

MELBOURNE AND METROPOLITAN TRAMWAYS BOARD

TESTING BRANCH

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Requested by Designing Engineer

INTRODUCTION

Tram No. 977 was tested for retardation under various conditions of load and gradient. The effect of dynamic braking on the tram equipment was observed. The results are discussed and recommendations are made to improve the effectiveness of such braking.

DESIGN OF TESTS

The tram was driven over selected gradients with various loads, was equipped with the necessary instruments as set out in Section 3.2, and carried a test staff of 10. See Appendix 4.

3.1 Gradients and Loads.

- Tram 977 was tested under 3 sets of conditions.
- A. On approximately level track (Miller St. Freston)
    - (a) with light load (1/2 ton)
    - (b) with seated load (3 1/2 tons)
    - (c) with crash load (10 1/2 tons)
  - B. On steepest gradient available for test (Riverdale Rd. Nettle Park)
    - (a) with light load (1/2 ton)
    - (b) with seated load (3 1/2 tons)
    - (c) with crash load (10 1/2 tons)
  - C. A series of runs each approximating to 24 miles of service running.

3.2 Instrumentation.

- The tram was equipped with the following instruments.
- (a) A Burday Traction Recorder consisting of Voltmeter, Ammeter, Speedometer, Air Pressure meter and Marker Pens.

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(b) Two Voltmeters to measure the voltage across each pair.

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(c) Two Ammeters to measure the current in each pair of motors. Requested by: Designing Engineer on:

(d) Two Stop Watches to time the stopping period.

(e) Two DYNAMIC BRAKING ON TRAM 977 to mark the point of brake application.

1. (f) Two Measuring Tapes to measure stopping distances. PURPOSE

The Designing Engineer requested that an investigation be carried out to determine the suitability of the dynamic braking as fitted to Tram No.977 for general use in the service.

2. INTRODUCTION

The report comprises 4 sections:-

1. Design of test including instrumentation.
2. Summary of results.
3. Discussion of results.
4. Recommendations.

Tram No.977 was tested for retardation under various conditions of load and gradient. The effect of dynamic braking on the tram equipment was observed. The results are discussed and recommendations are made to improve the effectiveness of such braking.

3. DESIGN OF TESTS

The tram was driven over selected gradients with various loads, was equipped with the necessary instruments as set out in Section 3.2, and carried a test staff of 10. See Appendix 4.

3.1 Gradients and Loads.

Tram 977 was tested under 3 sets of conditions.

- A. On approximately level track (Miller St. Preston)
  - (a) with light load ( $\frac{1}{2}$  ton)
  - (b) with seated load ( $3\frac{1}{2}$  tons)
  - (c) with crush load ( $10\frac{1}{2}$  tons)
- B. On steepest gradient available for test (Riversdale Rd. Wattle Park)
  - (a) with light load ( $\frac{1}{2}$  ton)
  - (b) with seated load ( $3\frac{1}{2}$  tons)
  - (c) with crush load ( $10\frac{1}{2}$  tons)

C. A series of runs each approximating to 24 miles of service running.

3.2 Instrumentation.

4.2.1. The tram was equipped with the following instruments.

4.2.1.1 (a) A Murday Traction Recorder consisting of Voltmeter, Ammeter, Speedometer, Air Pressure meter and Marker Pens. It is realized that just as abnormal driving can cause severe current flow during motoring, so abnormal braking, such as would be met with if tram speed were allowed to rise above 35 m.p.h. could cause short time peaks in the braking current.



Such conditions were established on 11 occasions during the tests without the motors requiring any attention whatsoever.

4.2.1.2 The heating of the motors was not materially affected by the dynamic braking. The temperature rise after 2 hours continuous testing with 10½ tons load was 63°C. The temperature rise of motors in a service car after 3 hours of peak service running was found to be 60°C.

4.2.1.3 The maximum voltage generated by the motors under the most adverse test conditions was 1500 V. (Note. This voltage was a peak lasting less than one second. The current corresponding to this voltage was 93 amps.) At this voltage, generated at a speed of 43 m.p.h., the motors did not flash over.

4.2.2 Effect on Resistors

During the 3½ ton load tests at Wattle Park, facilities were available for accurate determination of the temperatures of the resistors in the motor circuits and of the wheel tyres (see 4.2.5). The maximum temperature rise recorded on the resistors was 80°C. This is negligible relative to the materials employed in this equipment.

4.2.3 Effect on Contactors

The contactor contacts showed no sign of wear due to the extra duty. However 4 coils failed during the tests and all coils attained excessive temperatures.

4.2.4 Effect on Brake Shoe Wear

The increase of piston travel over the whole test was 1-3/16", and was caused by 155 test braking applications and 1162 accompanying normal brake applications. The distance travelled during these tests was estimated as 190-200 miles corresponding to 18 hours of normal service running. The increase in piston travel after 18 hours normal service is of the order of 7/8" for shoes of similar hardness (see Appendix 5).

4.2.5 Effect on Wheels

It was observed that after 3 hours continuous running requiring 108 brake applications and including 2 hours testing, the temperature of the wheel tyres was 43°C. Some service cars were tested on their arrival at Wattle Park. As the readings were taken between 12 noon and 12.30 p.m. the service cars would have been carrying light loads and running to easy schedules yet the temperatures of their wheel tyres were - Tram No.409 82°C and No.246 - 80°C.

5. DISCUSSION

5.1 Reduction of Brake Shoe Wear

From the figures set out in Appendix 6 it can be seen that although the ton-miles for tram 977 are 960 compared with an estimated 540 for a comparable service tram, yet the brake piston travel was 1-3/16" compared with 7/8" for the service tram. Also, the temperature of the wheel tyres of tram 977 was 40°C whereas that of service cars on light duty was at least 80°C. This indicates that brake shoe wear per ton-mile for tram 977 was 0.76 of that on the shoes of an air-braked tram.

## 5.2 Smoothness of Application

The speedometer chart showed a uniform retardation when dynamic braking only was used. There was no feel of jerkiness on the tram and persons standing had no difficulty in remaining erect. Because of the low retardation (approx. 1 m.p.h.p.s.) there was only a slight recoil if the dynamic braking was cut off before the tram stopped. The rises in current as each resistance step was cut out were relatively small.

## 5.3 Overvoltage at high speeds

When dynamic braking was applied at a speed of over 40 m.p.h., the voltage generated rose to not less than 1500 V with a current of over 90 amps. Although the motors did not flash over under this condition it must be remembered that they were in "as new" condition and that weather conditions being fine and dry were favourable to good commutation. There was a clearly audible squeal from the commutators at this speed. In view of the high voltage between commutator segments it is clear that with the normal deterioration due to service, the motors would be likely to flashover on the commutator if the dynamic brake was applied at high speeds. As they would be acting as generators in parallel and without any circuit breakers to isolate a defective unit, the extent of the damage attributable to flashover could be considerable. The possible damage to gears, suspension and undercarriage as well as to motors warrants the taking of precautions against the building up of such excessive voltages.

## 5.4 Braking and Power Supply Interruptions.

The contactors used in the control circuits for both power and braking are supplied with current from the overhead line. It was observed that the interruption due to the trolley wheel passing under a Section Insulator would allow the contactors to open and cut off the dynamic brake. On restoration of supply there would be a delay of  $\frac{1}{2}$ -2 $\frac{1}{2}$  seconds depending on the speed of the tram before maximum braking was reapplied. As approximately  $\frac{3}{5}$  of Section Insulators (over 70) are placed near Stop Marks (to reduce wear on O.H. fittings by placing them in positions where trams will not be drawing power) there will be many places where braking effort will be reduced just as a driver is making a stop.

## 5.5 Effect on Emergency Braking

The dynamic braking was not generally effective in emergency stops because the shoe brakes frequently gripped the wheels so firmly as to cause a near skid. Under these conditions of low r.p.m. of the wheels, there was of course little current generated, with consequently little retardation from this source. Under heavy loads and/or down steep grades the skidding was less and the dynamic braking was operative.

## 5.6 Reliability of equipment used.

The only portion of the dynamic braking equipment which proved unreliable during the tests was the contactor unit. It is recorded that four contactor coils failed. Of these, three coils, were on Resistor contactors, RR2, RR3 and R3, and one was on Braking contactor B4. The auxiliary contacts on the contactors also failed on several occasions.

5.7 Driver Reaction

5.7.1 "Feel of braking."

The smooth action of the dynamic braking together with the delay in building up does not give the feel of "bite" to which drivers are accustomed. Therefore they feel less secure than with clasp brakes so that it is to be expected that they will use some air with most applications. As a result, when the dynamic braking does build up, the tendency is for the driver to release both air and dynamic momentarily, then have to reapply them, thus causing jerky stopping. This could be avoided with training and practice.

5.7.2 Continuity of Braking Effect.

The loss of dynamic braking due to interruption to the 600 Volt supply such as would be caused by passing under an insulated overhead fitting, by the trolley wheel leaving the overhead wire or by failure of the power supply would cause some drivers to regard the equipment as unreliable.

5.7.3 Use of Interlocked Power/Braking

The drivers will soon learn that the first movement of brake handle will cut off power, and there will be a tendency to use this method of cut off, instead of using the controller in the approved manner.

An advantage will be that there will be less tendency for drivers to hold the motors on 1st notch at a stop with the air brakes applied. This will be impossible - unless the foot switch is used. It is noted that switching off the "Brake" switch on the canopy will not obviate the use of the foot switch in holding power on with brakes applied. The footswitch is used legitimately for such purposes as holding some air in the brakes with power on to operate Automatic Points Controllers.

6. RECOMMENDATIONS

6.1 Protection against overvoltage.

The power circuits used for dynamic braking should be redesigned to provide either (a) approximately double the resistance in the main circuit, or preferably, (b) a measure of field weakening. This addition should be so designed that the voltage generated at 35 m.p.h. would not exceed 900V. The current Control relay should control this additional equipment in one or more steps according to the method used.

6.2 Redesign of Contactors.

The contactors should be redesigned using an improved type of armature hinge in order to reduce the number of ampere turns, and hence the heating, in the coils. To provide against damage due to peak voltages induced when the coils are opened off, they should be layer wound on divided spools with special care against slip of end turns. They should be insulated every 10 layers with .003" Cellulose Acetate. Opportunity should be taken in the redesign of the carcass to provide improved auxiliary contacts. The make-before-break contacts should be of the positive overlap type. All auxiliary contact faces should be of silver with the stationary contacts faces serrated. The contactors should be so designed that they will operate continuously with not more than 6000 rise on a voltage range between 400V and 650V.

### 6.3 Braking and Power Supply Interruptions.

A 1000 Ohm 600 watt resistor should be provided to act as a discharge resistor to delay the decay of flux from the coils of all contactors used for braking. The circuit should be so arranged that the coils are free to release quickly in response to the operation of the brake controller, while providing for delayed release upon failure of the 600V supply. A possible circuit is shown in general form in Appendix 8.

### 6.4 Rearrangement of Braking Steps.

The values of resistance per step at present are as follows.

1 - 3.8	ohms	(all resistance in circuit)
2 - 2.9	"	RR2 closed.
3 - 2.0	"	RR2 & R2 closed.
4 - 1.4	"	RR2, R2, RR3 closed.
5 - 0.8	"	RR2, R2, RR3 & R3 closed.
6 - 0.4	"	RR2, R2, RR3, R3 & RR4 closed.
7 - 0.0	"	RR2, R2, RR3, R3, RR4 & R4 closed.

In order to achieve more even steps in the braking, it is recommended that the sequence should be as follows -

1 - 3.8	ohms	(all resistance in circuit)
2 - 2.9	"	RR2 closed.
3 - 2.0	"	RR2 & R2 closed.
4 - 1.0	"	RR2, R2, RR4 closed.
5 - 0.0	"	RR2, R2, RR4 & R4 closed.

In order to protect against excessive voltage at high speeds, it is further recommended that one step of field weakening and one step of extra resistance should be added ahead of the steps referred to above. Then the sequence would be -

1 -	Field weakened &	6.8 ohms in circuit	
2 -	Full field &	6.8 ohms.	
3 -	"	" & 3.8 "	
4 -	"	" & 2.9 "	RR2 closed.
5 -	"	" & 2.0 "	RR2, R2 closed.
6 -	"	" & 1.0 "	RR2, R2 & RR4 closed.
7 -	"	" & 0.0 "	RR2, R2, RR4 & R4 closed.

These 6 steps should be controlled by the Current Limit Relay as at present.

Report prepared by

*Ch. Steele*

Investigating Engineer.

10-9-54

*M. Hines* 10/9/54

for Testing Engineer.

Date : 9/3/54 TRAMCAR BRAKING TESTS Weather : Fine and dry  
 Locality : Miller St., Proton  
 Load : CLASS S.W.6. (ton) SEATED CAPACITY 52 TRUCK TYPE 15  
 Grade of Track : Level to 1%

Tare of Car	16.8 tons	Brake cylinder dia.	8"
Seated Load	3.5 tons	Air pressure range:	60 - 70 p.s.i.
Crush Load	10.25 tons	Brake Diagram drg.	R. 5553A
Motors : No. & Type	4 XGE247	Braking ratio:	% at lbs.
Relay Valve		Brake Eff'cy :	% of Theor. press.
Motorman's Valve		Shoe hardness :	Av. 227 Range 197-255
Emergency Valve		Wheel diameter.	28-3/16"

Resistances of Motor and Contactor Coils at 12°C (Ambient)

Resistances of Motor Windings.				Resistance of Coils.			
Motor	Armature	Field	Coil	Resistance	Coil	Resistance	
No.1 Motor) from No.1 end	0.54 Ω	0.342 Ω	B2	4378 Ω	RR2	4610 Ω	
2 )	0.58 Ω	0.344 Ω	B4	4270 Ω	RR3	4013 Ω	
3 ) from No.2 end	0.54 Ω	0.348 Ω	R3	6680 Ω	RR4	4099 Ω	
4 )	0.52 Ω	0.337 Ω	R4	4143 Ω			

\* Runs prior to 10 are not used for test results since Murray recorder required re-calibration of its speedometer and compensator.

\* No. of brake operations does not include test operations.

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 APPENDIX I.  
 Sheet 1.

INSTRUMENT CONNECTIONS(a) Murday Recorder

1. Voltmeter. The instrument was recalibrated by adding external resistances to read 1500V full scale. It was connected from terminal B3-B4 to Earth. It thus recorded the voltage of the motors above Earth.
  2. Ammeter. The instrument was connected to a 500 amp shunt which was inserted between terminal B3-B4 and the current limit relay. It thus recorded the total current from the four motors.
  3. Speedometer. The instrument was connected to the Murday generator which was chain driven from No.1 axle. The diameter of the wheels on this axle was measured and the compensator adjusted accordingly. The generator, compensator & instrument were then checked for accuracy and found to be within 2% in either direction of rotation. The instrument thus recorded the speed of the tram as determined by the revolution of No.1 axle.
  4. Air pressure Meter. This instrument was connected directly to the brake cylinder and thus recorded the air pressure applied to the piston.
  5. Marker Pens. The magnets of both pens were connected in series with each other and then connected in series with the coil of Contactor B1. The pens thus indicated, one on each chart of the recorder, the time at which the Braking Contactors were energised.
- (b) Two D.C. Model Avometers set to 1200 volt range were connected (1) from Terminal B3-B4 to Terminal B1 & (2) from Terminal B3-B4 to Terminal B2. They thus indicated (1) the voltage generated by motors Nos. 1 & 3 & (2) the voltage generated by motors Nos. 2 & 4. These instruments were used to determine the balance in voltage between the two groups of motors. They were also used in an endeavour to determine the maximum peaks in the voltage generated, as the pointers of these instruments moved more freely than the pen of the recorder. After several days testing, it was realized that there were no cognizable differences between the readings from the two groups of motors so one meter was dispensed with.
- (c) Two Evershed & Vignolkes Millivolt meters were connected to two 250 amp shunts which were inserted (1) in the cable connected to Terminal B1 & (2) in the cable connected to Terminal B2. They thus indicated (1) the current flowing from motors Nos. 1 & 3 & (2) the current flowing from motors Nos. 2 & 4. These instruments were used to observe the balance in current between the two groups of motors. After several days testing it was realized that there were no cognizable differences between the readings from the two groups of motors and so one meter was dispensed with. Owing to the relationship between the millivolts drop over the shunts and the scale of the meters, it so happened that the reading

Appendix 3.

of the meters could be taken as a direct measure of the current in amperes of each motor.

- (d) Two Heuer Stop Watches measuring  $1/5$  secs. were used by two testers practised in the use of these instruments. The time was measured from the moment of hearing the signal to "Brake" until the tram came to a final stop.
- (e) A suitable brush dipped in whitewash was fitted to the front offside corner of the tram and so arranged that it was normally held against a spring so that it was clear of the roadway. A catch operated by a wire attached to the brake lever was arranged so that the first movement of the lever released the catch and the spring caused the brush to swing down and touch the roadway so as to leave a white mark at a spot closely corresponding to the point at which the brake was applied. A similar brush was mounted at each end of the tram so that the readings could be taken in each direction of travel.
- (f) Two 66 ft. surveyors chains, handled by two testers, were used to measure and to check the distance from the Brush mark to the point of standstill of the tram.
- (g) An Evershed and Vignolles Ducter having scale from 0-500 microhms to 0-5 ohms was used to measure the resistance of the fields and armatures of the motors. It was found that there was negligible difference between the readings thus obtained at the motor terminals and those at the reversing barrell in the controller, provided that the readings of motors Nos. 1 & 3 were taken at the controller at No.1 end and Motors Nos. 2 & 4 were taken at the controller of No.2 end. From the readings thus obtained with the motors at ambient temperatures and again at various times during and immediately after tests, it was possible to calculate the temperatures of fields and armatures.

A 1000V Bridge-Megger and decade box was used to measure the resistances of some of the contactor coils. From the readings thus obtained with the coils at ambient temperature and again at various times during and immediately after tests it was possible to calculate the temperatures of the coils.

- (h) Two 200°C Mercury in glass thermometers were used to determine the temperatures of wheel tires at various times during and immediately after tests. The thermometer bulb was held against the tire by a piece of plasticene, and was kept in contact until the reading became steady for 1 minute.

The same arrangement was used to determine the temperature of the resistor R3-R4 - this being the last section of the resistor to be shorted out during either motoring or braking.

On one day of the test, Wednesday 26th March, it was possible to obtain the use of an Ethon Surface Contact Pyrometer. The readings obtained from this instrument confirmed the order of temperature obtained from the mercury in glass instruments.

- (1) The travel of the piston of the air brake cylinder was marked before the commencement of the tests, and was checked at various times during the series of tests, and again after the tests were completed. In each case the original marks were used in determining the increase in travel.

PERSONNEL

The following personnel were engaged on the tests and carried out the observations as shown.

- Barry J.                    Flagman
- Coates I.                 Stopping Time A Stopping Distance A1.
- Collins E.                Amps Balance.
- Drummond G.             Supervise & Assistance (Temp) Tests & Stopping Distance B2.
- Foster G.                 Stopping Time B Air Pressure.
- Fouvy L.                 Murday Recorder; Resistance (Temp) Tests & Brake Piston travel.
  
- Hopkinson S.            Driver.
- Ken-Allen R.            Stopping distance B1
- Miller J.                Stopping distance B2.
- Steele C.                Records, Wimperis.
- White B.                 Volts Balance.

$$\frac{225}{100} \times \frac{100}{100} = \frac{12}{16} \times \frac{100}{1} = \frac{1200}{16} = 75$$

REPORT B.15/1/133

APPENDIX 5A.

BRAKE SHOE HARDNESS AND WEAR.

The recorded increase in piston travel for 200 miles on Tram 977 was  $1 \frac{3}{16}$ " with shoes of Brinell Hardness No.227, and the ten miles travelled were 960. This is compared with the increase in piston travel for a service tram for the first 200 miles with a set of new shoes. Report S3/1/2347 Fig.2 shows an increase of  $1 \frac{1}{2}$  inches for the first 200 miles with new shoes on a tram with similar brake rigging to Tram 977. However, the shoes in this case had a Brinell Hardness No.160. From Fig.12 of the same report it is found that the ratio of wear for shoes of B.H.N.227 against shoes of B.H.N.160 is 75/128. Thus the corrected piston travel for the service tram would be  $\frac{75}{128}$  of  $1 \frac{1}{2}$  inch. =  $\frac{225}{256}$ " or .8789. This corresponds closely with a check taken on Tram 928 at Preston Depot on 21st. and 22nd. June, 1954 in which an increase of  $\frac{7}{8}$ " was observed for  $18 \frac{1}{4}$  hours service with shoes of normal hardness but which had done more than 200 miles.

From this it is found that the brake shoe wear per ton mile on the tram with dynamic braking expressed as a percentage of that on a service tram with air brakes only was of the order of

$$\frac{256}{225} \times \frac{540}{960} \times \frac{19}{16} \times \frac{100}{1} = \frac{1900}{25} = 76\%$$

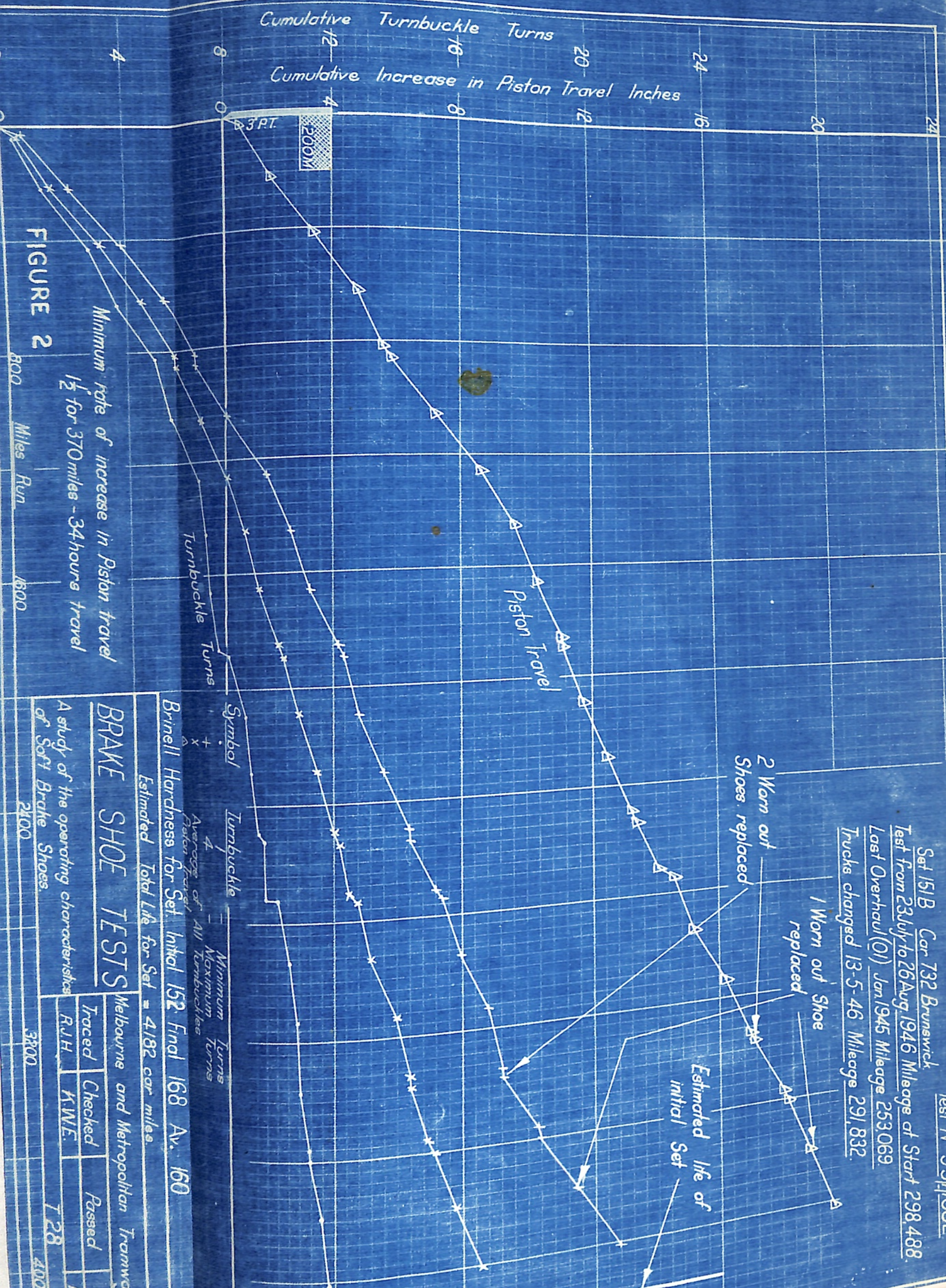


FIGURE 2

Minimum rate of increase in Piston travel  
 $1\frac{1}{2}$  for 370 miles - 34 hours travel

MILES PER POUND WORN OFF

Test No S311682  
 Set 151B Car 732 Brunswick  
 Test from 23 July to 26 Aug 1946 Mileage at Start 298,488  
 Last Overhaul (O) Jan 1945 Mileage 253,069  
 Trucks changed 13-5-46 Mileage 291,832

Symbol		Turnbuckle	
x	+	4	4
Average of All Turnbuckles		Minimum Turns	
Brinell Hardness for Set. Initial 152 Final 168 Av. 160		Maximum Turns	
Estimated Total Life for Set = 4182 car miles.			
<b>BRAKE SHOE TESTS</b>			
A study of the operating characteristics of Soft Brake Shoes.			
Traced	Checked	Passed	Date
R.H.	K.M.F.	T 28	17.2.47
2100	3700		4000

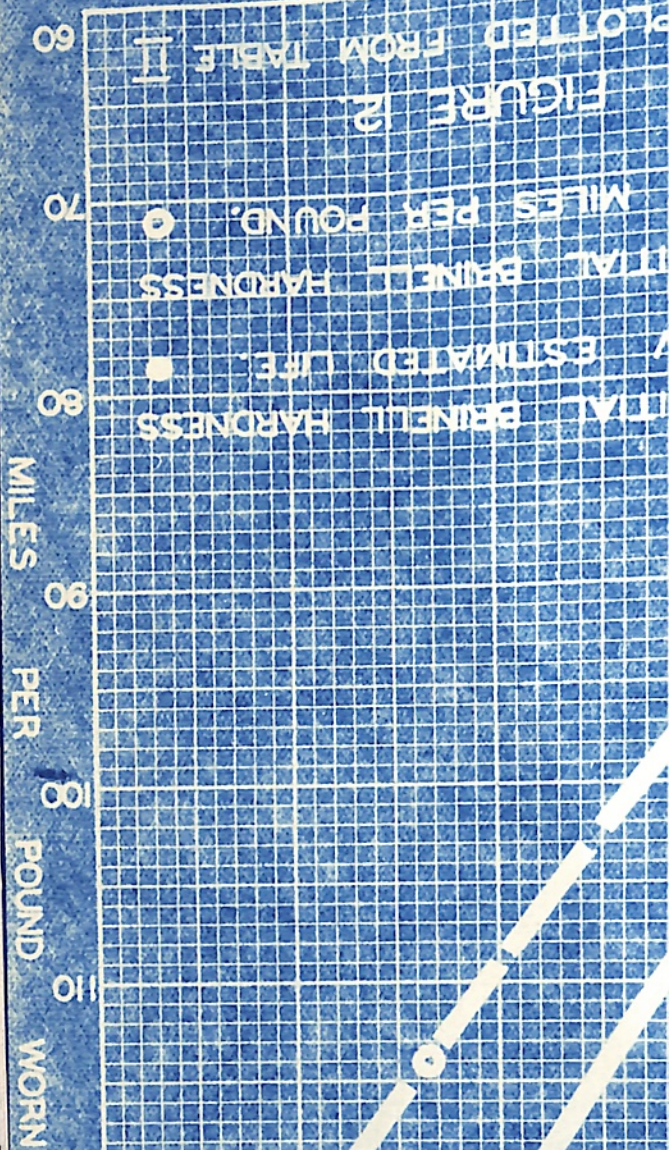
Melbourne and Metropolitan Tramways Board

of the at the a 100 lbs. sq. in. to fitting the the cause it is provided at end of Illinois

70  
70  
64  
56  
-----

... of 150 hours would be ...  
... is the average ...  
... and 15 ...  
... (periods)

RDNESS HD / 3000 . 10-11-50.  
210 220 230 240 250





CALCULATION OF TON-MILES PER TRAM

Tram 977 travelled a distance estimated at 200 miles and carried various loads as follow:-

Tests	1-42 and 126-155	74 miles at $\frac{1}{2}$ ton	= 37 ton-miles.
	43-62 and 100-125	56 miles at $3\frac{1}{2}$ tons	= 196 " "
	63-99	71 miles at $10\frac{1}{2}$ tons	= 728 " "

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The distances are estimated, to say 960 ton-miles.

Service Tram:

To obtain comparable figures for a service tram, reference is made to Report No. S5/1/2347 Fig.2 which relates brake shoe wear expressed in terms of piston travel, to miles run in service. In order to obtain ton-miles for a day's service running the following schedule of loadings was adopted. This schedule is based on figures obtained from the Traffic Branch giving probable loadings on the Brunswick lines in 1946 when the above report was prepared.

For trams on these routes, schedule speed was 11.69 m.p.h. with a running time of 70 minutes for the round trip. The route distance is 6.369 miles giving an average speed over the day of 10.92 m.p.h.

Schedule of Loadings

<u>Hours</u>	<u>Time (hrs.)</u>	<u>Estimated Loading (tons)*</u>	<u>Hour-tons</u>
0530-0545	0.25	0.25	0.062
0545-0630	0.75	2.5	1.875
0630-0715	0.75	2.0	1.5
0715-0800	0.75	5.0	3.75
0800-0845	0.75	2.0	1.5
0845-0930	0.75	4.0	3.0
0930-1230	3.0	2.0	6.0
1230-1400	1.5	2.5	3.75
1400-1530	1.5	3.5	5.25
1530-1615	0.75	4.0	3.0
1615-1700	0.75	3.0	2.25
1700-1745	0.75	6.0	4.0
1745-1830	0.75	2.0	1.5
1830-1915	0.75	1.5	1.125
1915-2000	0.75	4.5	3.375
2000-2300	3.0	1.5	4.5
2300-2345	0.75	4.0	3.0
2345-2400	0.25	0.25	0.062
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	18.5 hrs.		49.40

Thus the ton-miles per day of  $18\frac{1}{2}$  hours would be  $49.4 \times 10.92 = 540$  ton-miles.

\* (Note. The estimated loading is the average loading over the whole of each period and is not the peak load carried during those periods).

CONTACTORS.

It is recorded that 4 contactor coils failed during the tests. Of these, 3 coils were on Resistor Contactors R3, RR2, & RR3, and one was on Braking Contactor B4. Also the 4,500 ohm coil on R3 was changed for a 6,000 ohm coil. Subsequent to the tests all contactors used for Braking were changed to 6,000 ohm coils. The following data refers to the two types of coils. The resistance of the coils tested varied by + 4.6% to - 3.5% for 4,500 ohm coils and that of the 6,000 ohm coils tested varied by + 2.9% to - 3.6%.

	<u>4,500 type</u>	<u>6,000 type</u>
1. No. of coils tested.	10	10
2. No. of turns.	36,000	46,000
3. Gauge of wire.	37 SWG	34 B&S
4. Size of wire.	.0068 in.	0.0063 in.
5. Area of wire.	36x10 <sup>-6</sup> sq.ins.	31x10 <sup>-6</sup> sq.ins.
6. Current density.	3700 amps/sq.in.	3260 amps/sq.in.
7. Cylindrical radiating surface.	34.9 sq.ins.	34.9 sq.ins.
8. Resistance (average of 10 coils).	4,520 ohms.	5,945 ohms.
9. Current @ 600 V (av).	0.133 amps.	0.1009 amps
10. Ampere turns " " "	4,788	4,641
11. Watts " " "	79.8	60.5
12. Watts radiation per sq.ins.(av).	2.29	1.73

Some contactors were then tested for pick up and drop out current and pick up and drop out times. There were 10 contactors of each of two types.

- (A) One complete car set of RC2 equipment LS1, RR2, RR3, RR4, LS2 & JR, R2, R3, R4, G.
- (B) Contactors on Tram 977 - B1, B2, B3, B4, RR2, RR3, RR4, R2, R3, R.4.

Set (A) were 4500 ohm coils and were tested in the Laboratory.

Set (B) were 6000 ohm coils and were tested in situ.

The same equipment and procedure was used in both sets of tests.

The following figures were obtained.

R.C.2 EQUIPMENT.

Factor No.	PICK UP					DROP OUT									
	Contact V	m/A	Full V	m/A	Time m/A	Coil Data			Armature		Full		Cont.Full		
	V	m/A	V	m/A	m/A	V	m/A	ohms.	V	m/A	V	m/A	m/S	m/S	
R	225	47.5	305	64.5	140	600	125	4,800	130	27.0	75	15.0	64	108	
RR2	180	42.0	370	86.0	118	600	135	4,450	150	33.0	70	15.5	64	150	
RR3	180	42.0	335	78.5	126	610	140	4,350	150	35.0	68	15.5	64	126	
RR4	185	43.0	390	89.5	124	600	130	4,620	167	36.5	75	17.0	54	128	
LS1	195	44.0	475	105.0	130	625	132	4,730	152	33.0	90	20.0	64	150	
RR2	180	41.0	275	62.5	120	600	133	4,510	150	33.5	67.5	15.5	68	96	
RR3	180	42.0	265	63.0	124	610	139	4,390	120	28.8	65	15.5	58	128	
RR4	205	47.0	315	72.0	126	600	134	4,480	150	36.0	70	16.0	60	126	
LS2	175	42.5	325	80.0	132	600	135	4,450	125	32.0	60	15.0	70	96	
LS2	185	40.0	325	74.0	116	600	133	4,510	170	39.0	65	15.0	58	124	

Contact pressure with full excitation was 16 lbs. <sup>+</sup> 1 lb.in each case.

DYNAMIC BRAKING EQUIPMENT.

B1	170	29	265	46	134	585	102	5,730	85	15	75	14	-	70
B2	160	27	285	43	130	560	96	5,830	-	-	85	15	-	70
B3	165	28	215	35	120	590	96	6,140	-	-	85	13	-	64
B4	170	28	270	45	136	585	99	5,910	145	24	85	15	-	56
RR2	180	28	210	33	-	570	94	6,060	110	19	100	17	-	-
RR3	180	27	250	39	-	575	94	6,120	90	16	80	14	-	-
RR4	160	27	215	36	-	570	98	5,820	100	18	80	15	-	-
R2	175	27	235	37	-	580	96	6,040	85	17	-	-	-	-
R3	165	25	220	36	-	570	94	6,060	80	15	-	-	-	-
R4	175	28	280	45	-	570	96	5,940	95	17	-	-	-	-

On examination it was found that the magnetic circuit of the contactors was inefficient because of relatively large air gaps at the hinge. There was a strong leakage field in this area when the coil was energized. The following comparison was made between a 4500 ohm contactor and one of the PCC car having similar duty, i.e. 100 amp capacity.

	T.B.4,500	T.B.6,000	P.C.C.
Watts	79.8	60.5	27
Pick up volts %	56.4	47.1	37
Contact pressure	16 lbs.	11 lbs.	15-25 lbs.
Coil area	34.9 sq.in.	34.9 sq.in.	31.4 sq.in.
Watts/sq.in.	2.29	1.73	.86
Watts/sq.in.as %	266.0%	201%	100%

Examination of failed coils indicated that the failures were due to excessive heating with consequent movement of end turns thus permitting overvoltage between end turns especially during transients due to switching. These transient high voltages appear to puncture the insulation and fuse turns from different layers together. The resultant decreased resistance would set up further heating and the decreased number of turns increased the volts per turn which would cause further failures on subsequent switching. These troubles are avoided if (1) the coils are designed for a lower voltage and used with series resistors. (2) the spool is divided into 2 or more sections as at present. (3) the coil is layer wound with special care taken to ensure that end turns cannot slip down. (4) the layers are insulated with 003" Cellulose Acetate every 10 layers.

*WJG*  
for T.E. 10/19/54