TECHNICAL NOTE

U.S. Department of Transportation
Urban Mass Transportation Administration

TRANSPORTATION TEST CENTER

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TRI-COUNTY METROPOLITAN AUTHORITY LIGHT RAIL VEHICLE; FRICTION BRAKE MODIFICATIONS

by
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INTRODUCTION

In December 1983 a prototype of Portland, Oregon's Tri-County Metropolitan Transit Authority (TRI-MET) light rail vehicle was sent to the Transportation Test Center in Pueblo, Colorado for Specification Compliance and Performance Evaluation. Since this vehicle was a preproduction prototype, numerous adjustments and modifications were required before the vehicle could operate satisfactorily. One area that required considerable adjustment and modification was the New York Air Brake Company's friction brake system.

The purpose of this paper is to describe the problems incurred, the modifications made and to recommend a follow-up investigation for optimum friction brake performance on these transit vehicles.

DESCRIPTION OF THE FRICTION BRAKE SYSTEM

The friction brake system was specially designed and manufactured for application on the TRI-MET LRV by New York Air Brake Company. It consists of four major units:

1. Electronic Control Unit (ECU)

   Function: Sends electronic signal to the HPCU for the application or release of brakes.

2. Hydraulic Pressure Control Unit (HPCU)

   Function: Controls the amount of oil pressure to the brake actuator.

3. Brake Actuator

   Function: Exerts a spring force, proportional to the actuator oil pressure, to the calipers.

4. Calipers

   Function: Mechanically applies the actuator spring force to the brake disc through the brake pads.

BRAKE APPLICATION

The following events occur during full friction brake application. (Reference Figure 1)

1. No electronic signal is sent from the ECU to the HPCU servo valves.

2. 0 mA current to the HPCU servo valves allows the hydraulic fluid pressure to drop to its minimum level of 25 psi.

3. 25 psi of fluid pressure in the hydraulic actuator assembly allows the actuator spring to expand.

4. The actuator spring exerts a force on the brake clutch.

5. The brake clutch forces the yoke across the actuator studs to elongate.

6. The extended yoke width causes the caliper arm to rotate about the caliper bridge and produces approximately 9,000 lbs of compressive force between each brake pad and the disc.

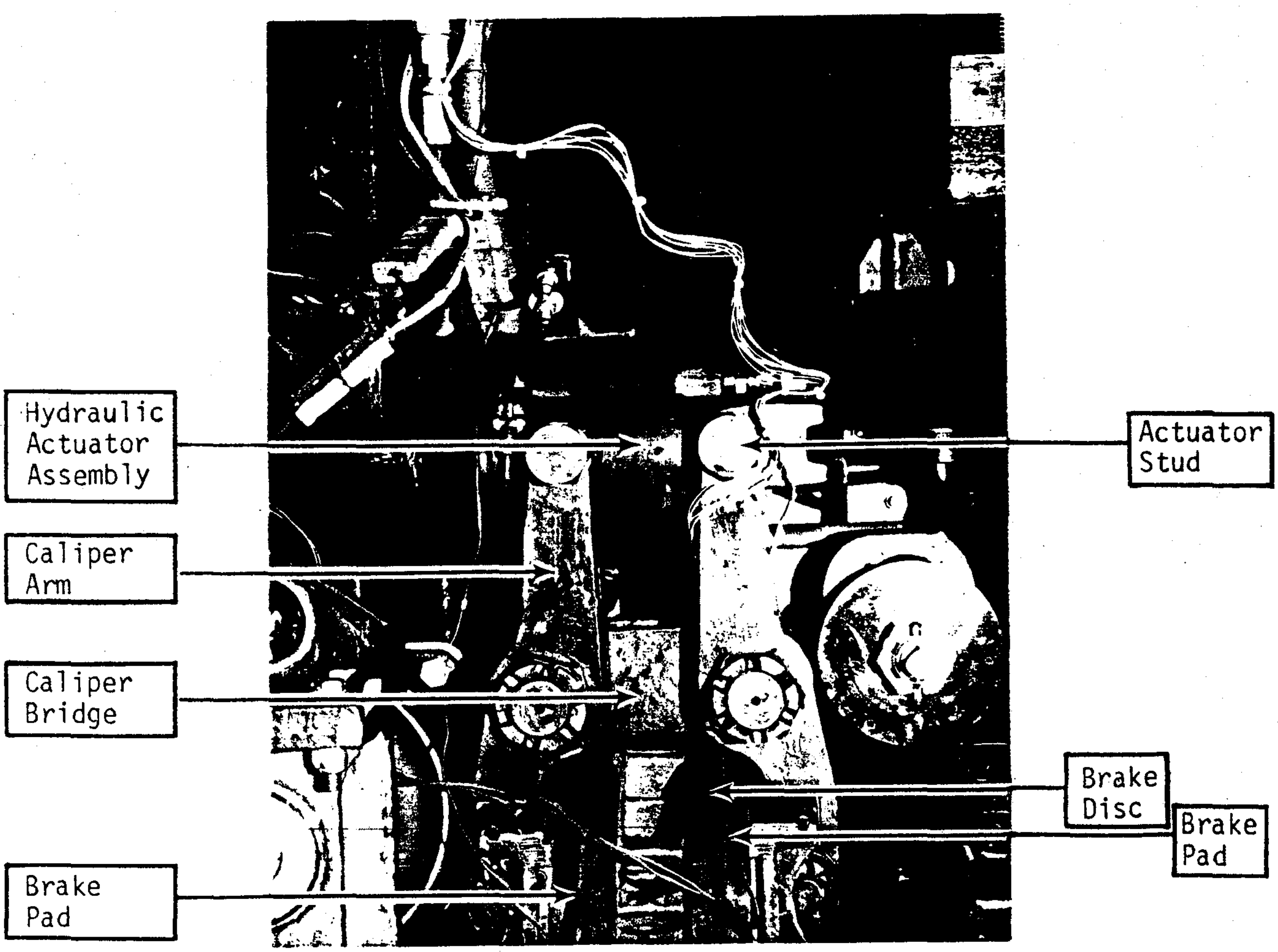

FIGURE 1. FRICTION BRAKE ASSEMBLY.

BRAKE RELEASE

The following events occur during friction brake release. (Reference Figure 1)

1. A 150 mA signal is sent from the ECU to the HPCU servo valve.

2. 150 mA to the servo valve produces approximately 850 psi hydraulic fluid pressure.

3. 850 psi in the hydraulic actuator assembly compresses the actuator spring.

4. The actuator spring exerts a force on the brake clutch proportional to the hydraulic fluid pressure.

5. The clutch forces the yoke distance across the actuator studs to become narrower.

6. The calipers rotate about the caliper bridge and the brake pads release the disc.

PROBLEMS AND SOLUTIONS

BRAKE PAD DRAG

The initial problem with the friction brake system was the overheating of the pads due to drag and improper brake releasing. It was felt that the problem was due to a loss of oil pressure caused by leaks at the actuators. Therefore, the actuators were changed and the servo valves adjusted, but the overheating and drag problem persisted.

During the next phase of adjustments the motor current from the ECU to the HPCUs was monitored. The current was too low and it oscillated in all notches of traction. This was corrected by changing resistors and capacitors in the ECU. The volts/amp level in the isolation amplifier also required adjustments. Upon completion of these modifications the vehicle was tested again, everything appeared to be operating correctly, however, the disc brakes were still overheating.

In an effort to better define the problem the following means were employed: (1) thermocouples were installed in the brake pads, (2) strain gauges were installed on the calipers to monitor the applied forces (Figure 2), and (3) LVDTs were installed across the brake yokes (which laterally connect the calipers) in order to measure lateral movement (Figure 3).

During vehicle operation, it was observed that initially no brake drag was present, but after several friction brake applications the pads began to heat-up and drag occurred. During approximately five friction brake applications the pad temperatures increased from an ambient temperature of 70°F to 400°F and the first sign of drag appeared. After numerous brake applications the pad temperatures increased to 700°F and the drag force was 400 lbs. When the friction brakes were not used no drag force was present and the temperatures did not increase.

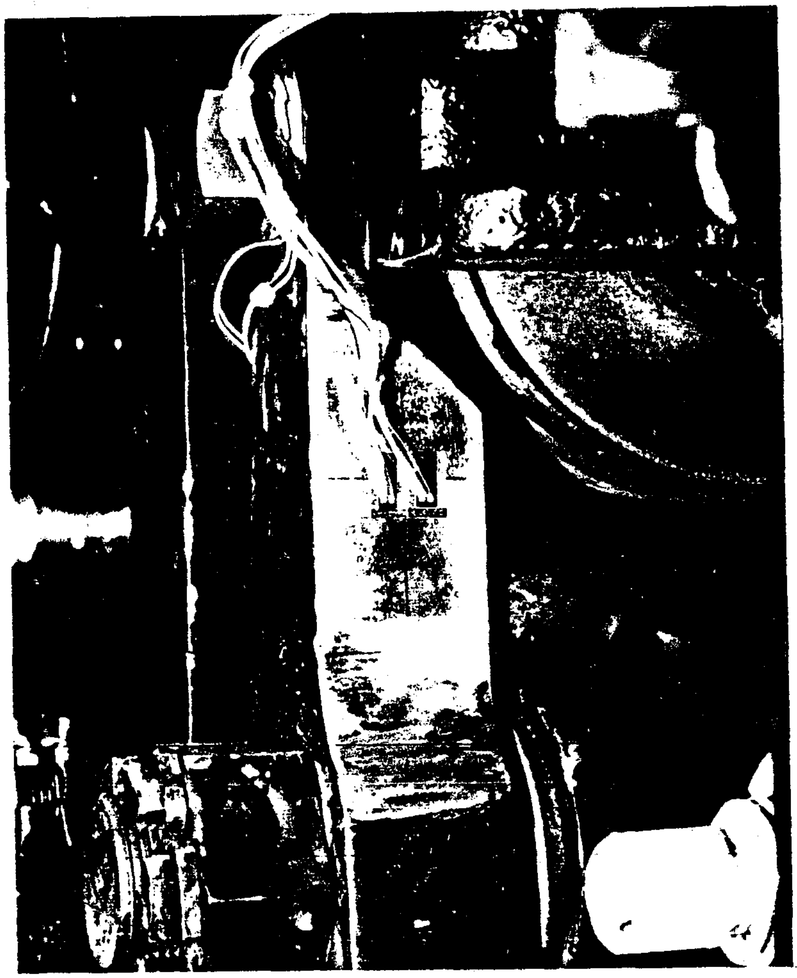

FIGURE 2. STRAIN GAUGES ON A BRAKE CALIPER.

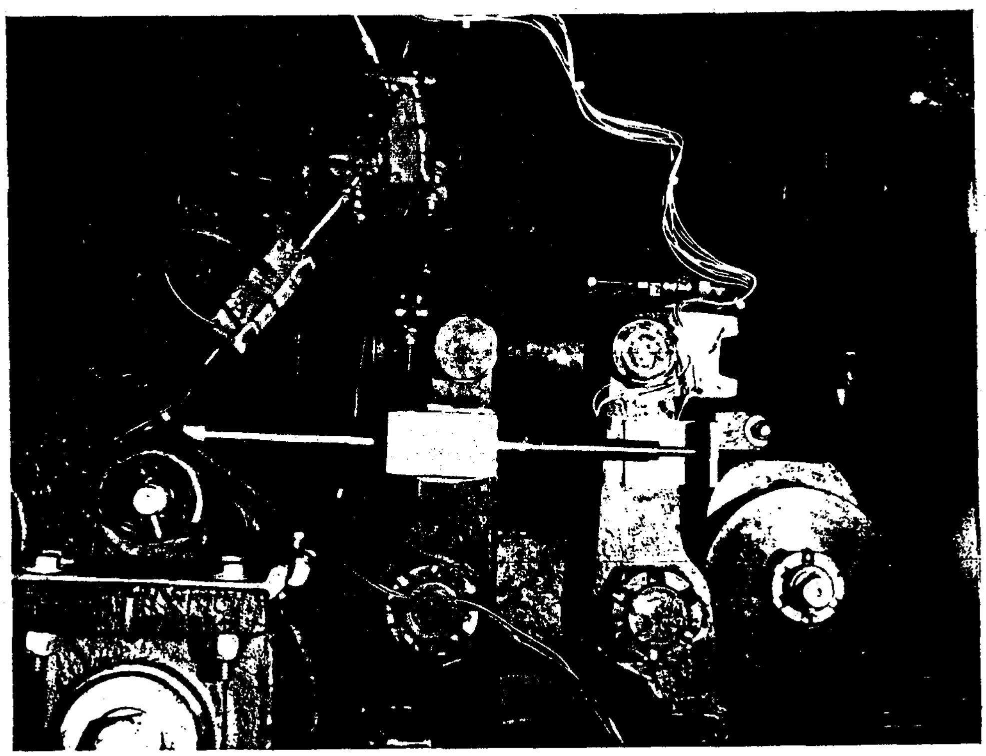

FIGURE 3. AN LVDT MEASURING MOVEMENT BETWEEN THE BRAKE CALIPERS ACROSS THE YOKE.

The brake pad and disc thicknesses were then monitored. The values, plus or minus one standard deviation, were as follows:

	Dimensions at 70°F	Dimensions at 500°F
Average Pad Thickness	0.9128" ± 0.0074"	0.9196" ± 0.0046"
Average Disc Thickness	3.5434" ± 0.0023"	3.5526" ± 0.0078"
Average Pad to Disc Clearance	0.0275" ± 0.0112"	0.0115" ± 0.0115"

From these results, the source of the pad overheating and the friction brake drag problem was clearly attributable to insufficient clearance between the pad and the disc as a result of thermal expansion due to friction brake use. Also, the greater the frequency of brake use the more severe the problem became as the pads and discs did not have time to cool-off between uses and their temperatures continued to increase.

The solution to the friction brake drag and overheating problem was to increase the clearance between the discs and pads. An approximate clearance of 0.045" was agreed upon, however, it was noted that there is a trade-off between increased clearance and decreased maximum actuator output force.

To increase the actuator output force the mechanical slack adjustors had to be modified. The stops within the units were machined to give greater pad to disc clearance and stronger springs replaced the original springs.

The results appear to be acceptable. Drag no longer occurs regularly during test operations and the maximum actuator output force is adjustable to in excess of 10,000 lbs.

MECHANICAL SLACK ADJUSTER MALFUNCTION

After the pad drag problem was corrected, further complications developed with the pad to disc clearances.

Prior to vehicle operation, all of the HPCUs and actuators were operationally checked out and all the pad clearances were adjusted to the revised specification. However, after just a few brake applications the pad to disc clearances tended to randomly increase by a significant amount.

After a close examination of the brake system it was found the slack adjusters were inoperative.

The mechanical slack adjuster is a simple device which compensates for brake pad wear so that the pad to disc clearance will always be within specification. The devise is designed with one small bolt to hold the adjustment, however this bolt sheared off during brake applications and rendered the slack adjuster inoperative.

A modification to the slack adjuster was made by using two bolts instead of one and the problem currently appears to be solved.

DRAG ON ROTATING CALIPER BOLT ACTUATOR PIN

During friction brake application the hydraulic actuator assembly, upon a reduction in oil pressure from the HPCU, extends through spring tension and thereby applies a force to the upper portion of the calipers. The reaction of the outward movement of the calipers from the force causes the brake pads to contact the disc thereby impeding the axle rotation.

For a quick and proper response of caliper movement to the actuator force there must be neglible rotational friction between the caliper pivot points on the actuator. The actuator studs shown in the upper portion of Figure 4 are threaded near the head which screws into the upper base area of the calipers. The remaining portion of the bolt is unthreaded and inserted into a sleeve on the actuator which serves as a pivot point.

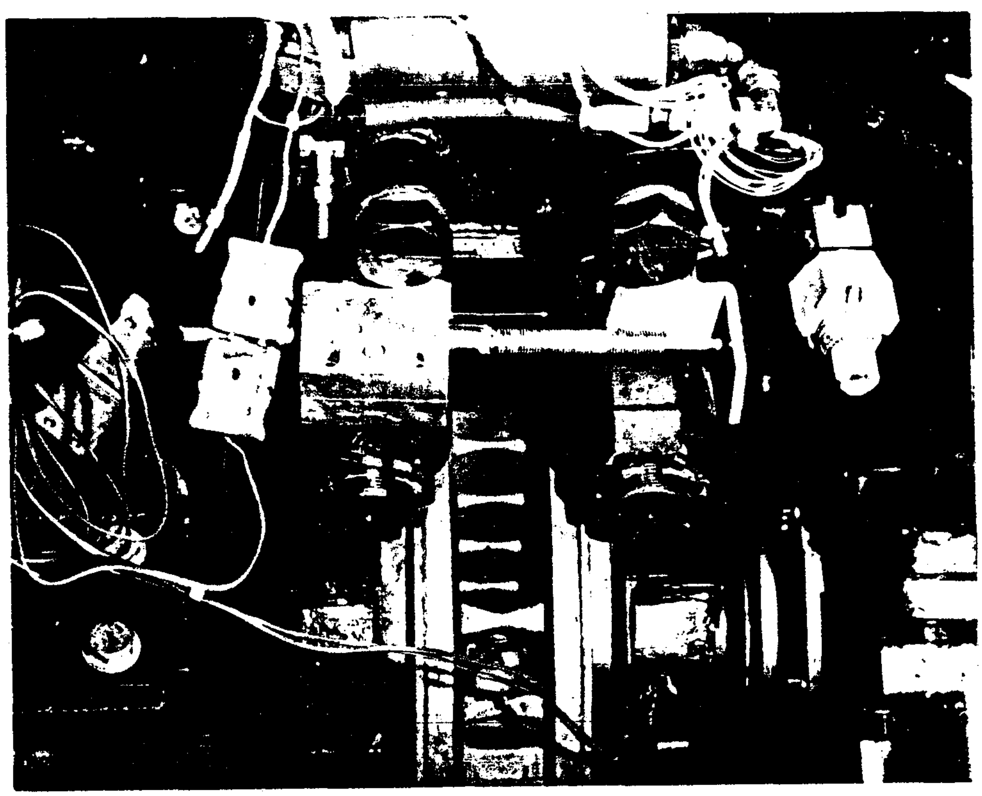

FIGURE 4. FRICTION BRAKE ASSEMBLY SHOWING ACTUATOR STUDS IN THE UPPER PORTION OF THE PHOTO THAT CONNECT THE CALIPERS TO THE ACTUATOR.

While correcting prior complications with the friction brake system, the calipers were modified and the thickness of the top portion was reduced. The actuator stud through this portion of the caliper was not modified and, as a result, the threaded portion of the bolt extended into the actuator sleeve, restricting free rotation. A correction was made by adding a washer under the bolt head. This combination should be replaced with a bolt of proper thread length.

MISCELLANEOUS FRICTION BRAKE PROBLEMS

During the four month test period, numerous problems (pad overheating, inconsistent and inappropriate pad application forces, brakes not releasing properly, etc.) occurred with the friction braking system. Many of these malfunctions happened at random and the causes still have not been identified.

FOLLOW-UP RECOMMENDATIONS

Numerous modifications were required to the original New York Air Brake system design during these tests and the system is still not operating consistently well.

As all components interreact with each other, the consequences of each individual change on the system as a whole must be investigated.

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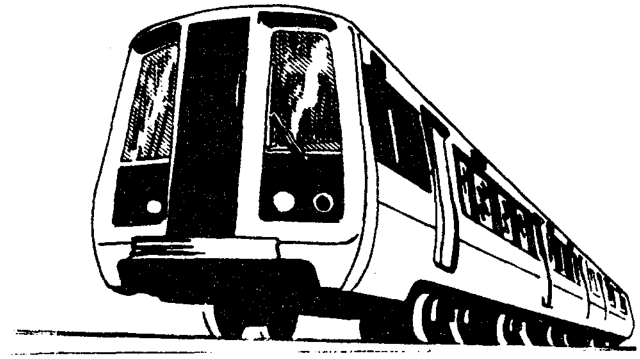


TRANSPORTATION TEST CENTER

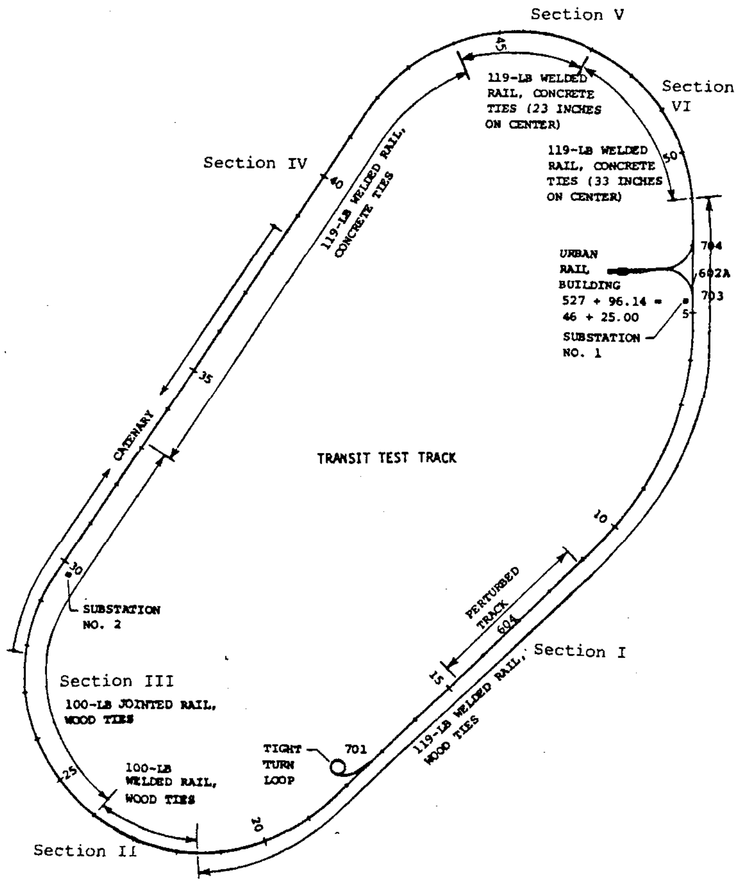
Test and evaluation activities of the Urban Mass Transportation Administration (UMTA) are coordinated through The Office of Technical Assistance in Washington, D.C., and are conducted by The UMTA Program Office at the Transportation Test Center (TTC) in Pueblo, Colorado.

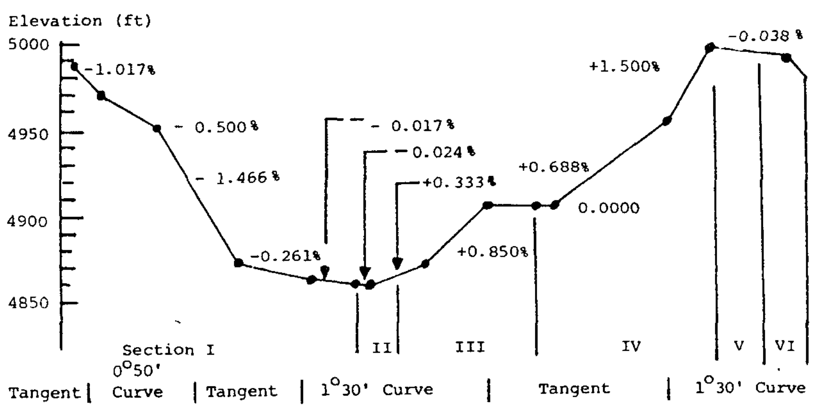
The urban rail transit test facilities at the TTC provide for test and evaluation of urban rail vehicles, subsystems, track, and structural components in an environment that is both safe and free from the scheduling constraints imposed by revenue service operations.

The Transit Test Track (TTT) is a 9.1 mile oval (see next page) designated for sustained 80 mi/h vehicle operation with the exception of the perturbed track section, which is subject to a speed limit based on ride quality test requirements and safety considerations. Power is provided either by a conventional third rail or a section of overhead catenary cable; the third rail was constructed to New York City Transit Authority specifications.

The rectifier station voltage can be varied infinitely from 400 to 1,200 V.d.c. with a current limit of 11,000 A. The stations each feed from one bus to all of the TTT and are designed to operate in several alternate modes, including computer control. Voltage can be controlled at a constant level at the substation, or at the position of the vehicle and held within the above constraints to a constant value at the vehicle regardless of demand or voltage drop through the rails. In alternate modes of operation the test vehicle can be subjected to a voltage profile or a voltage step such as might occur in revenue service at the transition between one substation and another.

The Test Center's technical support capabilities include test management, engineering instrumentation, calibration and electronic repair, photo-optical instrumentation, and data processing. In addition, TTC has the capability to assist users in developing test plans and requirements, and preparing reports.





NOTES:

Track Curvature:

Sta.	to Sta.	Degree of Curve
55.3	10.3	0° 50"
18.9	29.4	1° 30"
41.8	50.8	1° 30"

Elevation:

Minimum - 4863 ft at Station 22.0.
Maximum - 5003 ft at Station 46.0.

Curve Superelevation:

1° 30' curves are superelevated a maximum of 4.5". The maximum superelevation on the 0° 50' curve is 2".

Tight Turn Loop

150 ft radius.
119 lb AREA Head Hardened running rail.
85 lb ASCE restraining rail installed as per Massachusetts Bay Transit Authority specifications.