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Urban Mass Transportation Administration

Development of Transit Coach Bonded Brake Lining Test Equipment and Test Procedures - Progress Report

Lawrence F. Simeone

Transportation Systems Center
Cambridge MA 02142

January 1984
Final Report

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16. Abstract

This report documents the development of brake test equipment and procedures for heavy-duty transit coach brakes at the U.S. Department of Transportation's Transportation Systems Center. It presents a description of a heavy-duty dynamometer brake test apparatus and specifies proposed test procedures for an evaluation of brake shoe linings. Some preliminary experimental and analytical work is discussed.

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16. Abstract

Bonded brake linings have been introduced in limited quantities at several urban and suburban transit properties. The in-service capabilities of current bonding processes and brake materials are undergoing assessment, and field data on the wear and failure of bonded brake linings is being gathered. To support and complement the field data, laboratory testing is required to investigate bonded lining capabilities and failure modes in depth. Such testing will provide a data base for developing analytical techniques for predicting wear and failure of lining bonds.

This report documents the development and progress to date of brake test equipment and procedures for heavy-duty transit coach brakes at the Transportation Systems Center. It presents a description of a heavy-duty dynamometer brake test apparatus and specifies proposed test procedures for an evaluation of bonded brake shoe linings. Although many tests were completed, several of the planned dynamometer tests were discontinued as a result of programmatic changes.

The overall objectives of this test effort were to: 1) provide a performance evaluation of heavy duty bonded brake linings; 2) establish the parameters which lead to adhesion or delamination of the bonded linings; and 3) develop a bonded lining failure mode analysis that can establish the potential for lining failure under various operating conditions of speed, load, and temperature.

Implicit in the test effort is the development of test procedures and equipment necessary to evaluate the bonded linings.

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PREFACE

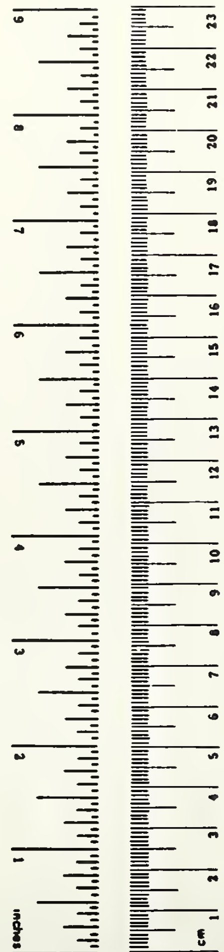
This report documents the development of transit coach brake test procedures. It presents a description of heavy-duty dynamometer brake test apparatus and specifies proposed test procedures for an evaluation of bonded brake shoe linings. Although many tests were completed, several of the planned dynamometer tests were discontinued as a result of programmatic changes. This report was sponsored by U.S. Department of Transportation, Urban Mass Transportation Administration, Office of Technical Assistance. The work was performed at the Transportation Systems Center. Lawrence Simeone was the Task Manager for the project.

The author gratefully acknowledges the contributions of C. Hoppen, C. Neckyfarow, and G. Plank of DOT/TSC for their effort in initiating the basic framework of the brake test facility and laying the foundation for much of the initial test procedure development. The invaluable contribution of Senior Engineering Technician, G. Ameral, in implementing assembly of the test apparatus is also acknowledged.

METRIC CONVERSION FACTORS

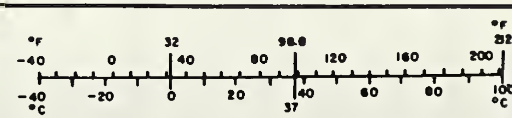
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. INTRODUCTION

Traditionally, transit buses have been equipped with brake linings that are bolted to the shoe plates. These bolted linings use up a portion of their thickness to satisfy bolt grip requirements. Thus, the lining must be replaced when worn down to the surface of the bolt heads. If the linings are bonded to the shoe plates, instead of bolted, practically the entire lining thickness can be utilized before replacement, thus effectively increasing the service life of the shoes with the same nominal lining thickness. Transit properties, however, have been reluctant to use bonded brake linings because of uncertainties in their performance. Early experiences with bonded linings have been unfavorable. Past performance failures have been attributed to bond adhesion failure under severe operating conditions of temperature and stress, and embrittlement when the friction material had worn thin. However, these earlier deficiencies are claimed to have been overcome, and there is renewed interest in using bonded linings.

Bonded brake linings have been introduced in limited quantities at several urban and suburban transit properties. The in-service capabilities of current bonding processes and brake materials are undergoing assessment, and field data on the wear and failure of bonded brake linings is being gathered. To support and complement the field data, laboratory testing is required to investigate bonded lining capabilities and failure modes in depth. Such testing will provide a data base for developing analytical techniques for predicting wear and failure of lining bonds.

2. OBJECTIVE

The overall objective of this effort was to (1) provide a performance evaluation of heavy duty bonded brake linings; (2) establish the parameters which lead to adhesion failure (delamination) of the bonded linings, and (3) develop a bonded lining failure mode analysis that can establish the potential for lining failure under various operating conditions of speed, load, and temperature. Implicit in the test effort is the development of test procedures and equipment necessary to evaluate the bonding linings. This report addresses the progress of this effort to date.

3. EXPERIMENTAL APPARATUS

The Transportation Systems Center (TSC) has available, as part of its complement of equipment, a high-speed, direct current, engine dynamometer with sufficient speed and power capabilities to simulate the operating conditions of a bus brake. Coupled with a gear reduction unit, the dynamometer provides speed and torque output as shown in Figure 1.

The test apparatus currently in place consists of a General Electric 225-hp high-speed dynamometer, a 15.44 to 1 parallel shaft gear reduction unit, and a General Motors RTS II transit coach rear axle assembly. The rear axle assembly is used as a test bench to carry the drum brake test assembly, a set of Rockwell Stopmaster™ drum brakes. The axle assembly has been modified to provide a direct drive from the gear reducer output shaft to the drum brake test apparatus.

A schematic and views of the test set-up is shown in Figures 2 through 4. The brake test apparatus is a wedge-actuated, air-operated, Rockwell Stopmaster drum brake equipped with two 14 inch by 10 inch brake shoes (Figure 5). Actuation of the brake mechanism is implemented from the operator's console with an electric servo-motor, which operates a compensating air control valve.

Operator control of the brake test bench is implemented through the dynamometer controller, a General Electric Directomatic Logic Controller™ (DLC). The DLC affects dynamometer speed and torque regulation and provides for programmed control of the dynamometer system. Two dynamometer operational modes are available to the operator: a speed mode and a torque mode. Operational modes are selected by the operator to meet test requirements.

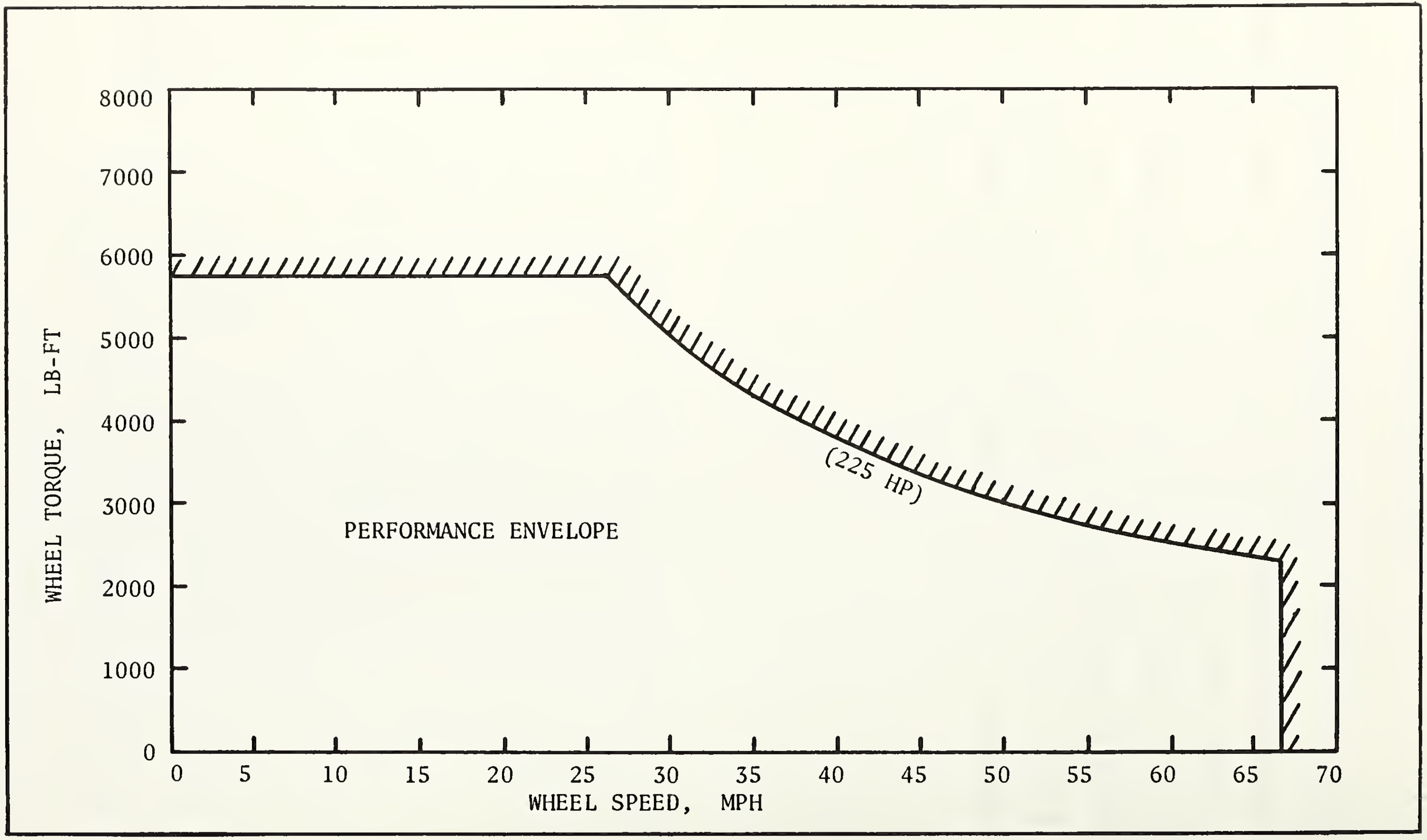
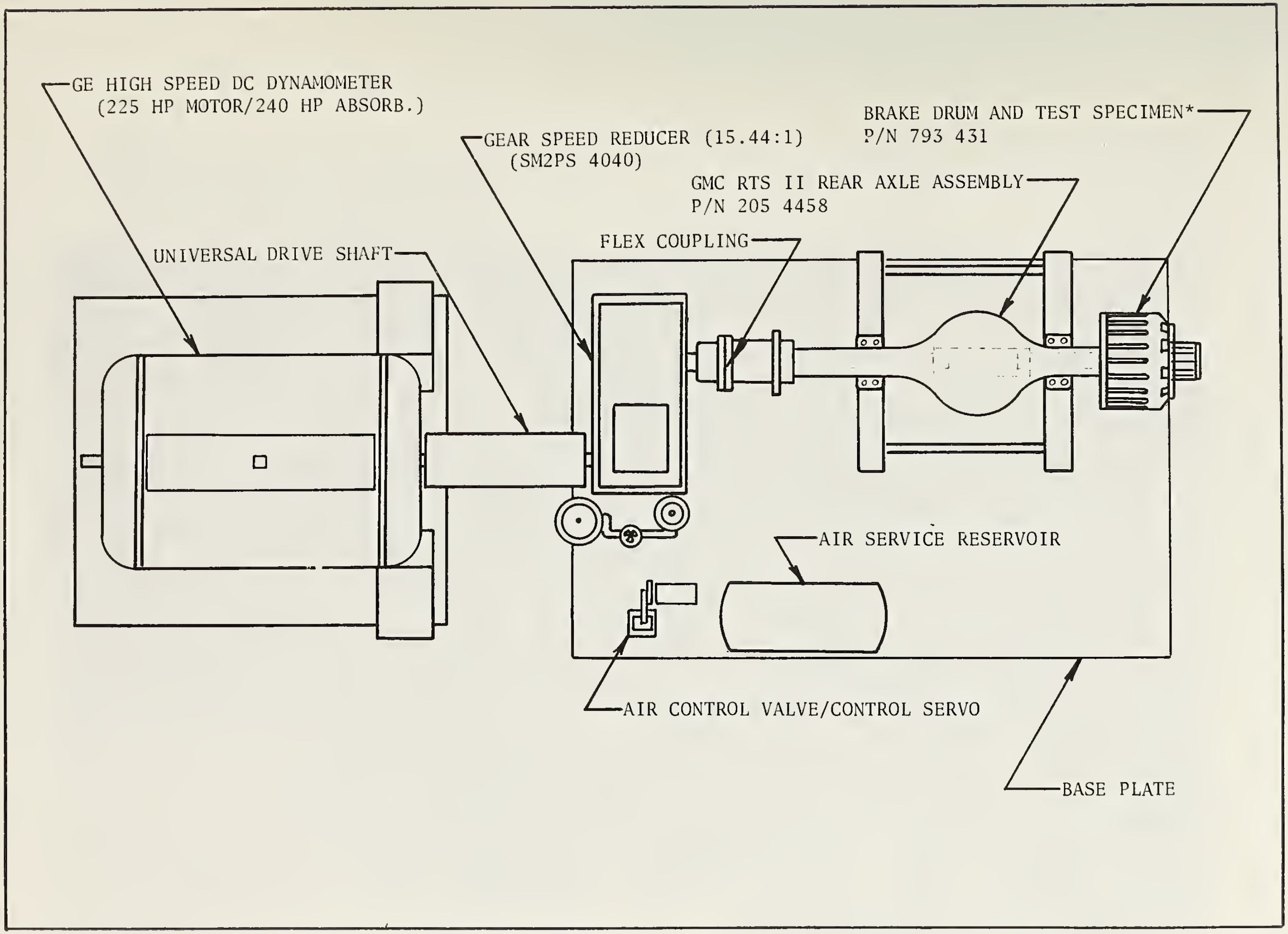


FIGURE 1. DYNAMOMETER/GEARBOX MOTORING PERFORMANCE CURVE, DOT/TSC BRAKE TEST FACILITY



* Rockwell Stopmaster™ Wedge Brake Assembly

FIGURE 2. DOT/TRANSPORTATION SYSTEMS CENTER HEAVY DUTY BRAKE TEST APPARATUS

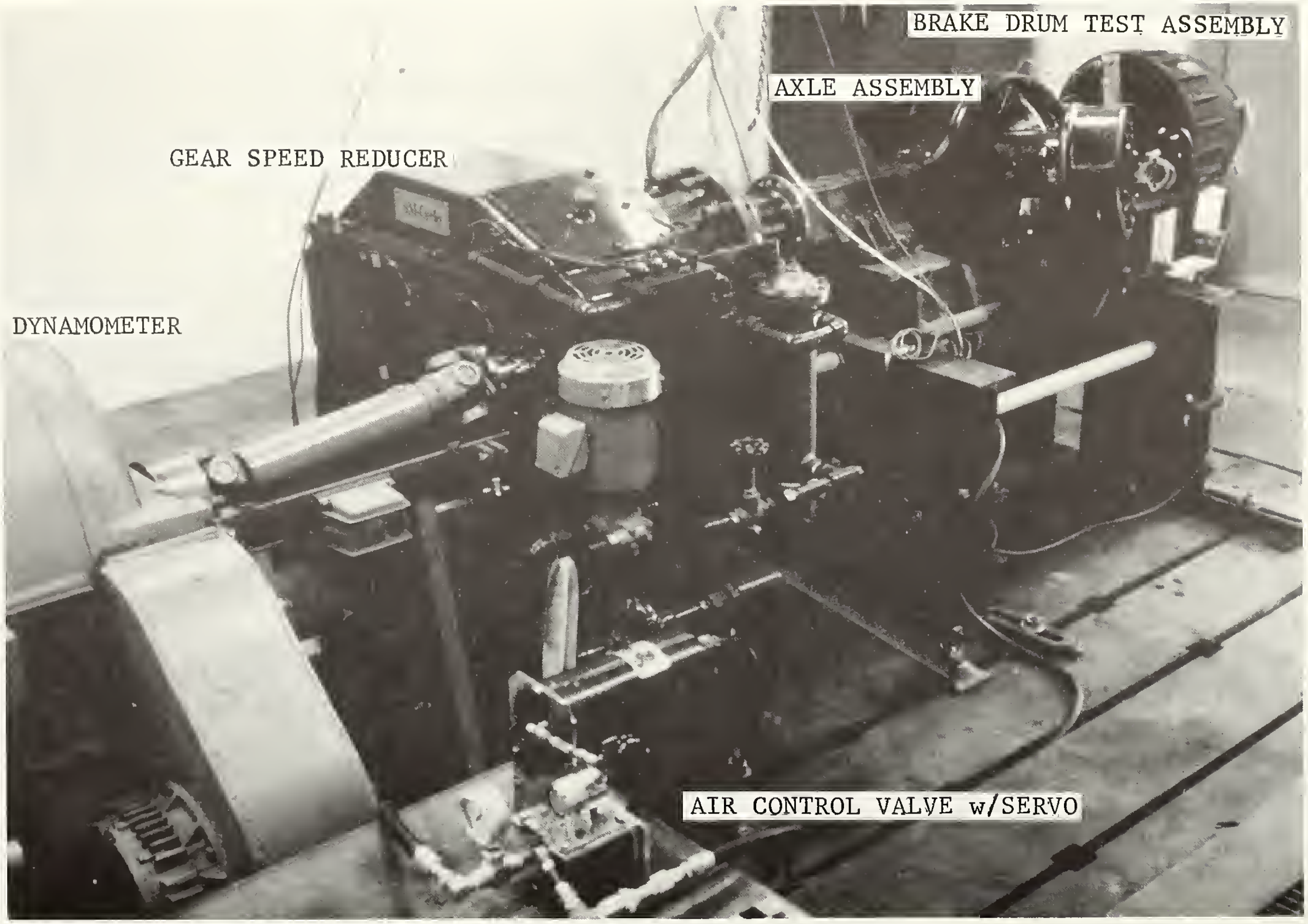


FIGURE 3. OVERALL VIEW OF THE DOT/TSC HEAVY DUTY BRAKE TEST APPARATUS

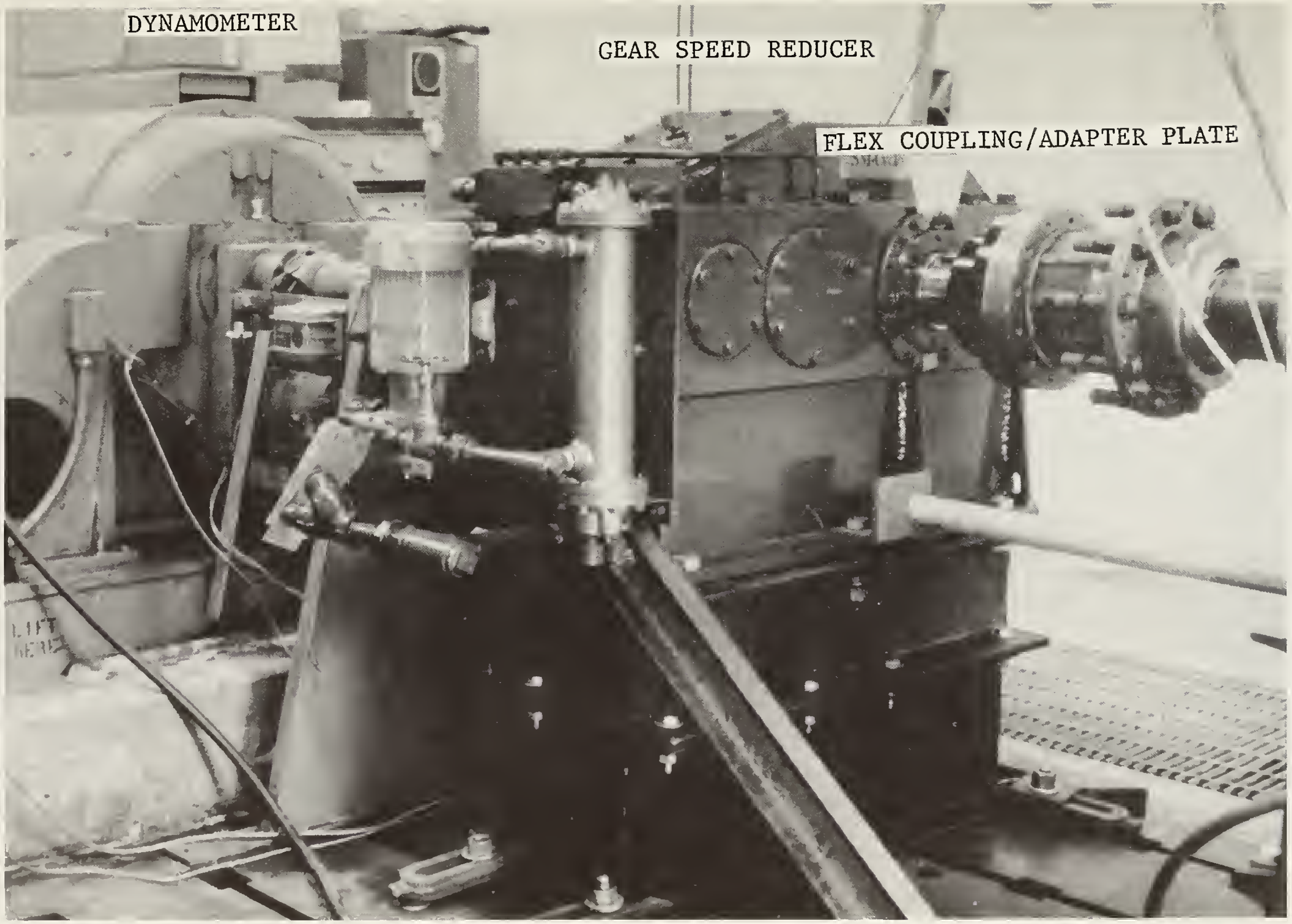


FIGURE 4. VIEW OF DYNAMOMETER WITH 15.44 TO 1 GEAR SPEED REDUCER INSTALLED

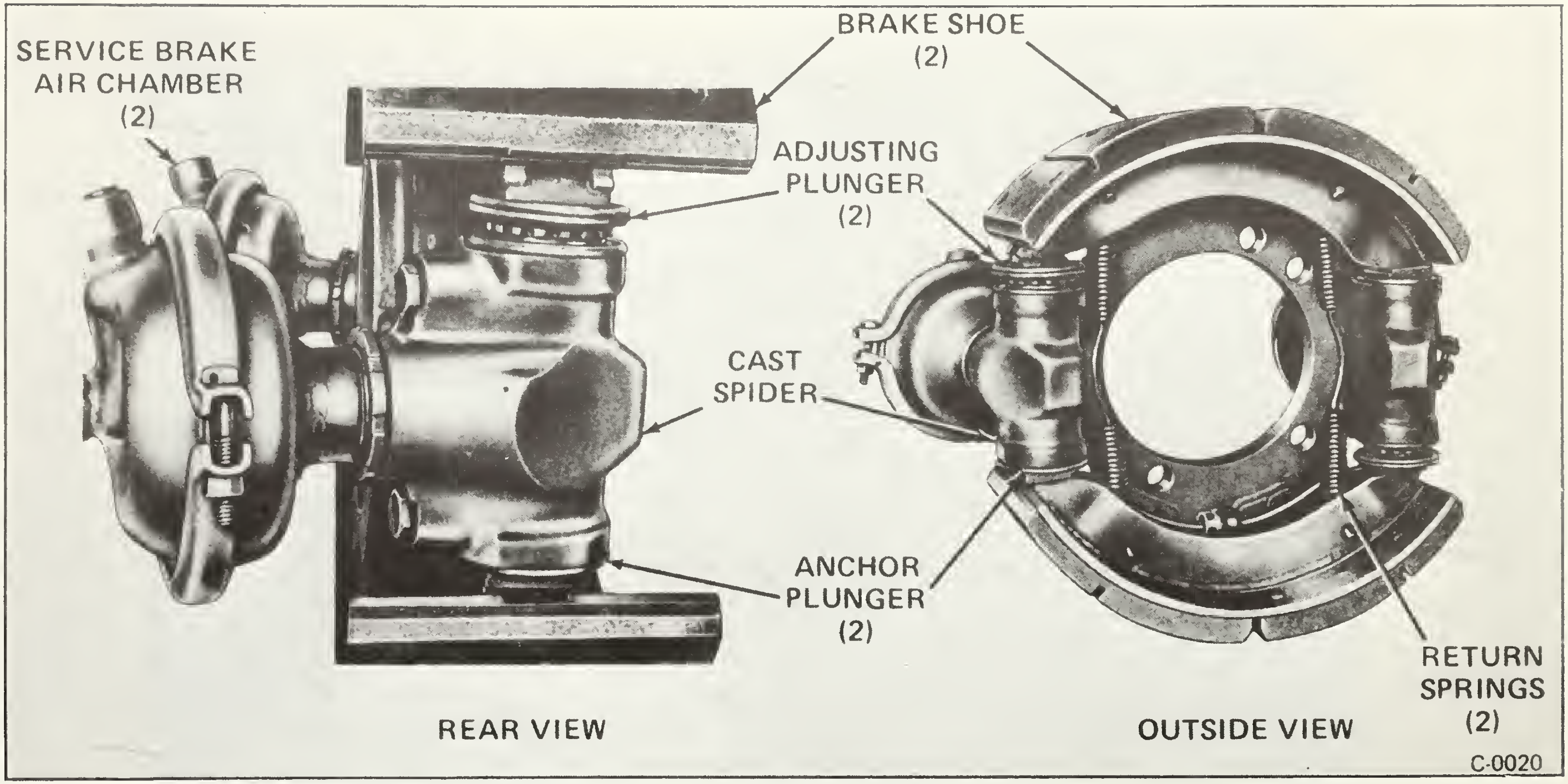


FIGURE 5. DRUM BRAKE ASSEMBLY

In the speed mode, dynamometer speed is the independent variable and torque is the test dependent variable. Speed is automatically regulated by the DLC and torque varies to maintain the regulated speed. As the brakes are applied, and drag on the brake drum increases, more torque is delivered by the dynamometer control circuitry in order to hold and maintain the target speed.

Speed is selected by the operator with a 10-turn potentiometer on the control console. In the constant speed mode, brake drag tests can be simulated by setting the speed and varying braking pressure to the desired brake torque level. The high temperature, bond strength tests and bond fatigue tests (Sections 5 and 6) are run in this manner.

When the dynamometer torque mode is selected, torque becomes the regulated variable and speed the test variable. Dynamometer torque is automatically regulated by the DLC, according to a pre-programmed schedule and speed is an operator variable. Torque regulation is programmed to simulate a characteristic vehicle road load (selected by the operator).

In the torque mode, the DLC's vehicle road load algorithm includes simulated aerodynamic loading and rolling resistances, as well as vehicle inertia. Thus, the TSC system does not require flywheels, as vehicle inertia is simulated electrically by the DLC torque command. In this mode, dynamometer response is similar to a vehicle on the road with brake actuations and dynamometer torque acceleration commands varied by the operator. Transit coach driving cycle simulations (Section 7) are run in this manner.

4. TEST BENCH INSTRUMENTATION

Test instrumentation installed at the DOT/TSC facility currently provide the capability for measuring and recording the following test parameters:

- Speed (rpm)
- Torque (lb-ft)
- Temperature (^{O}F) - Nine channels currently available for measuring lining/shoe temperatures and one "slip-ringed" channel for measuring rotating drum temperature. Additional channels, both stationary and slip-ring, are available as required
- Brake Air Actuation Pressure (psi)
- Actuator Stroke (10^{-3} inches)

A schematic of the currently installed laboratory test instrumentation and data flow chart is shown in Figure 7. The brake drum test assembly is illustrated in Figures 6 and 8.

Data acquisition is implemented with a Hewlett-Packard™ 1000F Series computerized data acquisition and control system. The scanning program converts transducer electrical signals to engineering units, saves the data on disc, and displays selected, real time, transducer readouts on the operator's video output screen (CRT). Data scans are operator selectable, and are automatically printed out on the lineprinter at the completion of each specified test sequence. Operator CRT readouts are updated for each test scan.

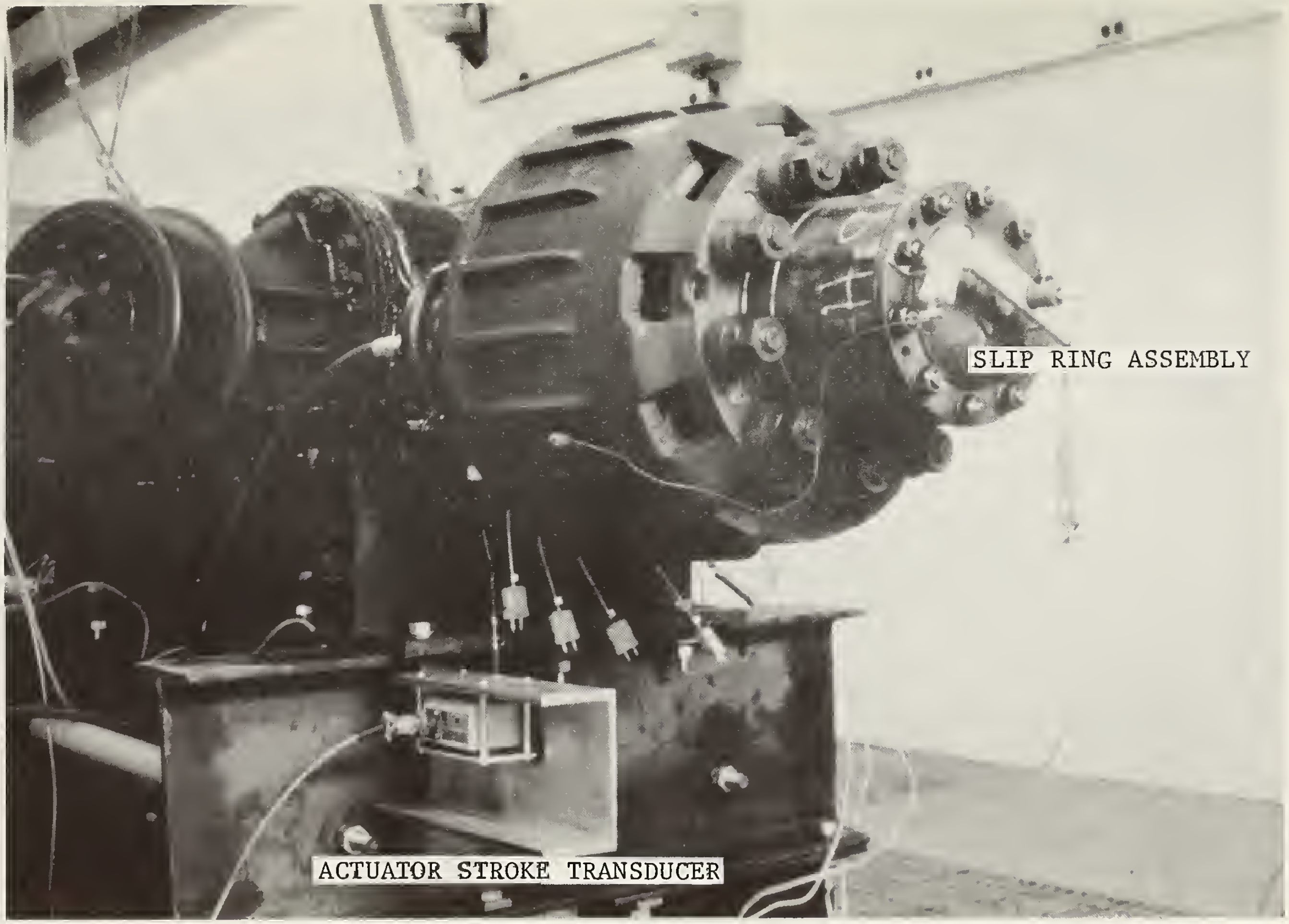
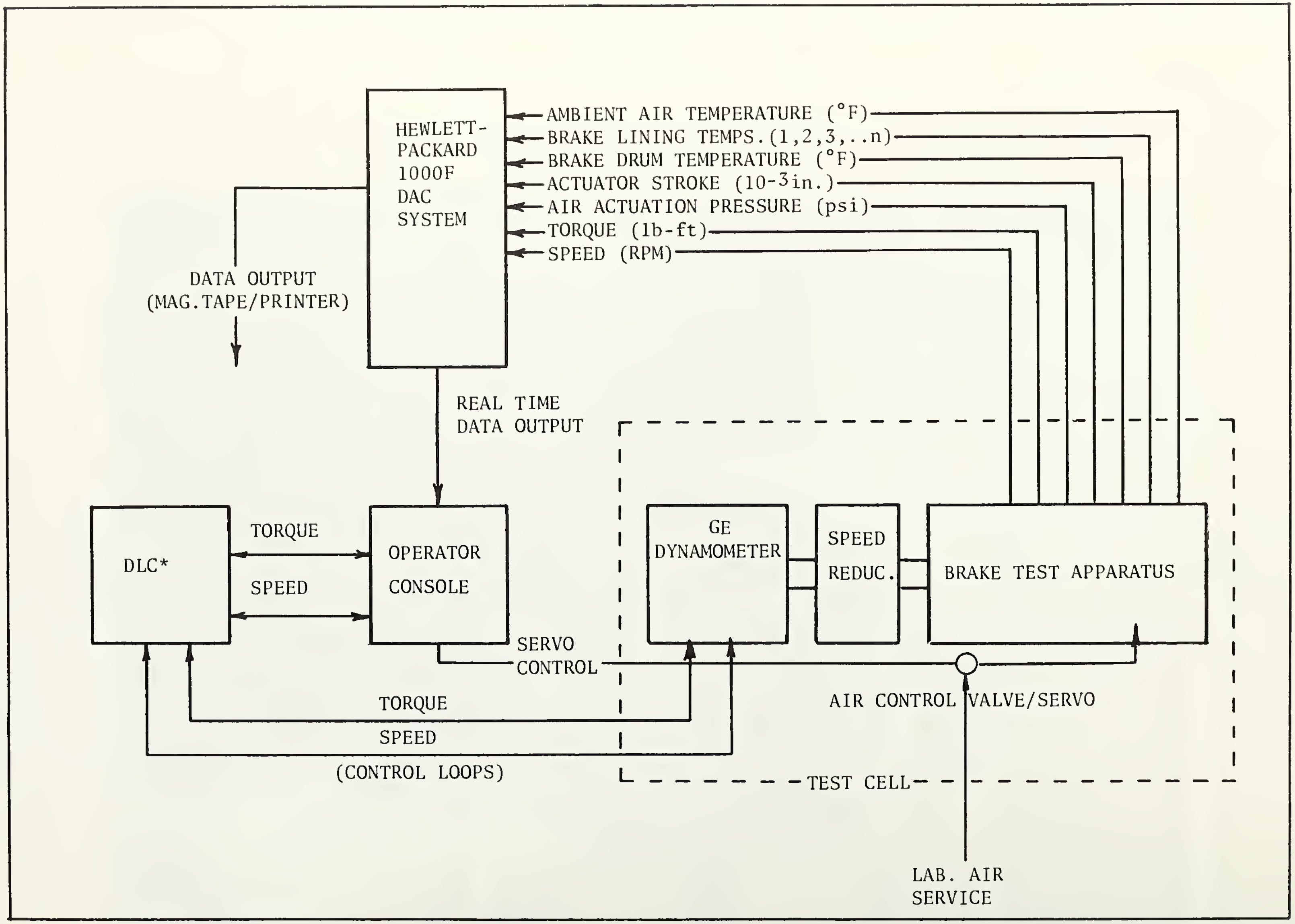


FIGURE 6. BRAKE DRUM TEST ASSEMBLY - FRONT



* General Electric Directomatic™ Logic Controller

FIGURE 7. DOT/TSC BRAKE TEST INSTRUMENTATION SCHEMATIC

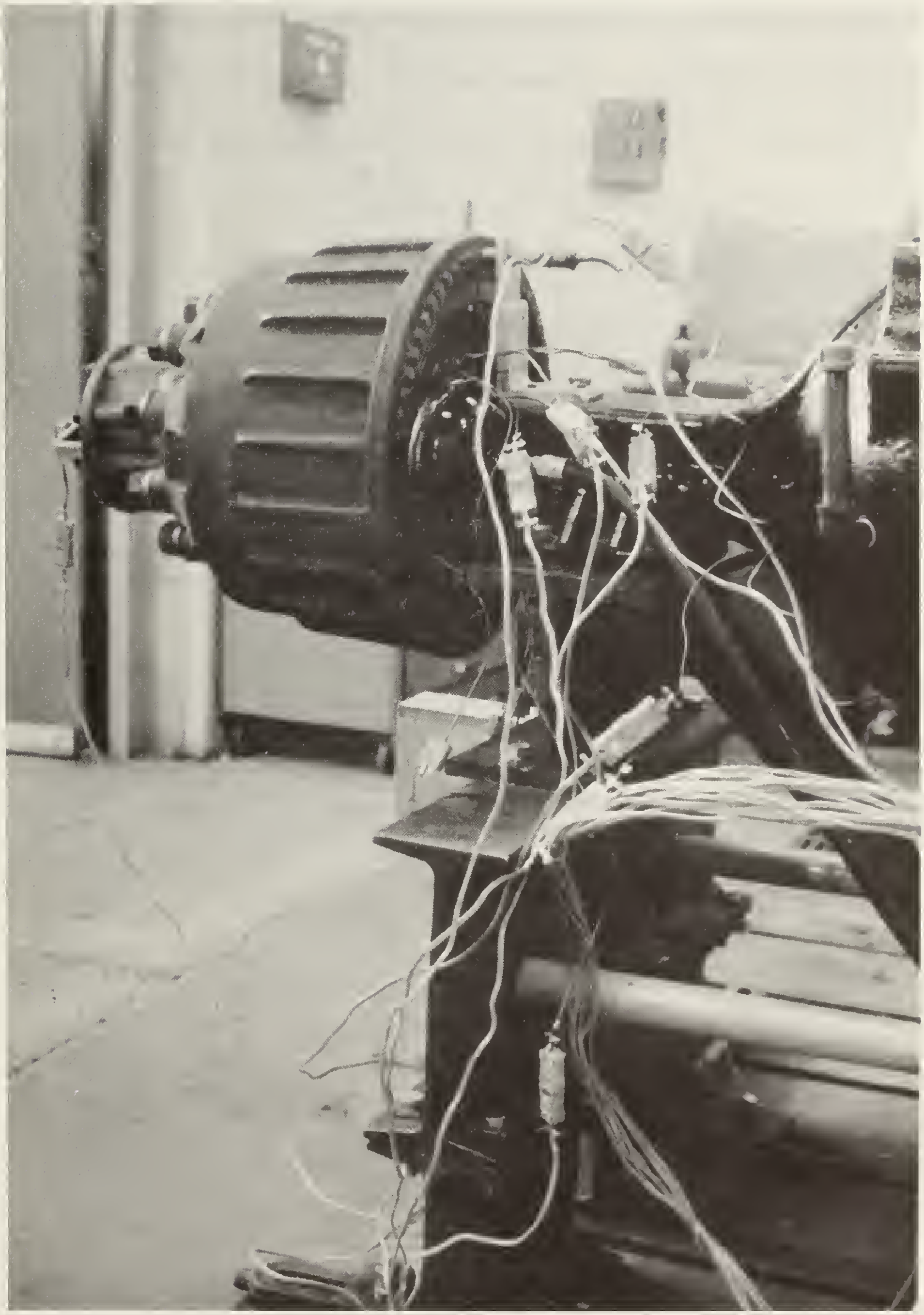


FIGURE 8. BRAKE DRUM TEST ASSEMBLY - REAR

5. TEST SERIES NO. 1: HIGH TEMPERATURE BOND STRENGTH TESTS

The purpose of these tests will be to determine the maximum effectiveness of the bond and to establish parameters associated with the adhesive failure of bonded linings (delamination). These tests are constant speed drag tests. The brake drum is driven at a constant speed, and brake pressure is applied to provide the required levels of braking torque.

Initial high temperature bond strength tests will be run at an average temperature of 1000°F. The drum temperature average is maintained by cycling the brake applications. The operator alternately applies and disengages the brakes so that drum temperatures do not exceed 1050°F when applied and do not drop below 950°F when disengaged (Figure 9). Tests will be run continuously until lining bond failure occurs or until the bond line temperatures stabilize (less than a 0.5°F rise per minute).

High temperature bond strength tests will be run at selected combinations of wheel speed and brake torque. The initial test series planned will consider two different lining materials, three different speeds, and two braking loads (Table 1).

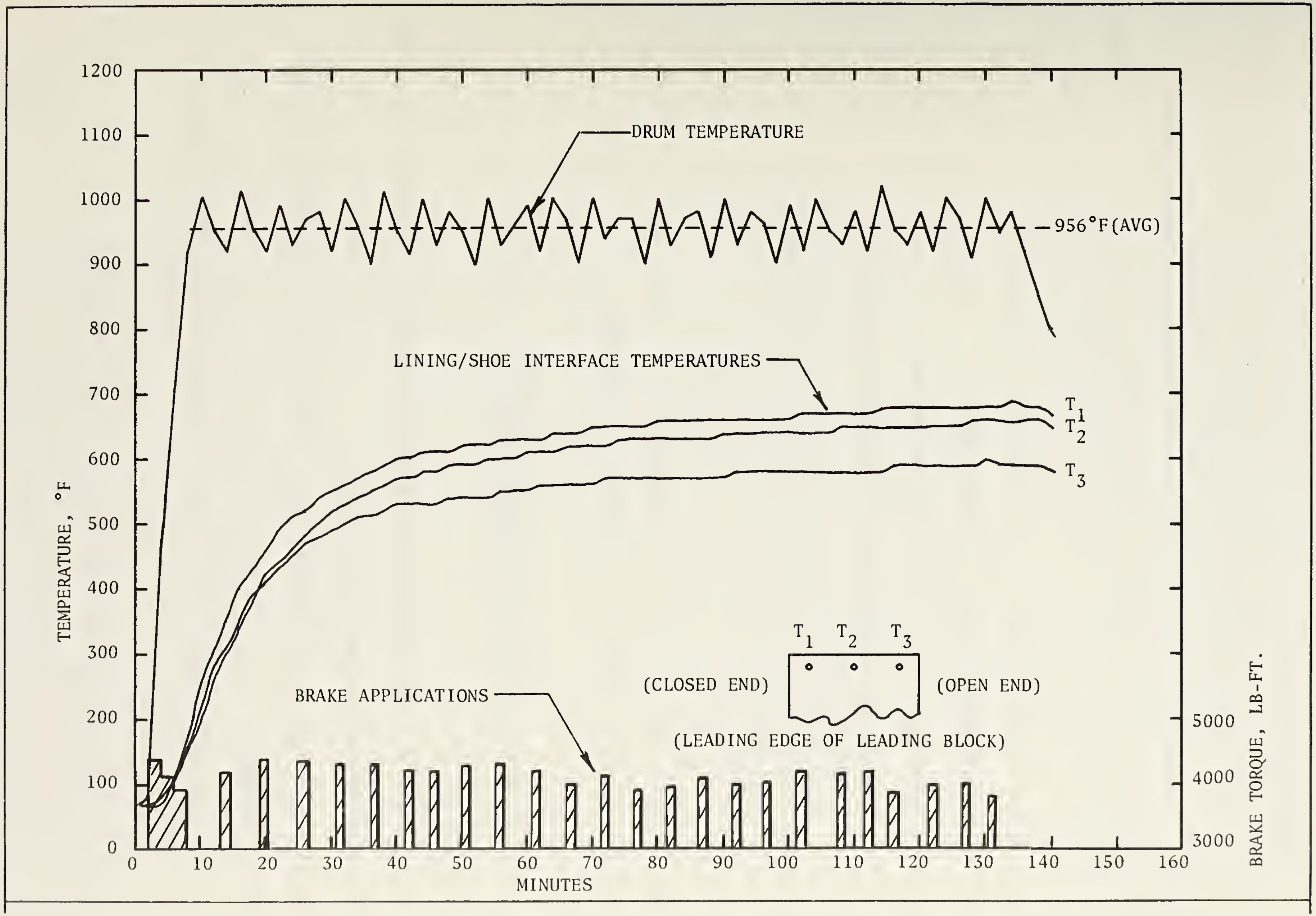


FIGURE 9. TEMPERATURE PROFILE OF RTS II REAR DRUM BRAKES w/ BOLTED LININGS: CONSTANT SPEED OF 15 MPH AND BRAKING TORQUE OF 4000 LB-FT (62.7 BTU/SEC); APPLIED TO MAINTAIN DRUM TEMPERATURE AT 950°F (AVG.). DRUM TEMPERATURE MEASURED AT CENTER OF BRAKE TRACK (SAMPLE: SEVERE DUTY CYCLE)

TABLE 1. THREE-FACTOR BOND STRENGTH TEST MATRIX

	V_1		V_2		V_3	
	P_1	P_2	P_1	P_2	P_1	P_2
L_1	E_{111}	E_{121}	E_{211}	E_{221}	E_{311}	E_{321}
L_2	E_{112}	E_{122}	E_{212}	E_{222}	E_{312}	E_{322}

V_i = Wheel speed; 10, 20, and 30 mph

P_j = Braking torque; 2000 and 5000 lb-ft

L_k = Lining type; Carlise B-33™ and World-Bestos TS-EF™

E_{ijk} = Total energy absorbed by lining to bond failure (Btu's)

The response variable E_{ijk} is obtained by measuring the total length of time braking torque is applied subsequent to bond line failure:

$$E_{(Btu)} = \frac{P(lbs) \times v(ft/sec) \times tn(sec)}{778.169\ (lb\text{-}ft/Btu)} - E_D(Btu)$$

Where P = Braking load, measured brake torque (lb-ft) divided by the radius of the test brake slip plane (ft)

v = Slip velocity between rotating brake drum and dragging brake linings

t_n = Total integrated time (sec) of n brake applications subsequent to bond failure

E_D = Heat dissipated during drum cooling phase (Btu)

Included in this test series will be an assessment of lining wear as a function of speed, load, and drum temperature. Lining thickness measurements will be made before and after each test (when possible). Test specimen lining measurement techniques are specified in Section 1 of Appendix B. The wear test results then become the response variable for this part of the test series (Table 2).

TABLE 2. THREE-FACTOR LINING WEAR TEST MATRIX

	V_1		V_2		V_3	
	P_1	P_2	P_1	P_2	P_1	P_2
L_1	W_{111}	W_{121}	W_{211}	W_{221}	W_{311}	W_{321}
L_2	W_{112}	W_{122}	W_{212}	W_{222}	W_{312}	W_{322}

V_i, P_j, and L_K are as in Table 1.

W_{ijk} = Lining wear (gm/hr, inches)

The test series can be easily expanded by introducing brake drum temperature as a variable. Brake drum temperatures can be varied by using average temperatures as noted above. Table 3 outlines a proposed test matrix for an extended bond strength test series (sample size can be reduced by dropping a speed test point, V_3). T is the average drum temperature and V_i, P_j, and L_K are as above. The response variable, E_{ijk}, can also be the wear variable, as before.

TABLE 3. FOUR-FACTOR, TWO-LEVEL, BOND STRENGTH TEST MATRIX

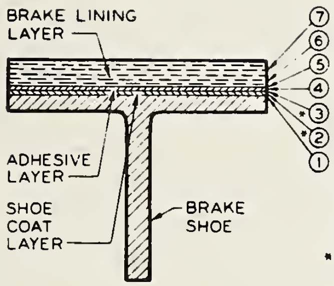
		V_1		V_2	
		P_1	P_2	P_1	P_2
L_1	T_1	E_{1111}	E_{1211}	E_{2111}	E_{2211}
	T_2	E_{1112}	E_{1212}	E_{2112}	E_{2212}
L_2	T_1	E_{1121}	E_{1221}	E_{2121}	E_{2221}
	T2	E_{1122}	E_{1222}	E_{2122}	E_{2222}

The factoral test matrices allow for an assessment of the relative significance of each of the variables on bond failures and lining wear. By applying an analysis of variance technique, an assessment of the relative interaction between the variables can also be determined.[1]

A minimum of two randomized test replications for each test point will be required in order to maintain statistical control. This will require a minimum of 24 test points for the initial program or 32 points for the expanded program (which includes a drum temperature variable). A randomized schedule of test points will be determined by the test engineer prior to implementation of the test series. The operator's test procedure for the high temperature bond strength test series is listed in Section 1 of Appendix C.

In addition to the energy absorption (E_{ijk}) and wear (W_{ijk}) parameters, all bond failures will be characterized in accordance with the Society of Automotive Engineers (SAE) recommended Practice J840 (test procedures for brake shoe and lining adhensive and bonds) as shown in Figure 10.

1. See Gionet, P., "Analysis of Variance," Statistics for the Engineer, Society of Automotive Engineers Special Publication (April 1973).



(7) DEEP FAILURE WITHIN THE LINING
(6) SHALLOW FAILURE WITHIN THE LINING (LESS THAN 0.02 IN (0.51 MM) OF LINING REMAINING
(5) ADHESION FAILURE BETWEEN LINING AND ADHESIVE
(4) COHESION FAILURE WITHIN THE ADHESIVE LAYER
*(3) ADHESION FAILURE BETWEEN ADHESIVE AND SHOE COAT
*(2) COHESION FAILURE WITHIN THE SHOE COAT
(1) ADHESION FAILURE (BARE METAL) BETWEEN BRAKE SHOE METAL AND SHOE COAT OR BETWEEN BRAKE SHOE METAL AND ADHESIVE, WHEN SHOE COAT IS NOT USED

*ELIMINATE WHEN SHOE COAT IS NOT USED

TO REPORT FRACTURE PATTERN, EXAMINE THE DESTROYED BOND TO DETERMINE EXACTLY WHERE THE FRACTURE TOOK PLACE, IE, BETWEEN THE ADHESIVE AND THE SHOE COAT (3), OR BETWEEN THE LINING AND THE ADHESIVE (5).

SHOULD THE EXAMINATION SHOW MORE THAN ONE TYPE OF FRACTURE, REPORT, IN DECREASING ORDER, ALL OF THE DIFFERENT TYPES THAT ARE PRESENT, AND INDICATE THIER APPROXIMATE PERCENTAGE OF THE TOTAL AREA, IE 60 6, 40 2, OR 50 1, 30 3, 20 4.

FIGURE 10. SAE J840c METHODS OF BOND FRACTURE

6. TEST SERIES NO. 2: BOND FATIGUE TESTS

This series of tests will be run to compare linings that are worn in the field (aged) to linings that are newly bonded. The aim of this test is to determine if the bonds of bonded linings aged in service over a period of time will retain the same strength and qualities as newly bonded linings.

Two sets of in-service, worn, bonded brake shoes are obtained from a transit property and tested as described in Section 5 (constant speed drag tests). Ideally, one set of shoes will have been removed from service at one-half of expected service life and the other removed when considered fully worn. After the service-aged linings are tested, the tests are then repeated with newly bonded linings of the same type. The new linings will be ground down to approximately* the same thickness as the in-service worn linings.

Two representative test points from Section 5 will be used in this initial characterization of in-service bond fatigue (Table 4). The points will be selected by the test engineer after the Series 1 tests have been run.

---

* It may not be possible to exactly duplicate the wear profile of the service-worn linings.

TABLE 4. BONDED FATIGUE TEST MATRIX

<table>
<tr><td colspan="2" rowspan="3"></td><td colspan="4">V_2</td></tr>
<tr><td colspan="2">P_1</td><td colspan="2">P_2</td></tr>
<tr><td>t_1</td><td>t_2</td><td>t_1</td><td>t_2</td></tr>
<tr><td rowspan="2">L_1</td><td>Service Aged</td><td>E_{111}</td><td>E_{121}</td><td>E_{211}</td><td>E_{221}</td></tr>
<tr><td>Newly Bonded</td><td>E_{112}</td><td>E_{122}</td><td>E_{212}</td><td>E_{222}</td></tr>
</table>

V_i, P_j, L_K, and E_{ijk} are as above.

t_m = Normal lining thickness of the worn linings (inches)

The new "worn" linings will be broken in (burnished) prior to testing. Information obtained from the bond strength tests (Section 5) will be applied to estimate the lining wear expected during burnishing. Thus, when the linings are machined to the "worn" thickness, allowance can be made for wear.

Test results will be as in Section 5: total energy absorbed to failure (Btu's), wear rate (gm/hr), bondline temperature history, and bond fracture characterizations.

7. TEST SERIES NO. 3: SIMULATED SERVICE CYCLES

7.1 APPROACH

Any simulated vehicle driving cycle can be run on the DOT/TSC test apparatus in order to establish the temperature profile and wear characteristics of the bonded brake shoes over simulated service runs. These data can be applied to help develop and verify analytical expressions describing the brake temperature environment, and to characterize lining wear during different service cycles.

Two of the UMTA design service cycles will be simulated in the DOT/TSC brake test program: the City Business District (CBD) service cycle and the Arterial Service Cycle. Characteristics of these two duty cycles are shown in Figure 11. A third service cycle, the Commuter Cycle, can also be simulated on the DOT/TSC apparatus although at a reduced top speed of 50 mph instead of 55 mph. This cycle has not been included in the initial test series since it is a significantly less severe braking cycle than the Arterial and CBD cycles (approximately 11 Btu/min braking effort for the Commuter cycle versus 44 and 37 Btu/min for the Arterial and CBD cycles).

Currently, a modified "Data-Trak" chart programmer is being utilized as a control device to implement the service cycle simulations. The programmer sends acceleration, cruise, and braking command signals to the dynamometer control circuit according to a pre-programmed schedule. Data-Trak programming is implemented by a chart tracking mechanism which follows a line scribed on a chart. The chart, in turn, is mounted on a rotating drum. Service cycles can thus be "driven" continuously by the programmer with minimal control from the operator. Accuracy and flexibility are limited however, and some operator inputs are necessary to adjust braking effort and correct error build-up.

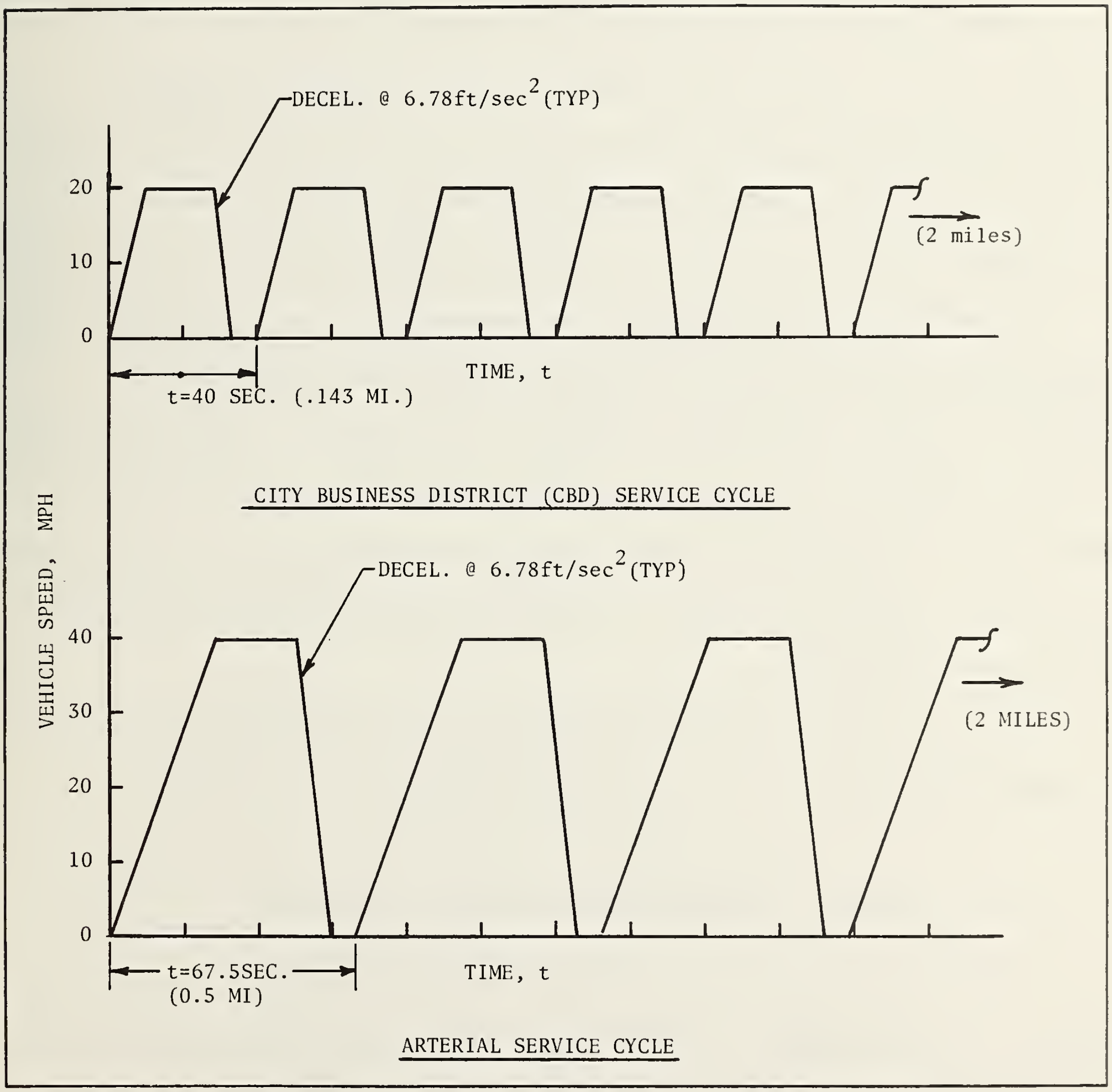


FIGURE 11. UMTA TRANSIT COACH DESIGN SERVICE CYCLES

A second-generation development effort which will utilize Hewlett-Packard 1000F computer control circuitry is planned. This will significantly increase test cycle flexibility and improve the accuracy of the simulated service runs.

A programmed "driver" is desirable for these tests since the driving cycles will run well beyond the originally designed lengths of two miles. This is required in order to insure that temperature transients have a chance to stabilize (approximately two to three hours for the CBD cycle and three to four hours for the Arterial), and that sufficient measurable lining wear is induced.

Lining wear will be tracked by removing the brake drum prior to each day's test and measuring lining thickness (as in Appendix B). The measurements will be made after the test specimen and apparatus have had a chance to cool completely to ambient temperatures (minimum 8 to 12 hours). Initial test plans call for six hours of continuous cycle testing during each shift. On this schedule, four to eight days of cycle testing will be required for each lining and drive cycle combination. More testing may be necessary if closer lining wear tracking is required.

Two different linings will be tested over each service run for a total of four simulated service run tests, as shown in Table 5.

TABLE 5. SIMULATED SERVICE CYCLE TEST MATRIX

	L_1	L_2
1. CBD	W_{11}	W_{21}
2. Arterial	W_{21}	W_{22}

L = Lining type (Carlise B-33 and World-Bestos TS-EF)

W = Wear data test results (gm/hr)

The operator's test procedure for the simulated service cycle test series is tabulated in Section 2 of Appendix C.

Bond failures are not expected during the simulated service runs. Test results will consist of drive cycle temperature profiles (brake drum and several shoe/lining temperatures) and lining wear data (gm/hr, gm/mi).

7.2 PRELIMINARY OBSERVATIONS

Some preliminary drive cycle simulations have been run on the DOT/TSC test bench using bolted brake linings. Temperature profile test results over the CBD cycle are shown in Figure 12 (wear data was not collected in these developmental tests). The temperature profiles for both the drum and the shoe/lining interface are regular and continuous; drum test results are nearly approximated by classical Newtonian convective cooling:[2]

$$T_{DRUM} = \Delta T_{BA} \frac{(1 - e^{-nkt_c})}{(1 - e^{-kt_c})} + T_{AMB}$$

where ΔT_{BA} = Temperature rise per brake application

n = Number of brake applications

k = Thermal properties of brake drum

t_c = Length of time between brake applications

The analytical expression and test data are illustrated in Figure 12. There appears to be good agreement between the experimental data and the analytically predicted temperature profile. It must be noted though, that some adjustment of the constants in the analytical expression was necessary to

2. See Army Material Development Readiness Command, Engineering Design Handbook: Analysis and Design of Automotive Brake Systems. NTIS No. AD-A035 143, (December 1, 1976).

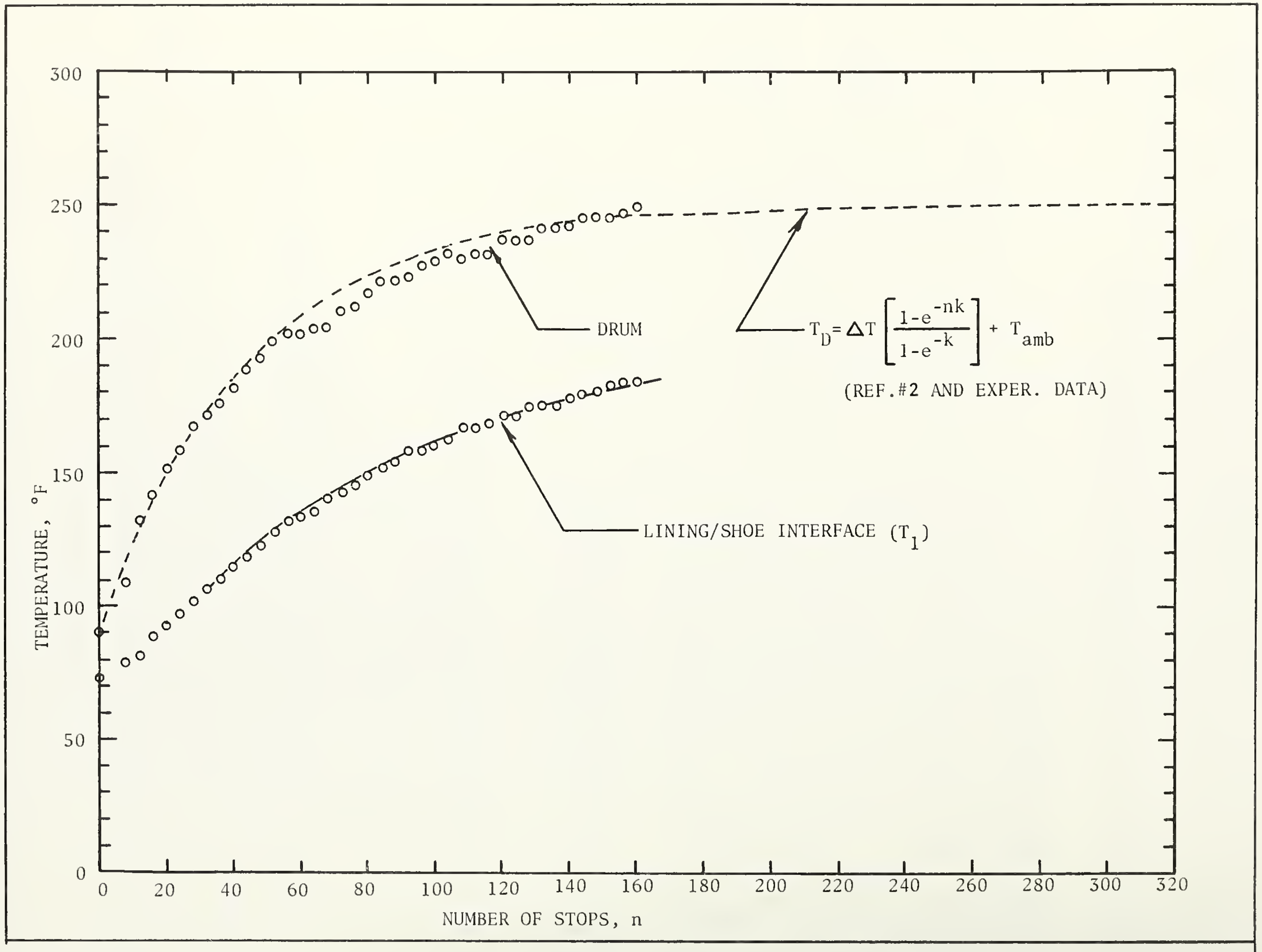


FIGURE 12. TEMPERATURE PROFILES OF TRANSIT COACH REAR DRUM BRAKES DURING UMTA CITY BUSINESS DISTRICT (CBD) SERVICE CYCLES: 160 STOPS FROM 20 MPH (APPROX. 23 MI, 2 HRS.)

facilitate the agreement. This implies some disagreement between the two approaches and suggests that further testing and analytical effort is required to resolve differences between the theoretical and experimental results (Figure 12 represents a single two-hour test run).

For example, an issue that was not considered in the initial analysis is lining thickness (wear). Lining thickness is an important consideration is this effort since it governs the proportion of heat ejected to the drum and the portion of the braking energy absorbed by the lining/shoe interface. This is an important element if the bond line temperature profile is to be adequately characterized.

The theoretical analysis fitted to the TSC data (Figure 12) suggests that drum temperatures during the CBD drive cycle will stabilize at 250 to 260°F after about 200 or so stops (approximately 2-1/2 hours). Although no similar expression for bond line temperatures has yet been derived, it seems reasonable to assume that bond line temperatures will follow a similar heating trend, and, in the limit (as lining thickness goes to zero), approach drum temperatures. However, even at predicted drum temperatures, bond line temperatures do not approach the expected adhesive failure temperatures of 500 to 600°F. This implies a relatively mild braking schedule for the CBD cycle with little danger of adhesion failure. A "severe duty" simulation can be applied to the CBD cycle to provide better validation for the high temperature bond strength test. An example of such a severe duty cycle is shown in Figure 9.

The underlying assumption of the theoretical expression, though, is that the heat generated during braking is uniformly distributed over the entire drum rub path. This is not always the case. The drum can become distorted under the heat and pressures of braking service, and cause a non-uniform contact patch between the lining and the drum.[3] This results in bands of localized "hot spots" as the effective rub area becomes less than the total lining band width, or when braking pressure becomes non-uniform across the rub area.

For example, a rub area reduction of 75 percent can result in drum temperatures 3.4 times higher than those predicted for full contact cases.[4] For the CBD cycle, this means temperatures in excess of 850°F. Thus, temperatures can approach delamination potentials even in the relatively mild CBD braking cycle. These effects can be exacerbated by more severe braking cycles, by uneven lining wear, and/or by reduced lining thicknesses.

A study of brake drum thermal distortions are beyond the immediate scope of the bonded brake lining test project, but it is a phenomenon that must be closely monitored because of its significant influence on the test results. Bond line temperatures will be measured across the entire brake rub path so that any distortion effects (hot spots) can be detected. The temperature profile can then be used to compare any atypical test to test distortions.

For example, preliminary test results (measured in three places across the rub path, see Figure 9) have shown a decrease in bond line temperatures from the closed end of the drum to the open end. Whether this is due to distortion of the open end of the drum ("bell-mouthing") or due to improved convective cooling at the open end is not known at this time. Regardless, it is important that subsequent tests exhibit the same apparent rub path temperature profile if valid test-to-test comparisons of the results are to be insured. This includes not only this test series, but the bond strength and bond fatigue test series as well.

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3. See Ashworth, R., M. El-Sherbiny and T. Newcomb, "Temperature Distributions and Thermal Distortions of Brake Drums," Proceedings of the Institute of Mechanical Engineers, Vol. 191 (1977).

4. Ashworth, R., M. El-Sherbiny and T. Newcomb, "Temperature Distributions and Thermal Distortions of Brake Drums," Proceedings of the Institute of Mechanical Engineers, Vol. 191 (1977).

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APPENDIX A

THERMOCOUPLE INSTRUMENTATION

A.1. THERMOCOUPLE ASSEMBLY

Temperature sensors shall be "plug" thermocouples fabricated from 20-gauge chromel-alumel (Type K) wire, coated with asbestos and glass insulation (Figure A-1). Thermocouple plug leads shall be three to four feet long and terminated with a male quick-disconnect, color coded, thermocouple plug. Previously used thermocouple assemblies may be re-used. Restore plug assembly if plug is sacrificed during test or disassembly of the thermocouple. Wire lead should be sufficient to clear the drum by a minimum of one foot.

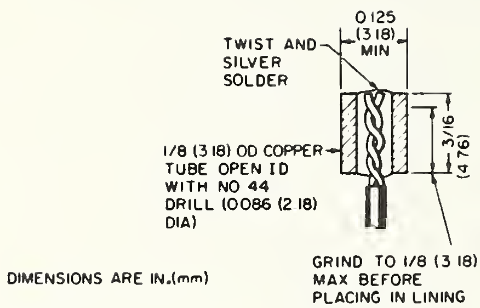


FIGURE A-1. TYPICAL PLUG THERMOCOUPLE ASSEMBLY

A.2. THERMOCOUPLE INSTALLATION

Install thermocouples in brake shoes by drilling a 1/8-inch hole from the back side of the shoe assembly. Drill to required depth (to the surface of the brake block, at the bond line). Insert the TSC plug assembly and cement into place with a high-temperature cement (Omega CC Hi-temp™ or Sauerisen Hi-temp™ adhesive). Locate thermocouple positions along the center lines of the brake blocks and at the leading edge of the first brake block as shown in Figure A-2. The tip of the plug thermocouples shall be located at the bond line of the brake block and shoe, approximately flush with the shoe surface (Figure A-3). Both brake shoes are to be instrumented similarly.

The brake drum shall be instrumented with a thermocouple located in the center of the brake track and 0.100 inches from the rub surface (Figure A-4). Secure into place with a high-temperature adhesive and connect thermocouple to slip-ring assembly bolted to the hub of the brake drum.

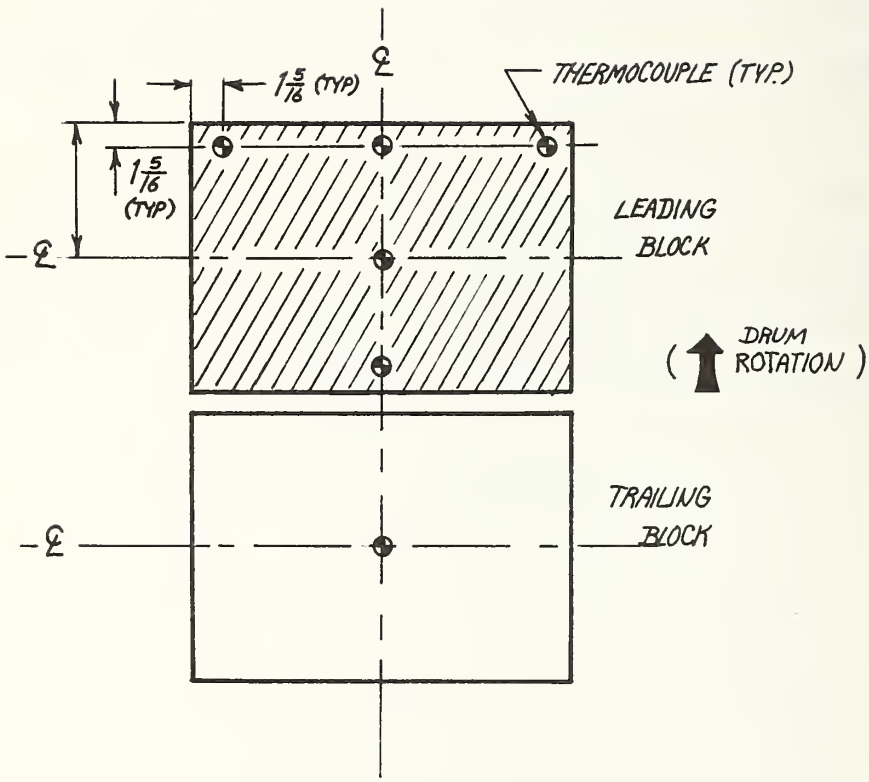


FIGURE A-2. BRAKE BLOCK THERMOCOUPLE LOCATIONS (MINIMUM NO. OF TCs)

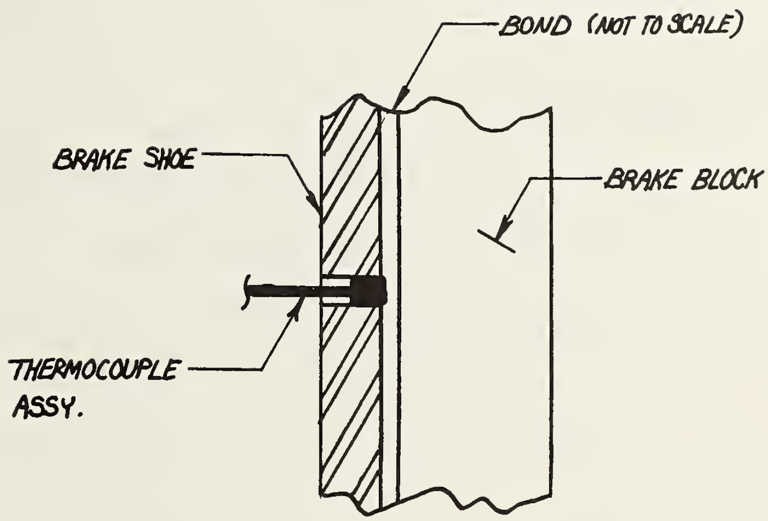


FIGURE A-3. TYPICAL BRAKE SHOE THERMOCOUPLE INSTALLATION, SECTION VIEW

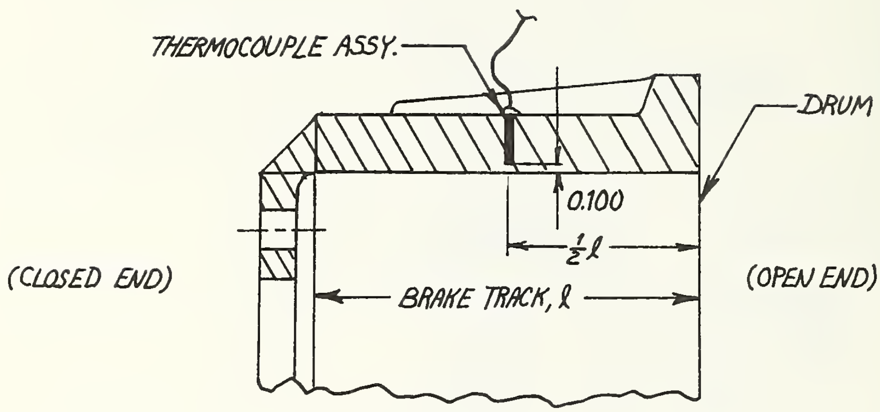


FIGURE A-4. BRAKE DRUM THERMOCOUPLE LOCATION

APPENDIX B

TEST SPECIMEN PREPARATION

B.1. LINING MEASUREMENTS

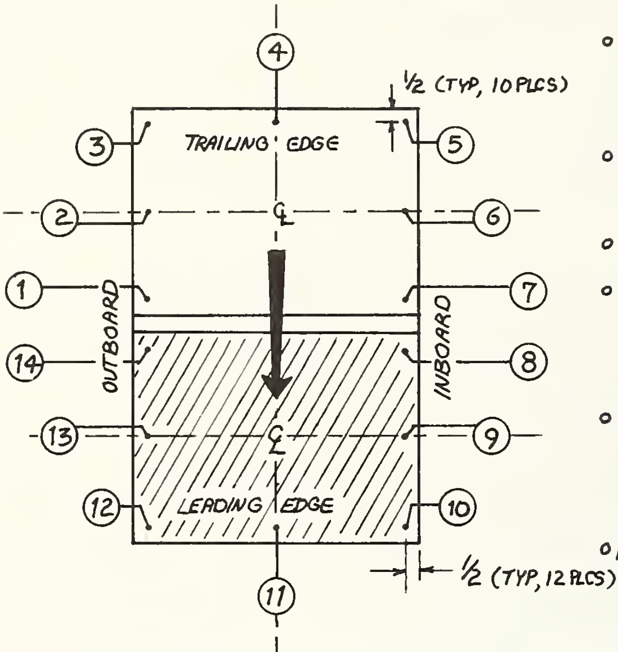
Prepare and measure all test brake shoes prior to installation on the brake test apparatus.

Remove any foreign matter from the brake shoes. Visually inspect shoes for cracks, voids, and defects. Discard and return to the bonder any shoe having defects which might impact bond strength or braking effort.

Measure shoe lining thickness prior to installation on test rig, after burnishing (break-in of new brake blocks), and after each test. Using a micrometer, measure brake block thickness to the nearest 0.001 inch and record data in log book. Measure three places along each outside edge of each block and in the center of the trailing and leading edges (for a total of 28 measurements: 2 shoes x 2 blocks/shoe x 2 edges x 3 places + 2 leading edge centers and 2 trailing edge centers - see Figure B-1).

In addition, weigh each shoe to the nearest 0.5 gram. Note and record the ambient temperature and humidity of the weighing room when measurements are taken. The test brake shoe must be cold-soaked in the weighing room for 8 to 12 hours prior to measurement. Weigh brake shoes with thermocouple assemblies installed (both before and after test).

o TEMP. ________ o HUMIDITY ________ o DATE ________ o INITIALS ________



o BRAKE SHOE I.D. NO. ________ (TOP)

________ (BOTTOM)

o MATERIAL ________

____

o TYPE BOND ________

o FRICTION SURFACE

LENGTH ________

WIDTH ________

o TYPE OF TEST ________

____

____

o REMARKS ________

____

____

TOP SHOE DIM. (INCHES)				BOTTOM SHOE DIM. (INCHES)			
LOC.	NEW	AF. BURNISH	AFTER TEST	NEW	AF. BURNISH	AFTER TEST	REMARKS
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
WEIGHT (GMS)							

FIGURE B-1. TEST SPECIMEN MEASUREMENT FORM

B.2. BREAK-IN OF NEW BRAKE SHOES (BURNISHING)

All new brake shoes to be tested must be broken in prior to implementation of test. Break-in (or burnishing) shall consist of stops from 35 mph at an average deceleration of 11 ft/sec^2. Burnishing procedure shall consist of a minimum of 100 stops. Allow suffficient time between stops to hold drum temperature under 250°F. After 100 or so stops, remove drum and check that at least 80 percent of the linings are in contact with the drum. Repeat procedure if necessary.

After completion of break-in, remove shoes and repeat lining measurements (allow to cool to ambient temperature of measurement room, see Section B.1). Record results and general condition of the lining. Reassemble shoes, adjust and record clearances.

APPENDIX C

OPERATOR TEST PROCEDURES

C.1. TEST PROCEDURES FOR TEST SERIES NO. 1 AND NO. 2: CONSTANT SPEED, BRAKE DRAG TESTS

The test matrix (speed, brake torque, and lining combinations) shall be determined by the test engineer. Test points shall be randomized, and a schedule of speed/load points specified. Proceed as follows:

A. Identify and record test specimen characteristics (two shoes with linings for each test point).

B. Install thermocouples and prepare pieces for testing according to Appendix A; additional thermocouples may be added as specified by the test engineer.

C. Measure test pieces as in Section 1 of Appendix B and record data. Maintain a file of measurement data.

D. Install shoes on brake test apparatus, adjust and record running clearances (per manufacturer's specifications).

E. Burnish (break in) the new brake shoe linings (see Section 2 of Appendix B). Note: Burnishing is not required for service-aged linings in Test Series No. 2.

F. After break-in requirements are met (minimum of 80 percent drum/lining contact), remove brake shoes and repeat lining measurements. Record data in log.

G. Re-install test specimens on test apparatus and re-set and record running clearances.

H. Turn on dynamometer, switch into "speed" mode and bring dynamometer up to target test speed. Warm up at test speed for a minimum of 20 minutes.

I. While dynamometer is warming up, bring up data scanning program on the computer. Measure and set instrument zeros, set scan rate at one scan per second, and take several test scans prior to any brake applications to establish initial test conditions.

J. When dynamometer is fully warmed up and scanning program ready, start test: Initiate scan program and adjust brake air pressure until target torque is attained. Continually monitor torque readout, manually adjusting the brake air pressure to maintain torque target. Note that dynamometer field current meter has the fastest response to torque fluctuations.

K. Maintain target test torque until drum temperature reaches 1050°F ("TD" on CRT readout); release brakes at TD = 1050°F and allow drum to cool. At TD = 950°F, reapply target test torque.

L. Repeat Step K until a lining failure is evident (erratic loss of braking torque or a heavy drag or rubbing noise following a brake application) or until shoe bond line temperatures stabilize (less than a 0.2 °F/min temperature rise). Terminate test. Turn off dynamometer and break out of test scan program (data will automatically print out).

M. Allow test apparatus to cool; remove the test brake shoes (and linings) and temperature soak the test specimens in the weighing/measurement room for 8 to 10 hours.

N. Repeat measurement as in Step C and record results.

O. Characterize the bond fracture of each test specimen that fails in accordance with the method specified in SAE recommended practice J840c. Record this data on the test specimen measurement sheet under "remarks".

C.2. TEST PROCEDURES FOR TEST SERIES NO. 3: SIMULATED SERVICE CYCLE TESTS

Test matrix and cycle test schedule to be determined by test engineer. Proceed as follows:

A. through G. Follow set-up procedures outlined in previous test procedure for constant speed drag tests (Section C.1), Steps A through G.

H. Turn on dynamometer, warm up dyno in "speed" mode at the maximum speed of the anticipated drive cycle; warm up for a minimum of 20 minutes.

I. While the dynamometer is warming up, bring up test scan program on the computer; set scan rate at ten seconds. Measure and set instrument zeros; take several test scans prior to initiating tests to establish initial conditions.

J. Set up "Data-Trak" chart programmer for anticipated drive cycle; start at beginning of acceleration mode.

K. Prepare X-Y Recorder to monitor speed/time profile of anticipated cycle.

L. When the dynamometer is fully warmed up, turn down speed and switch into "torque" mode; check that DLC logic control parameters for road load and vehicle inertia are implemented. Zero brake application counter.

M. Start drive cycle tests; monitor speed versus time profile of cycle on X-Y Recorder. Adjust brake air pressure of dynamometer acceleration command as required. Monitor profile throughout duration of test and correct any error build-ups.

N Run service cycles continuously for a minimum of six hours. At the end of the six hour test sequence, shut down dynamometer and break out of data scanning program. Record number of brake applications.

O. Allow test apparatus to cool for 8 to 12 hours. Remove drum and measure lining thickness around perimeter of shoe as in Appendix B. Record data.

P. Repeat test sequence until satisfactory wear data is acquired (more than a 10 percent change in lining measurement or as specified by the test engineer).

Q. At the end of the service cycle test, remove the brake shoes and repeat measurements as specified in Section 2 of Appendix B. Record results.

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