefore, the signaling system must be examined, and the susceptibility envelope of each critical component must be determined. In addition, the propulsion system electromagnetic interference (EMI) must be measured to determine if it will interfere with the signaling system.

The approach taken by UMTA and TSC was to obtain samples of each element of the signaling system currently installed at a major transit authority where ac propulsion testing will take place. The relay circuits were assembled in the UMTA and TSC laboratory and adjusted to nominal operating specifications. Then specific laboratory tests were performed to obtain the desired susceptibility data. Thirteen different relay circuits were tested in the laboratory, and three representative circuits were tested in the field.

Field tests of selected circuits were conducted on the ac propulsion test bed site to validate the laboratory data as well as to assess susceptibility of signaling systems under normal operating conditions. In addition, data from an existing European system, which uses ac propulsion in daily revenue service, were collected to investigate typical emission levels.

Based on known problem areas of rail transit EMI, three separate mechanisms of coupling undesired signals to signaling circuits have been identified. These include inductive, conductive, and radiated interference. The low impedance of power frequency (dc, 300 Hz) track circuits presents a formidable barrier to radiated emissions; therefore, this type of interference was not considered. Inductive and conductive interference was considered. Much effort was expended in data acquisition, analysis, modeling, and field verification of the models of each type of interference.

Modeling of the electromagnetic coupling between electrical components that reside on the transit vehicle and the running rails, and between the third rail and running rails, provides information on interference at the receiving end of the track circuit. Theoretical analysis and circuit checks included rail-to-rail magnetic coupling, impedance bonds, and impedance of running rails, ballast, and the third rail.

Two cases of EMI were considered--one that affects safety, and the other that affects reliability. A safety problem arises when EMI causes a dropped relay to be picked up by interference, which results in the false indication of train absence in a particular block. A reliability problem arises when EMI causes a picked up relay to drop, which results in the false indication of train presence and needless delay of approaching trains.

The discussion that follows outlines the procedures for measurement of current and voltage levels and of relative phases or frequencies that lead to a circuit malfunction for the safety and the operational reliability cases. From these measurements the values of input impedance to the track circuitry at the rail leads may also be determined.

SIGNAL CIRCUIT LABORATORY TESTS

Procedures and Equipment

The objective of the laboratory test was to duplicate in the laboratory the condition of track relay reference voltage, track signal voltage, and their relative phases that exist in actual operation. Each track circuit was connected in the laboratory according to a diagram supplied by the transit authority. Before the testing apparatus was put into the circuit, voltage and current amplitudes were adjusted to specified operating levels. Currents were measured by use of 0.1-ohm sense resistors. Voltage was measured by using a high impedance voltmeter. Relative phase angles were measured by oscilloscope or network analyzer.

A phase shifter and a power operational amplifier were then inserted in each test connection. The power operational amplifier and the phase shifter were adjusted to obtain the proper phase and amplitude of simulated track signals.

An ohmmeter was connected to detect a change in the track circuit relay position. This change provided an indication of a signal light changing from the go to the no-go condition or vice-versa. The ohmmeter, on the 1k-ohm scale, was used to sense circuit malfunction. When the needle on the ohmmeter began to flutter because of a momentary break or make in the contact (depending on which case was being tested), the threshold malfunction condition was noted.

Noise Burst Test

The purpose of the noise burst test was to determine how tolerant the relay under test was to bursts of noise at the track signal ports. Results of this test were measured as a function of the noise burst time duration and amplitude.

To accomplish this test a relay contact was inserted between the output of the phase shifter and the input of the power operational amplifier. This relay had a coil that was activated by a 12-V signal that was generated by a pulse generator. The pulse generator was triggered manually, and it was set to generate several pulse widths.

The pulse width was varied until the front contacts of the track relay just barely closed. The parameter that was measured was the interval from when the relay closed to when it opened. This test was repeated for several different combinations of line reference and track voltages applied to the track relay. The range of local voltage applied as a line reference consisted of its nominal value and 10 V more than its nominal value. For each of these two voltage settings, the test was repeated for three track voltage values, including its nominal value, a low value (10 V less than nominal), and a high value (10 V more than nominal).

Interruption of Track Signal

The purpose of the interruption of track signal test was to measure the tolerance response characteristics of the track relays under test caused by interruption of track signals for various time durations. The circuit configuration for this test was the same as that used for the noise burst test, with the exception that the wires to the relay controlled by the pulse generator would interrupt the track signal for the duration of the pulse. The pulse duration was adjusted until the multimeter needle just began to flutter. The duration was measured across the relay contacts of the pulse generator relay with a slow sweep speed on a storage oscilloscope. This configuration was repeated for several combinations of track and reference voltages. The track voltage was varied +10 V and -10 V from that specified in the schematic diagram for normal operation. The reference relay coil voltage was varied to +10 V and to nominal voltage.

Phase Relationship Test

The purpose of the phase relationship test was to measure the root mean square (rms) voltage level and phase angle of an interfering signal with relation to that of the reference signal that would cause the track relay under test to be falsely energized. In this test the phase shifter was used to vary the phase relationship between the interference signal and the reference signal. For each phase setting, the interference voltage level was adjusted until the relay began to flutter. In addition, at several phase angle settings the interfering voltage was increased from zero to a voltage where the track relay contacts closed, and decreased from a high voltage level until the contacts opened.

Safety Failure Mode

The safety failure mode test measures the frequency and amplitude of an interfering signal voltage that falsely indicates a clear track during the time that a block is occupied. This creates a signal that falsely indicates to an approaching train that the block ahead is clear, when it indeed is occupied with another train. The sensing by the train that the block ahead is clear can result in a collision; thus it is a safety problem.

For this test, track signal voltage was absent as it would be with a train present in the block. Signals from an interference source were injected into the track relay at the track circuit terminals. The amplitude of the signal was increased slowly until it was noticed on the multimeter that the needle was fluttering. This signified the fluttering of the track relay contacts. This test was performed at nominal voltage and at 10 V more than the nominal reference voltage. At each of these voltage settings various frequencies that were more than and less than the nominal track circuit frequency, as well as various levels, were injected into the circuit. Relay response was monitored during this test.

Operational Reliability Failure Mode

During the operational reliability failure mode test the normal track signal was present as is typical with a clear, unoccupied block of track. The purpose of this test was to measure the voltage and frequency characteristics of an interfering signal that would cause the relay to flutter. The test was conducted at a range of frequencies, from 10 Hz more than the nominal to 10 Hz less than the nominal operating frequency of the track relay. As in the previous test, reference voltages of nominal and 10 V less than nominal were used.

FIELD VERIFICATION OF LABORATORY RESULTS

Three representative types of track circuits were chosen to be tested on the ac propulsion test bed transit system. These were chosen to field validate the results of TSC laboratory testing. Tests were conducted for the unoccupied operational reliability and the occupied safety cases at the transmitting end and at the receiving end of the track circuit. The transmitting end is a current source of ac in the power frequency range. The frequencies checked here were either at 25 or 60 Hz. The receiving end circuit consists of a relay and a current limiter such as a shielding reactor, capacitor, or resistor. Relays were of the vane or rotary type. These tests were conducted by using the same apparatus and general procedures as those used in the TSC EMI laboratory.

EUROPEAN EXPERIENCE

EMI emission levels of a 1-year-old heavy rail transit system that uses ac propulsion have been measured, and data were taken during a 3-day period under various operating conditions. The data consisted of recordings and spectral plots that showed levels and frequency domain information. The spectral content of this system proved to be quite different from chopper-controlled solid-state propulsion systems. These data are currently being reduced and analyzed through the efforts of the TSC. These data are the first such data that are available to researchers in the United States, and when the data are analyzed, it will provide researchers with a measure of the emission data of a typical ac propulsion system. These data can be compared with the susceptibility levels obtained in the tests described previously. This will provide a measure of subsystem compatibility.

Future tests will provide emissions data to be obtained from prototype ac propulsion systems specifically designed for U.S. transit system applications; these data will be compared with the susceptibility data described in this report. In view of the fact that European systems are running several variations of similar types of ac propulsion systems in revenue service, it is the intent of researchers to measure select samples of these systems and analyze the emissions in terms of frequency management as it relates to U.S. systems.

SUMMARY

The results of each test were repeatable, and the field data correlated well with the laboratory results. In general, the susceptibility of track circuits to EMI can vary by a significant amount, depending on normal limits of ballast leakage and uncontrolled natural environment factors and the judgment of signaling system maintenance personnel. The work described in this paper was performed as part of an overall effort by UMTA and TSC to guarantee compatibility of signaling and propulsion systems. It is believed that this and future activities will minimize the problems that occur when ac propulsion equipment enters revenue rail service in the United States.

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