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MINES BRANCH INVESTIGATION REPORT IR 74-9

EXAMINATION OF A WHEEL AND AXLE ASSEMBLY REMOVED FROM TANK CAR UTLX 13695 (File No. 31385.2344)

by

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PHYSICAL METALLURGY DIVISION

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SUMMARY OF RESULTS

The nondestructive examination of the wheels and axle sections submitted included visual examination, hardness tests, and detailed measurements of the wheel bores and the wheel seats.

The hardness measurements showed that the rims had been heat treated and probably fulfilled the requirements for a Class C wheel.

The measurements of the bores and wheel seats showed several conditions which engendered criticism of the machining and confirmed that the wheel had been loose for a period of time in service. The excessive taper in the wheel seat of R1, combined with other machining characteristics, was deemed to have played a significant role in the loosening of this wheel.

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FIGURES (cont.)

INTRODUCTION

A letter dated July 25, 1973, was received from Mr. Keith Thompson, Counsel to the inquiry into the derailment and wrecking of tank cars on the TH&B Railway near Welland, Ontario, on December 1, 1972. This letter describes briefly the progress of the inquiry at that time and confirms a request for assistance in furthering this inquiry by conducting certain procedures at this Branch. This request was made informally by discussions with Mr. E. J. Hase, Director of Operations of the Railway Transport Committee and supported in the July correspondence by Mr. J.A.D. Magee, Commissioner appointed to conduct the inquiry.

The inquiry concerning the derailment has concentrated on a set of wheels and an axle, specifically described as wheels number 566Z486877MWCR (L1) and 566Z96877MWCR (R1), taken from tank car UTLX 13695. This car was near the forward end of the derailed section of a unit train made up of tank cars carrying acid, and the wheel in question was described in volume 1 of the inquiry transcript as "the leading wheel of the trailing truck". One of the wheels (R1) had moved off the wheel seat on to the reduced central section of the axle. The second wheel of the set was subsequently pressed off during the investigation and the axle was cut in half. The two wheels and the two sections of the axle were received at the Mines Branch in November 1973.

This stage of the examination included a visual examination, detailed measuring procedures, and any nondestructive tests that might be appropriate to establish as much information as possible prior to destructive tests which would be required for a more complete metallurgical examination.

Based upon the results of the inquiry and prior investigations conducted, theories had been developed concerning the cause of the derailment which had not met with unanimity among those organizations directly involved. To help resolve this issue certain suggestions were proposed by the Railway Transport Committee as guidelines within which this investigation should be conducted to help resolve those points still unsettled by the inquiry. The non-destructive phase of this work with which this report is concerned is outlined as follows:

1. (a) Bore diameter of wheel determinations - with at least three positions and 13 measurements each.

   (b) Wheel seat measurements on axle - with at least three positions, 13 diameter measurements each.

2. Bore radius determinations from the centre line - same locations as before - making 13 measurements every 60°.

3. Determination of "out of roundness" of (a) tread (b) flange (c) hub, and any distortion in the wheel web.

4. Determination of surface roughness on both wheel bores and on both axle seats in a direction parallel to the length of the axle.

The wheel seat of the axle and the bore of the wheel which had separated appeared darker or more tarnished than those surfaces which had been exposed by pressing off the opposite wheel. The surface of the former appeared smoother, or more polished, than the latter and it was evident, without using visual aids, that the dimensions were not uniform. Some of this lack of uniformity appeared to be due to the wheel having come off and received severe deformation by contact with some other object. However, much of the dimensional nonconformity appeared to be due to other causes. This will be further elaborated by the detailed measurements described subsequently.

HARDNESS MEASUREMENTS

Hardness measurements were taken with a portable scleroscope. This instrument usually gives greater scatter than a Brinell tester, but the use of a more sensitive instrument would have required cutting the wheels and wheel seats. It was understood that these wheels were made to specification AAR M-107-64 and the axle to AAR M-101-64, Grade F. The letters CR on the wheels show that they were made to comply with Class C service, rim treated. This means that the entire wheel was heated and the rim was quenched. Following suitable cooling the entire wheels would have been charged into a furnace and reheated (tempered) to provide the desired mechanical properties for this Class. The axle, Grade F, normally would have been double normalized and tempered to comply with the requirements of the specifications.

The hardness values obtained on the rims of the wheels and on the wheel seats were as follows when converted to Brinell* from Shore readings. The wheels were ground lightly in the area where the readings were taken.

R1		Axle	
Rim (Flange Side)	Hub	Wheel Seat (R1)	Centre of Axle
Range - 301-331	Range - 200-219	143-181	
Average - 302	Av. - 208	Av. - 162	150

L1			
		Wheel Seat (L1)	Centre of Axle
Range - 302-336			
Average - 311		162 only (4 readings)	150

Hardness values of 150 to 160 Brinell could be consistent with a Grade F axle as described in M-101-68. However, the tempering temperature was not provided, and slight variations dependent upon this temperature and upon the actual carbon content could be anticipated.

The hardnesses of the rims were similar by this method, although both averages were less hard than the minimum required for Class C wheels but harder than the minimum required for Class B. It is possible that some decarburization remained to which the scleroscope would be quite sensitive. The readings show that the rim did receive a heat treatment and the likelihood remains that the hardness values are on the low side of the true value.

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*Brinell readings converted from Shore (scleroscope readings) are not completely reliable, but the scleroscope was the most suitable instrument available.

DIMENSIONAL MEASUREMENTS

The following physical dimensional measurements were taken.

(a) Wheel seat L1 diameters at 120° intervals in 1/2-in. increments along the seat length
(b) Wheel seat R1 diameters also at 120° intervals in 1/2-in. increments along the seat length
(c) Wheel bore L1 diameters at 120° intervals in 1/2-in. increments along the bore length
(d) Wheel bore R1 diameters also at 120° intervals in 1/2-in. increments along the bore length
(e) Wheel bore R1 total indicator reading (TIR) variations at 60° intervals in 1/2-in. increments along the bore length
(f) Wheel seat L1 surface roughness readings
(g) Wheel bore L1 surface roughness readings
(h) Wheel seat R1 surface roughness readings
(i) Wheel bore R1 surface roughness readings
(j) Wheel R1 TIR variations at various locations between the wheel hub and rim.

Method

In order to provide easy identification of the positions where dimensions would be obtained, a convention was adopted throughout this inspection procedure. Radial positions were designated as alphabetic stations and longitudinal positions were designated as numerical locations. A schematic illustration of the designated measuring positions is shown in Figure 1.

Both wheel seats, R1 and L1, had marked upon them three longitudinal lines 120° apart. On these lines, at 1/2-in. increments from the bearing end of the seat, cross lines were constructed. Each of these cross lines was to be a location point at which diameter measurements would be taken. Using a conventional micrometer caliper which had been calibrated against a set of gauge blocks, a series of diameter readings was recorded. These recordings for both the L1 and R1 wheel seats are shown in Tables 1 and 2.

Wheel L1 was then selected and three stations 120° apart were arbitrarily chosen, and the locations starting from the front of the wheel along these three stations were marked off. In order to be able to accurately measure the diameter, a dial-read Alina W08 bore gauge was employed. This gauge is capable of measuring bore diameters from 2 to 12 in. with depths of up to 8 in. The dial gauge is graduated in 0.0001-in. divisions and has a total recordable travel of 0.140 in. There is incorporated in this gauge a spring loaded shoe which causes the gauge to automatically seek the diametrical axis of the hole, and, on rocking the gauge, the smallest reading recorded on the dial is the measure of the bore diameter. A photograph of the gauge is shown in Figure 2. Again, as with the micrometer caliper, this bore gauge was calibrated against a set of gauge blocks. The bore diameters for the L1 wheel are shown in Table 3; although the dial gauge is capable of measurement to four decimal places the diameters shown in the Table are rounded off to three significant figures.

Wheel R1 was then marked out for measuring, using the same procedures as for the L1 wheel except that, instead of choosing arbitrary stations, station A was selected as that station which passed through the point of greatest bore deformation. The other stations, namely C and E, were then located at 120° and 240° positions respectively from station A. The same technique of rocking the bore gauge was attempted but, because of the bore deformation, it was difficult to actually record the true diameter. In order to overcome this problem the rocking technique was dispensed with and each end of the bore gauge was supported on a series of 1/2-in. high blocks and the measuring anvil was aligned perfectly horizontal. By successively removing a pair of 1/2-in. blocks and recording the diameter readings, we were able to obtain, accurately, the location points as marked out on the bore. The set-up that was used for these series of measurements is illustrated in Figure 3 and Figure 4, together with the micrometer used for the seat measurements and the gauge block equipment for calibrating the bore gauge. Again, the bore readings have been reduced to three significant figures and are shown in Table 4.

The wheel R1 was then mounted on the rotary table of a San Rocco 3-in. Horizontal Boring Mill and the tread portion of the wheel indicated to give a zero reading. It was necessary that this portion of the wheel be taken as the reference surface, as it was felt that the bore contained too many variations to be used for this purpose. When the wheel had been adjusted to give a zero tread reading it then was concentric with the axis of the rotary table and a dial indicator with 0.001-in. graduations was mounted in the head of the machine so that TIR measurements of the bore could be obtained to show the bore profile. A photograph of this operation is illustrated in Figure 5.

The point of greatest deformation (in this case station A, location 1) was used as the bench mark and all the readings were the variations from this point. One set of readings was taken at location 1 going from stations A to F, the indicator was then positioned at location 2 and a set of readings taken from stations A to F. After a total of 78 measurements was recorded in this manner, the indicator was repositioned on the bench-mark to ensure that no accidental movement had taken place of either the table or the wheel. As a double check against the recorded measurements, another set of readings was taken, this time starting at station A location 1 and moving successively along station A to location 13. The table was rotated so that station B was aligned for measuring and a set of readings taken from location 1 to location 13. This procedure was continued until all the previous 78 TIR readings had been duplicated. The two sets of readings coincided within the limits of resolution of the dial indicator. The result from these sets of readings is shown in Table 5. Where there is a discrepancy of 0.001 in. between the first and second set of readings, only the even figure has been recorded.

All those values shown in Table 5 have been plotted graphically, as shown in Figure 6. The curves in Figure 6 show the bore profile through each station and the reference line is in effect the bench mark position.

With the wheel still clamped in the same position, a series of TIR readings was taken to determine the flatness of the wheel. As with the previous test, the tread portion of the wheel was used as the reference surface. The readings recorded at their respective positions are shown in Table 6. The station readings were located at approximately the mid-point of the area being measured.

For comparison purposes, surface roughness readings were taken on both the R1 and L1 wheel seats and wheel bores. For this inspection procedure, a Taylor Hobson Model 3 Talysurf Surface Measuring Instrument, as illustrated in Figure 7, was used. During all the series of roughness measurement readings, the calibration of the instrument was checked after each change of range. The stylus of this instrument was set to traverse first across the longitudinal scratch pattern of the L1 wheel seat; this scratch pattern being generated when the wheel and seat were separated. The instrument was then set to measure longitudinally across the machining marks. A graphical recording of the L1 wheel seat produced by the above instrument is shown in Figures 8(a) and 8(b). The magnification on the vertical scale is 1000 and on the horizontal scale 20; this means that each small vertical division represents 0.0001 in. and each small horizontal division represents 0.01 in. on the component being measured. A similar graphical pattern of the surface of the R1 wheel seat to the same scales is shown in Figures 9(a), 9(b) and 9(c). On this particular unit a satisfactory portion of the wheel seat extended beyond the wheel, so an extra roughness reading was taken at this location.

The instrument was then set up to measure the surface roughness of the machining marks in the wheel bores. The stylus of the instrument was now riding over the scratch pattern in the bore moving parallel to the wheel axis. Graphical recordings of the surface of the L1 wheel bore and the R1 wheel bore are shown in Figures 10 and 11 respectively to the same scales used for the wheel seats.

As well as producing a graphical print-out of the surface profile, the Talysurf is also able to provide a roughness reading in micro inches (0.000001 in.). This roughness reading is the Centre Line Average (CLA) which is the variation in the average of the peak and valley heights above and below the centre line of the roughness profile. The centre line of the roughness profile is automatically determined by the instrument, as is the arithmetical or CLA average. The figures obtained for the roughness readings are shown in Table 7. As the instrument in question can only read up to values of 200 μin., then the rougher surfaces are only shown as exceeding 200 μin.

OBSERVATIONS

The manufacture of the wheels and axles is governed by the Association of American Railroads Wheel and Axle Manual. Section 1 of the eighth edition of this manual covers "Mandatory Rules Governing Wheel Shop Practice".

Rule 1.16 lays down a maximum wheel seat taper of 0.002 in. with the small diameter of the taper at the journal end of the axle. This rule also specifies the assembly conditions for tapered seats and bores.

Rule 1.26 specifies the same amount of taper for the wheel bore.

Rule 1.27 does not give specific interference fits but only offers a guide of 0.001 in. per inch of wheel seat diameter. For steel wheels, the determining parameter for acceptable wheel fit is the mounting pressure as defined in Figure 2C3 of the AAR manual. Section 2 of the AAR manual gives the Recommended Wheel Shop Practice and Paras. 2A.10 and 2B.11 of this Section covers, amongst other things, the surface finish of the wheel bores and seats. These paragraphs give only qualitative guidance rather than specifying surface roughness values in micro-inches.

Para. 2A.22 of Section 2, eighth edition, gives a warning of the danger that a tapered wheel seat can lead to a loose wheel.

Para. 2B.14 of the eighth edition states the three conditions that are necessary for a tight wheel fit. Paraphrased, these three conditions are that the wheel bore be within the prescribed tolerances, the wheel seat be within the prescribed tolerances and the fit comply with Rule 1.27. Attention is drawn to Table 2 of this report which shows a maximum taper of 0.008 in. for the R1 wheel seat which is well in excess of that permitted under mandatory Rule 1.16 and is, in fact, 400% of the maximum allowable taper. For comparison purposes the L1 wheel seat has a maximum taper of 0.003 in. which is just beyond the mandatory tolerance. The maximum taper on the bore of the L1 wheel is 0.004 in., which is beyond that permitted, but, from a scrutiny of the values in Table 3 of this report, the deviation of the bore from the specifications is not too great. The bore of the R1 wheel is considerably distorted and, from the profiles shown in Figure 6, has acquired a bell-mouthed profile. This bell mouthing, it is felt, could occur if the wheel first became loose on its seat then proceeded to rock during its normal working conditions. It is felt that the very heavy distortion (the point at which the bench mark was located) was caused when the wheel left the seat and "cocked" across the body of the axle whose diameter is smaller than that of the wheel seat. The heavy deformation in the wheel bore at location 1 station A has a complementary deformation on the opposite side of the wheel at location 13 station D. The localized nature of this deformation, together with its position, lends support to the theory that this occurred after the accident and was due to the wheel cocking across the axle body.

The surface roughness readings were made over surfaces that had been assembled under load. It is difficult therefore to assess the surface roughness values in the original machined but yet unassembled state; however, the roughness readings would be no less than those shown in Table 7. The recordings in the transverse direction on wheel seats L1 and R1 are shown for comparison purposes only to illustrate the extent of the longitudinal scratch marks. The scratch marks generated when removing the L1 assembly are more pronounced than on the R1 assembly. If, as previously suggested, the R1 wheel did in fact rock on its seat, then a burnishing effect would take place and this is evidenced by the difference between the two longitudinal direction readings for this wheel. The portion of the seat which was not in contact with the wheel bore clearly shows the even pitch of the toolmarks. A small area that still contained toolmarks on the L1 seat was measured for surface roughness and the value obtained is recorded in Table 7, but there is no way now of knowing what the roughness was prior to assembly.

The roughness readings taken from the wheel bores are illustrated in Figures 10 and 11. The roughness value for the L1 wheel is less than for the R1, but by how much we don't know as the roughness for the R1 wheel was beyond the range of the instrument used. It is interesting to note that a "shadow" of the waviness pattern of the L1 wheel bore is visible on the L1 wheel seat; due to an oxide film on the R1 seat such a pattern is impossible to see. Until such time as quantitative values for roughness are given for wheel bores and seats, the surface finishes specified are really only guidelines, and are not considered to be very good.

From the evidence presented it seems reasonable to believe that three conditions, either separately, or in combination with one another, caused the R1 wheel to come loose from its seat.

(a) the excessive taper on the wheel seat

(b) the degree of surface roughness of the wheel seat, assuming that it was the same as that measured on the residual unfitted area

(c) the degree of roughness of the wheel bore

RDMcD/DMN/sg

TABLE 1

Wheel Seat Diameters (in.)

Wheel Seat UTLX 13695 L1

Location	Station X	Station Y	Station Z
1	8.749	8.751	8.749
2	8.750	8.751	8.750
3	8.750	8.751	8.750
4	8.750	8.751	8.750
5	8.751	8.751	8.750
6	8.751	8.752	8.750
7	8.751	8.752	8.751
8	8.751	8.752	8.751
9	8.752	8.752	8.751
10	8.752	8.753	8.752
11	8.752	8.753	8.752
12	8.752	8.753	8.752
13	8.752	8.752	8.752
14	Too rough to obtain accurate measurements		
15	Too rough to obtain accurate measurements		

TABLE 2

Wheel Seat Diameters (in.)

Wheel Seat UTLX 13695 R1

Location	Station X	Station Y	Station Z
1	8.750	8.752	8.751
2	8.753	8.752	8.753
3	8.753	8.753	8.755
4	8.754	8.754	8.754
5	8.754	8.755	8.756
6	8.755	8.755	8.756
7	8.756	8.756	8.756
8	8.756	8.756	8.756
9	8.756	8.756	8.756
10	8.756	8.756	8.757
11	8.757	8.757	8.758
12	8.757	8.757	8.758
13	8.757	8.758	8.758
14	8.757	8.757	8.757
15	8.754	8.737	8.735

TABLE 3

Bore Diameters (in.)

Wheel UTLX 13695 L1

Location	Station A	Station C	Station E
1	8.738	8.740	8.740
2	8.740	8.739	8.739
3	8.739	8.740	8.739
4	8.739	8.741	8.740
5	8.739	8.739	8.739
6	8.740	8.739	8.741
7	8.739	8.741	8.740
8	8.741	8.740	8.740
9	8.740	8.742	8.741
10	8.741	8.743	8.741
11	8.741	8.741	8.742
12	8.742	8.743	8.743
13	8.742	8.743	8.743

TABLE 4

Bore Diameters (in.)

Wheel UTLX 13695 R1

Location	Station A	Station B	Station C
1	8.877	8.793	8.868
2	8.843	8.784	8.832
3	8.819	8.790	8.805
4	8.798	8.774	8.790
5	8.788	8.767	8.780
6	8.779	8.764	8.775
7	8.777	8.762	8.773
8	8.789	8.762	8.772
9	8.785	8.764	8.777
10	8.797	8.768	8.783
11	8.809	8.774	8.790
12	8.824	8.776	8.809
13	8.840	8.781	8.849

TABLE 5

Bore Radius Variations (in.)

Wheel UTLX 13695 Rl

Location	Station A	Station B	Station C	Station D	Station E	Station F
1	0	0.020	0.156	0.166	0.151	0.096
2	0.036	0.068	0.156	0.161	0.148	0.102
3	0.066	0.092	0.156	0.160	0.146	0.112
4	0.090	0.112	0.150	0.156	0.148	0.121
5	0.111	0.126	0.149	0.147	0.142	0.128
6	0.126	0.134	0.148	0.142	0.140	0.135
7	0.136	0.141	0.145	0.135	0.136	0.141
8	0.145	0.146	0.143	0.125	0.130	0.143
9	0.149	0.149	0.140	0.115	0.126	0.145
10	0.154	0.152	0.129	0.100	0.119	0.149
11	0.160	0.156	0.124	0.082	0.108	0.152
12	0.162	0.159	0.116	0.065	0.092	0.153
13	0.167	0.159	0.106	0.046	0.060	0.157

TABLE 6

Flatness Measurements (in.)

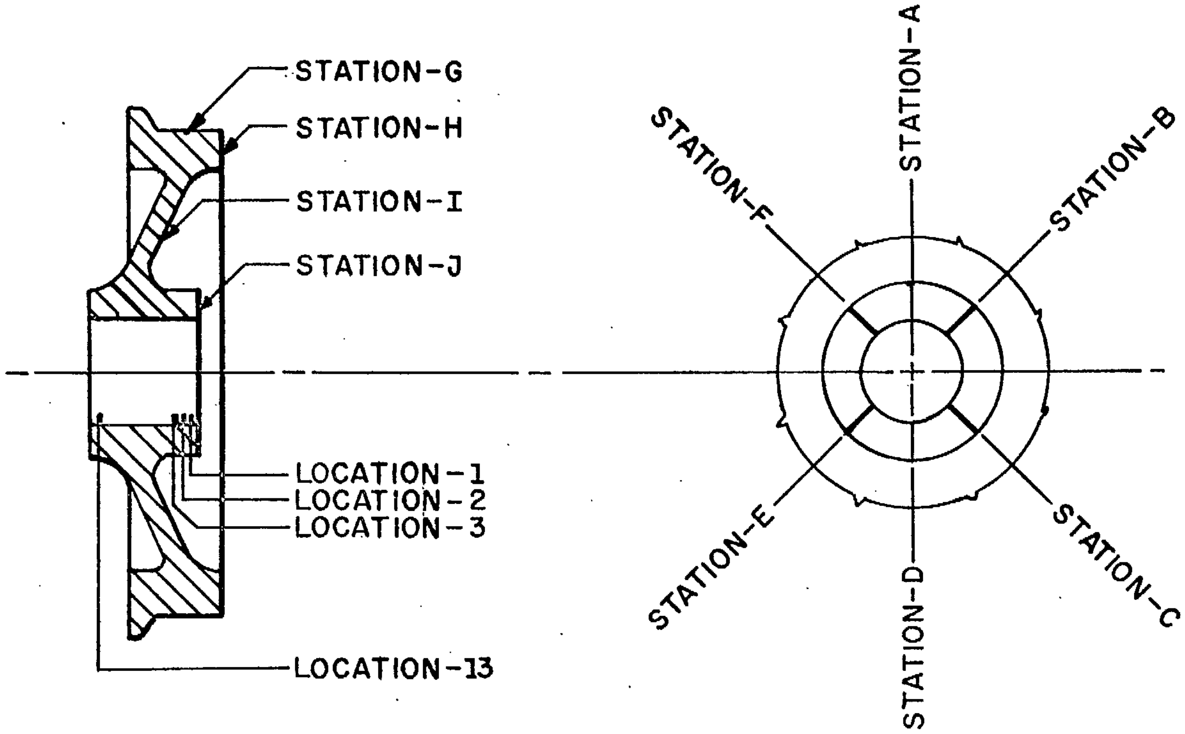
Wheel UTLX 13695 R1

Station	Station G	Station H	Station I	Station J
A	0	0	0	0
B	0	+0.005	+0.013	+0.001
C	0	+0.008	+0.029	-0.005
D	0	+0.004	+0.031	+0.001
E	0	+0.002	+0.020	-0.006
F	0	-0.001	+0.003	-0.008

TABLE 7

Surface Roughness Measurements

Location	Roughness (micro inches)
L1 Wheel Seat	42
R1 Wheel Seat (Inner end of seat between locations 14 and 15)	Exceeded 200
R1 Wheel Seat (Centre of seat)	52
L1 Wheel Bore	140
R1 Wheel Bore	Exceeded 200



LAYOUT OF MEASURING POINT CO-ORDINATES

FIGURE 1

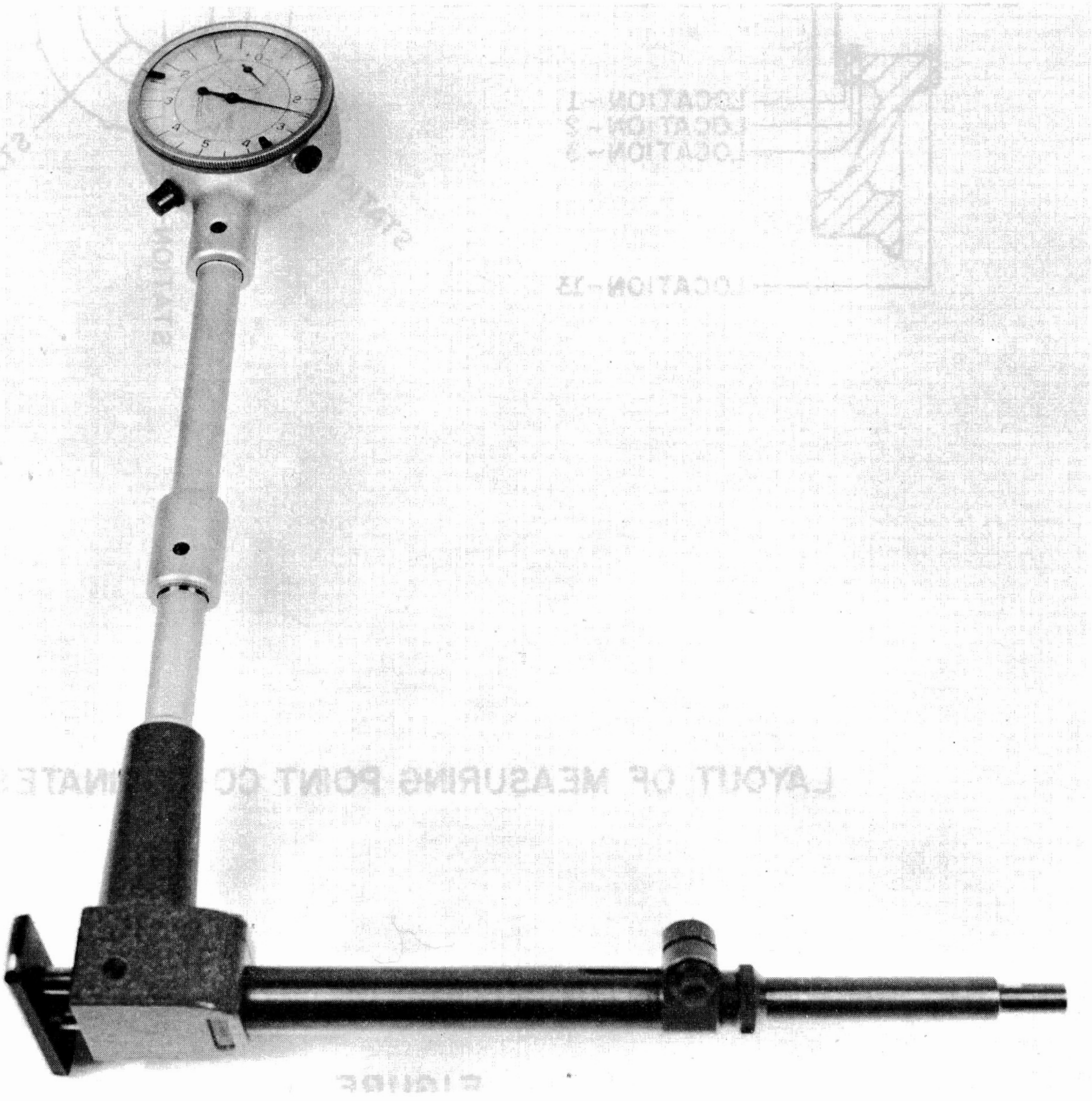


Figure 2. Alina W08 bore gauge.

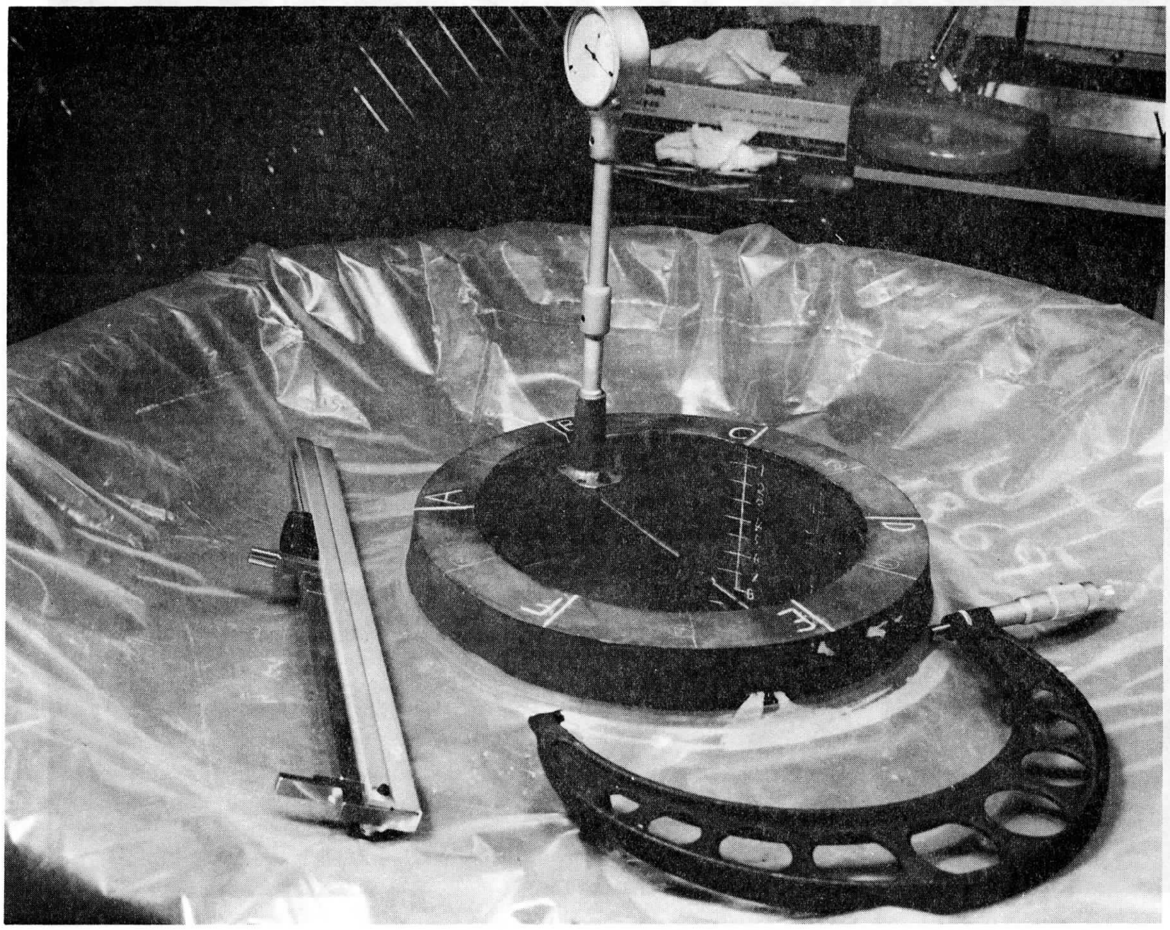


Figure 3. Measurement of R1 wheel bores.

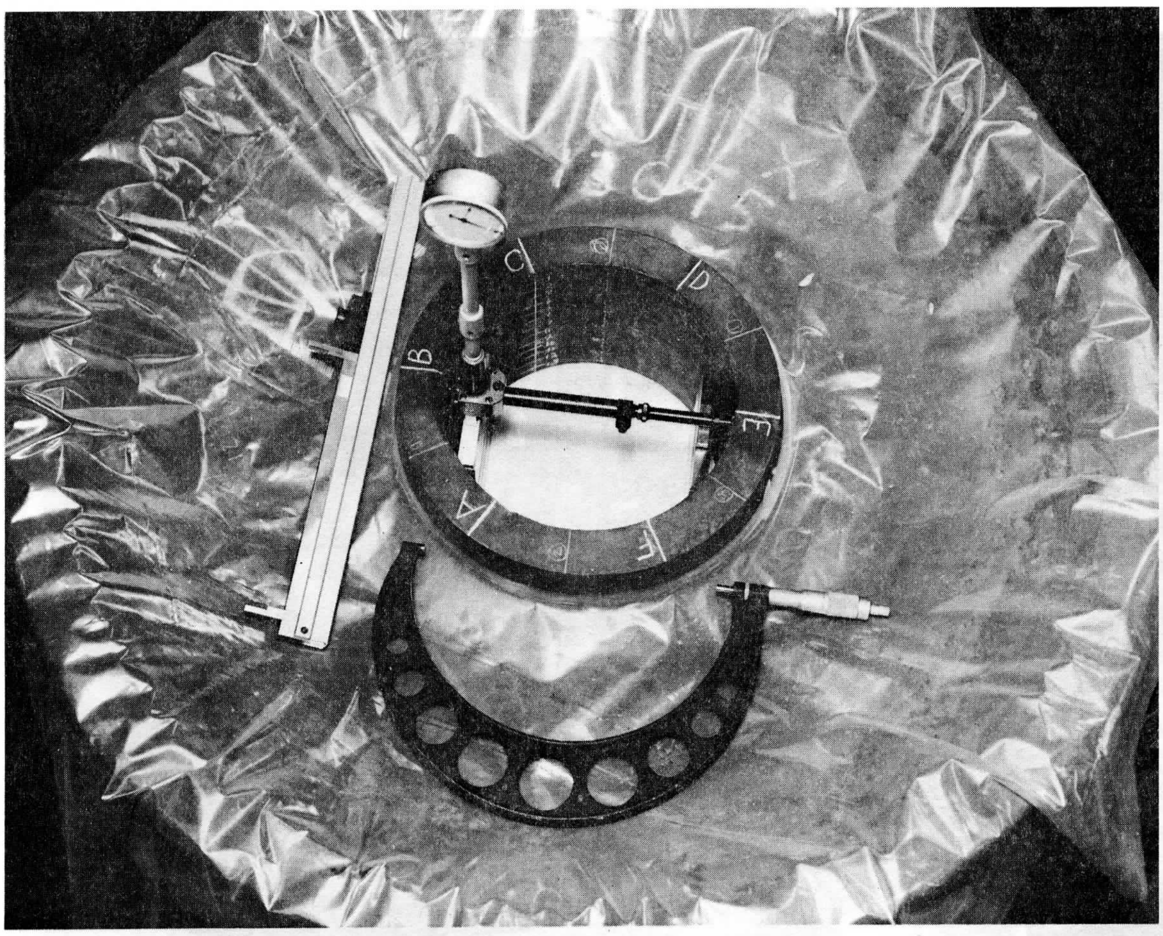


Figure 4. Measurement of Rl wheel bores.

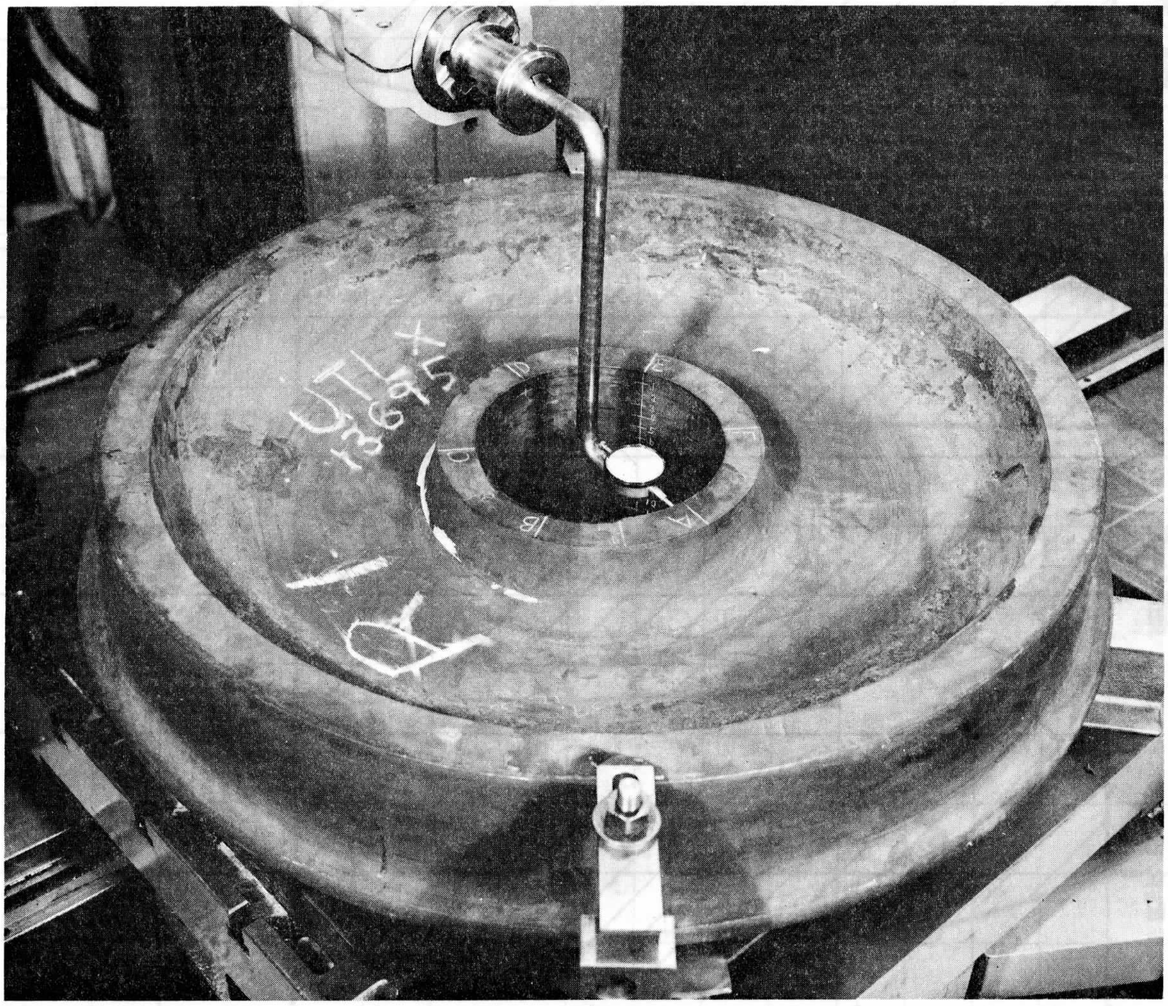


Figure 5. Measurement of R1 bore radius variations.

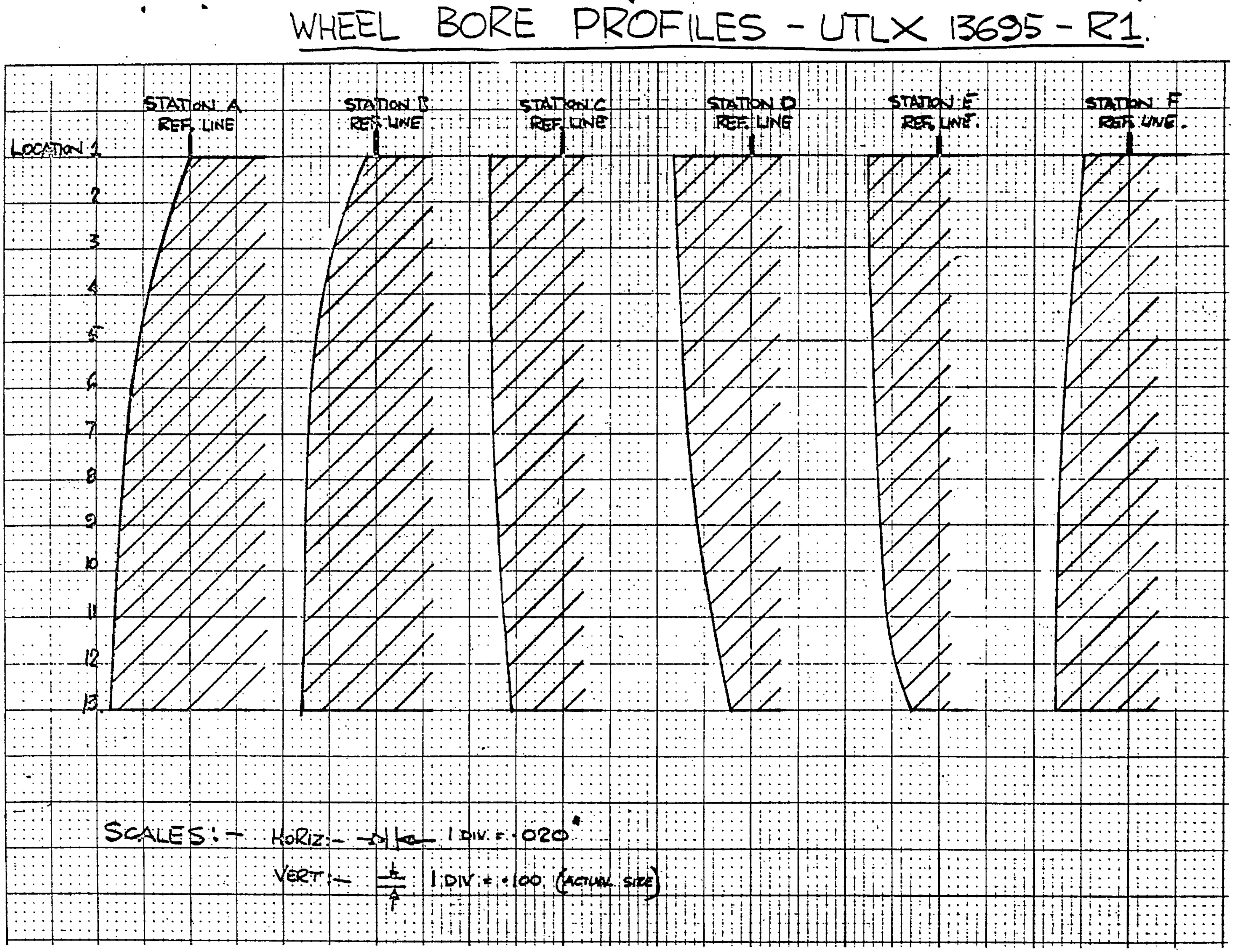


Figure 6. Wheel bore profiles - UTLX 13695 - R1.

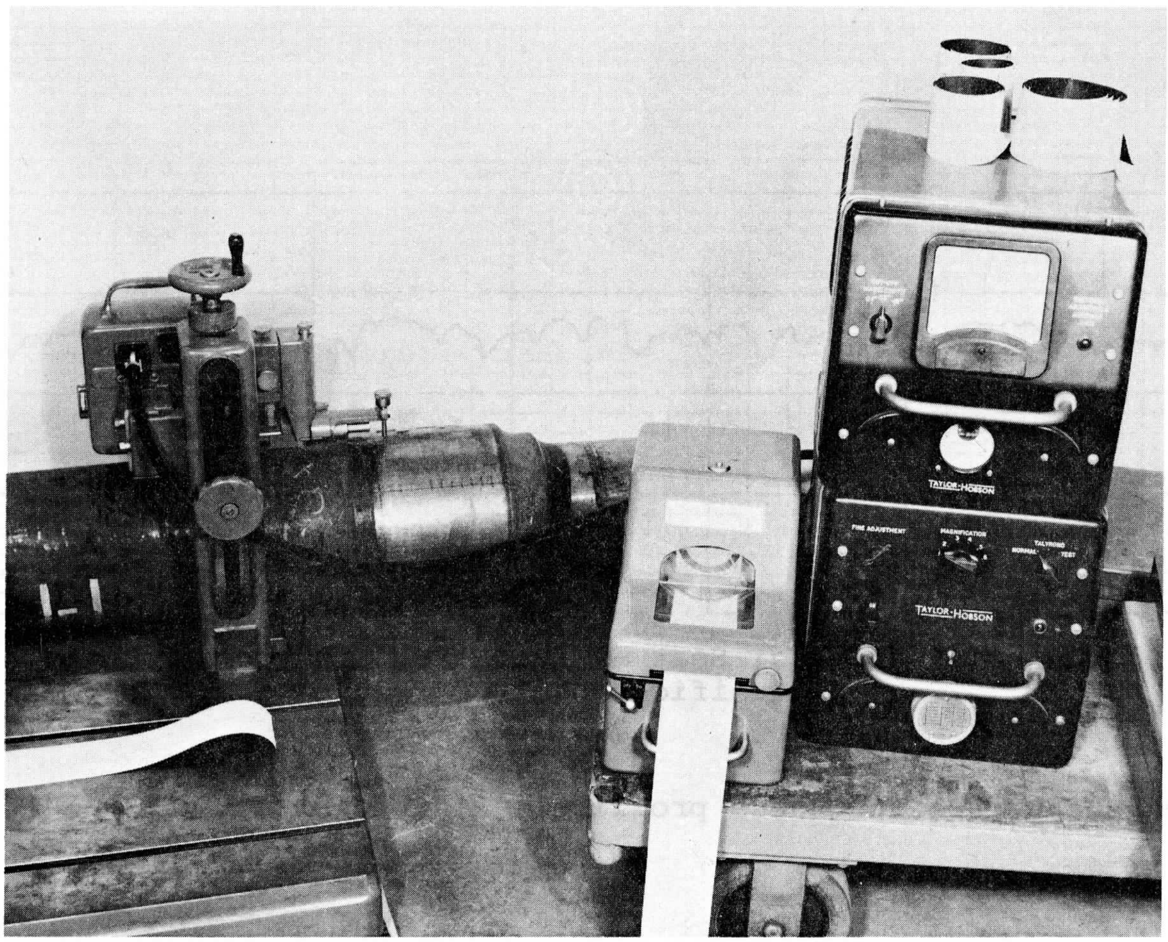
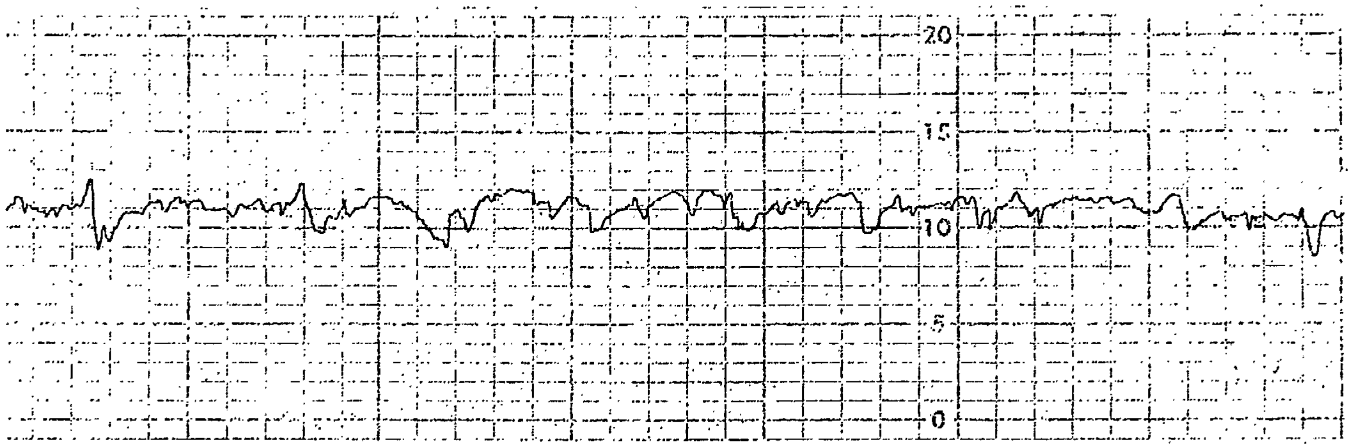
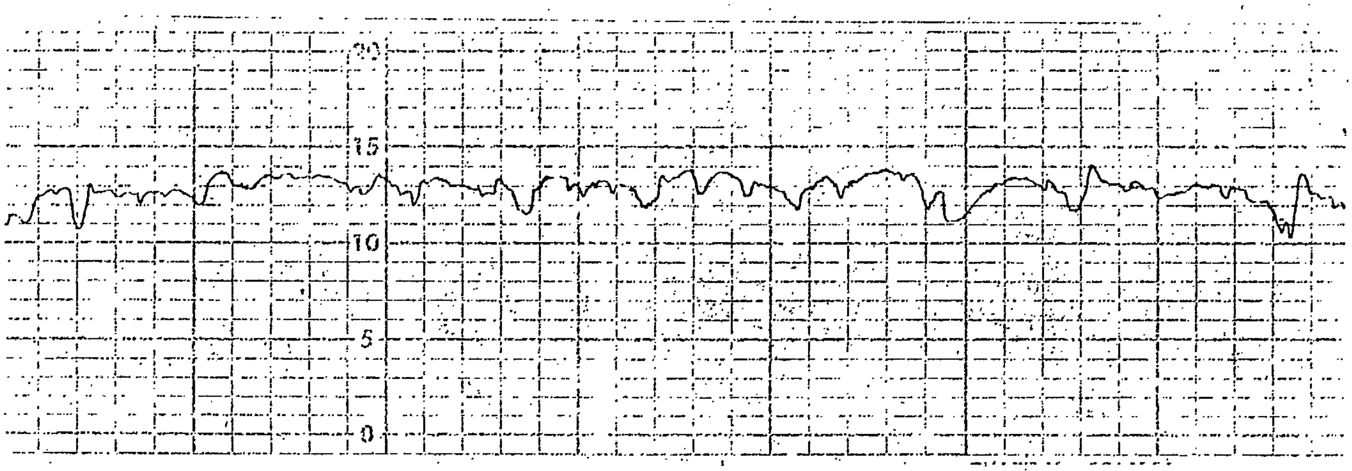


Figure 7. Taylor-Hobson, Model 3, 'Talysurf'.

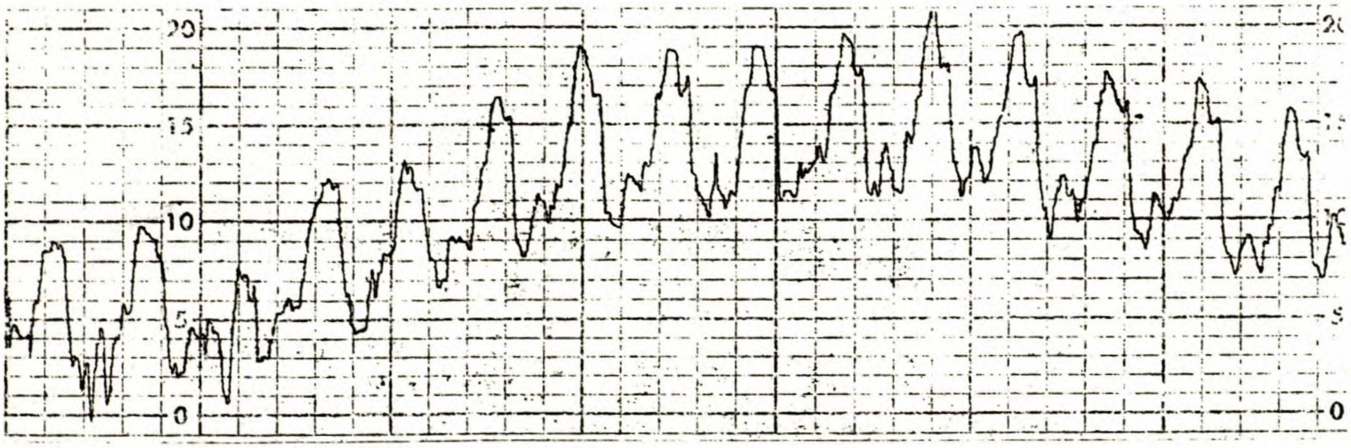


(a) L1 Wheel Seat - Longitudinal Direction
Magnification 1000 x 20
CLA 42 μin.

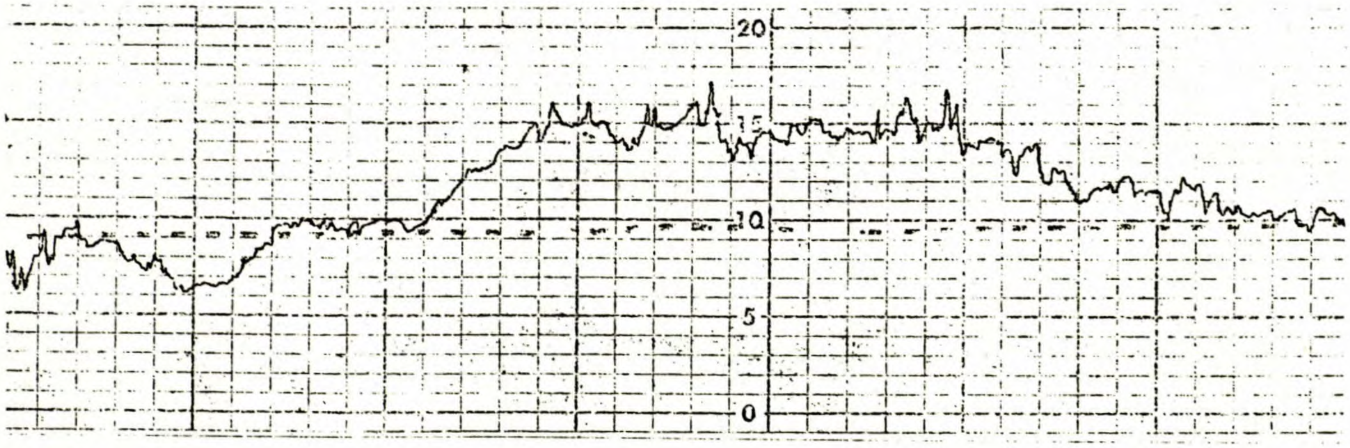


(b) L1 Wheel Seat - Transverse Direction
Magnification 1000 x 20

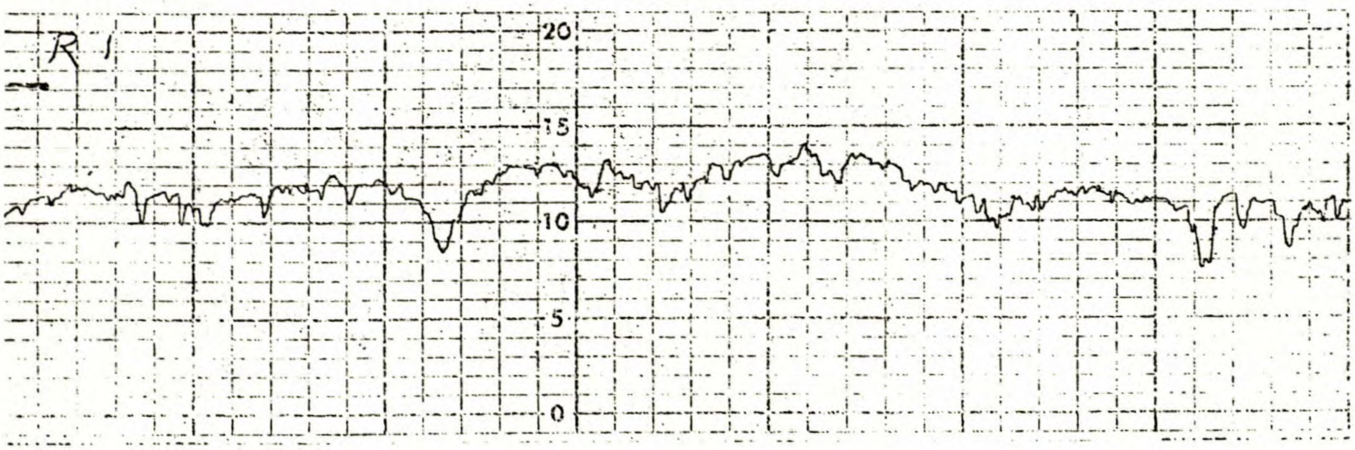
Figure 8. Surface roughness profiles - L1 wheel seat.



(a) Rl Wheel Seat - Longitudinal Direction
(Inner end of seat between locations 14 to 15)
Magnification 1000 x 20. CLA exceeded 200 μin.

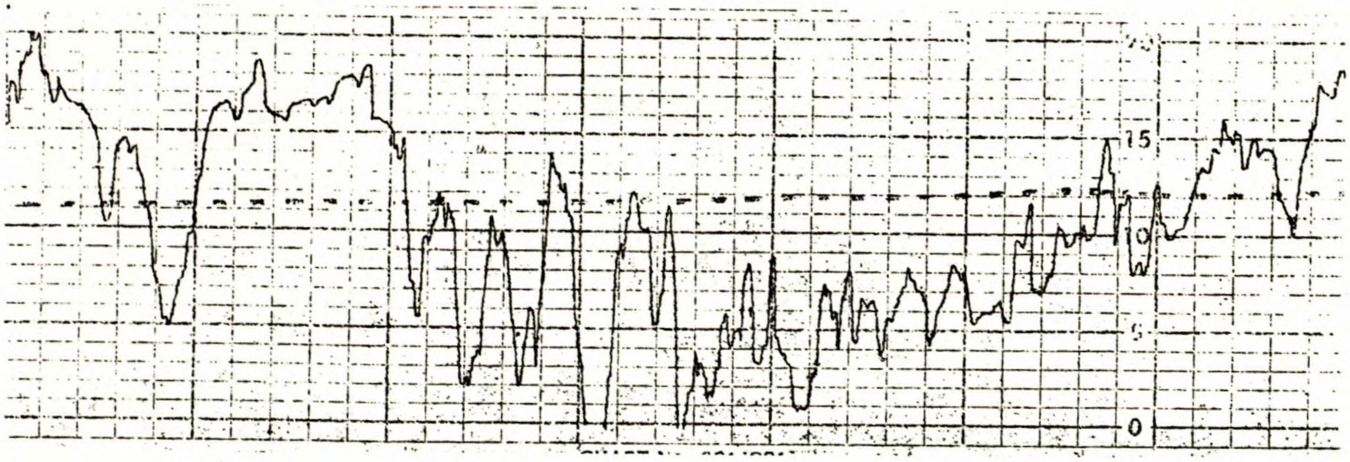


(b) Rl Wheel Seat - Longitudinal Direction
(Centre of Wheel Seat)
Magnification 1000 x 20. CLA 52 μin.



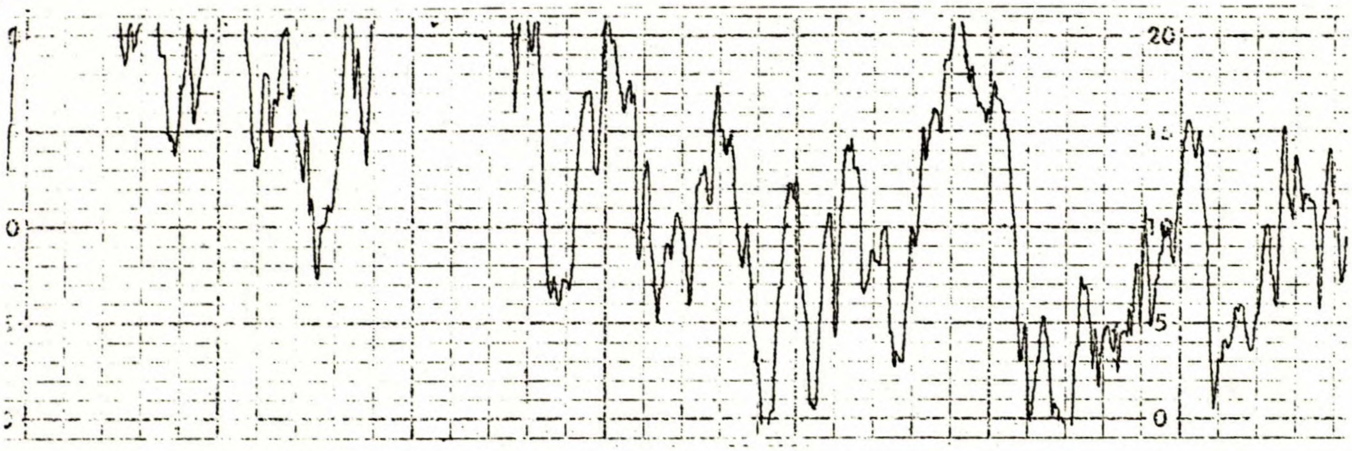
(c) Rl Wheet Seat - Transverse Direction
Magnification 1000 x 20.

Figure 9. Surface roughness profile - Rl wheel seat.



L1 Wheel Bore - Longitudinal Direction
Magnification 1000 x 20
CLA 140 μin.

Figure 10. Surface roughness profile - L1 wheel bore.



R1 Wheel Bore - Longitudinal Direction
Magnification 1000 x 20
CLA exceeded 200 μin.

Figure 11. Surface roughness profile - R1 wheel bore.