OTTAWA October 1, 1946.

REPORT

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 2055.

(Subsequent to Investigation Reports Nos. 1991, 2002, 2014, and 2105, Jan.-Sept., 1946.)

Research on Optimum Thread Form for Proposed Anglo-American-Canadian Screw Thread.

PART VI. - Calibration of the Dynamometer of the Avery Pulsator Machine under Dynamic Tension.

(This research is performed in collaboration with the National Bureau of Standards, Washington, U. S. A., the National Physical Laboratory, Teddington, England, and the National Research Council, Ottawa, Canada.)

(Copy No. 8.)

(Report of Investigation)
(No. 2035, Oct. 1, 1946.)

Abstract

This report describes the methods employed for calibrating the dynamometer of an Avery fatigue machine under dynamic tension. Two measuring instruments have been used, a Morehouse ring and a calibrated weighbar with strain gauges. Results obtained with the latter method are analysed and discussed with reference to the static calibration.

Bureau of Mines
Division of Metallic
Minerals

Physical Metallurgy
Research Laboratories

CANADA

DEPARTMENT
OF
MINES AND RESOURCES

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Research on Optimum Thread Form for Proposed Anglo-American-Canadian Screw Thread.

PART VI. - Calibration of the Dynamometer of the Avery Pulsator Machine under Dynamic Tension.

Origin and Purpose of Investigation:

This machine is to be used for fatigue tests for development of the proposed A.B.C. standard thread form. The work of testing specimens is to be shared by three laboratories, the National Bureau of Standards, Washington, U.S.A., the National Physical Laboratory, Teddington, England, and the Physical Metallurgy Research Laboratories, Bureau of Mines, Ottawa, Canada. This report gives the results of the calibration in dynamic tension of the P. M. R. L. machine, and supplements the report on the static calibration given in Investigation Report No. 2002, February 18, 1946.

PROCEDURE:

Two procedures were used for the dynamic calibration. One was to use the Morehouse ring in the same manner as for static measurements. This method permitted measurement of the minimum load during the cycle, which could then be compared with the load calculated from the static characteristic of the dynamometer and the minimum deflection as determined by the microscope.

The Morehouse ring (Figure 1) consists of an elastic steel ring with means of attaching it to the grips of the machine to be tested. Inside the ring, at one end, is a very fine-reading micrometer. This micrometer terminates in a hardened steel button. Facing this button is a steel reed with a small, accurately machined weight at its free end. To make an observation, the reed is set vibrating by plucking it with the finger and the micrometer is advanced till the button begins to touch the reed. This is indicated by a sudden increase in the damping of the reed. During static tests very decisive observations can readily be made. A series of readings at a given load can be repeated as accurately as they can be taken. The 50,000-pound ring, loaned to us by the National Research Council, Ottawa, could be read to about 63 pounds directly, and to 6 pounds by estimation to one-tenth of a micrometer division. Readings could be reproduced to one-tenth of a division. Unfortunately, this accuracy could not be achieved under dynamic loading because the natural frequency of the reed was about 35 c.p.s., whereas the Avery machine operates at about 45 c.p.s.

Thus the button was moving sinusoidally with respect to time parallel with the axis of the ring with a frequency of 45 c.p.s., while the end of the reed was vibrating sinusoidally perpendicular to this axis at a frequency of 35 c.p.s. The result was that coincidence of the two, on which readings

(Procedure, cont'd) -

depended, occurred only three or four times per second. This, combined with a slow drift in the amplitude of oscillation of the beam of the machine, made measurement difficult, and an accuracy of ±200 pounds is the best that can be claimed for this procedure. The results obtained in this way have been given in a report of the National Research Laboratories, Ottawa, Report No. P.M. 929, dated April 6, 1946, and agree substantially with the results obtained from the static tensile calibration given in Investigation Report No. 2002. Under the conditions of observation a coincidence of the button and reed is impossible if the ring is adjusted to a reading corresponding to a load lower than the minimum during the cycle, while it is very unlikely to occur if adjusted for exactly the minimum value, because coincidence occurs, if at all, only about four times a second. If the micrometer be adjusted for a value somewhat greater than the minimum, fairly positive damping is quite likely to occur, and this favours ring readings on the high side. With this fact in view it might be expected that this method of dynamic calibration would give a higher value of the calibration factor in pounds per division than the true one.

The second method of dynamic calibration involved the use of a calibration specimen (hereinafter referred to as a weighbar) with SR-4 strain gauges attached. The weighbar was designed to withstand indefinitely a load range of 0-30,000 pounds tension. To it were attached two sets of strain gauges, i.e., six 1,000-ohms C-10 gauges connected in series, and four 120-ohm A-3 gauges placed equidistant around the bar, opposite pairs connected in series

(Procedure, cont'd) -

and the two pairs connected in parallel so that the terminal resistance was 120 ohms. This arrangement completely compensated for any bending effect, so that only the axial component of load affected the strain indicator, but gave a low resistance gauge with accompanying relative freedom from noise pick-up. The 120-ohm gauges on the weighbar were connected to the active gauge terminals of an SR-4 strain indicator, and a similar gauge, from the same lot, cemented to a small block of steel, was connected to the compensating gauge terminals.

The SR-4 Strain Indicator contains two arms of a Wheatstone bridge designed especially for measuring small proportional changes of resistors in the range of 120-500 ohms. The dial is calibrated in terms of micro-inches per inch and can be read to 10 micro-inches per inch and estimated to 1 micro-inch. It has a range of about 12,000 micro-inches. The active and compensating gauges are the other two arms of the Wheatstone bridge. A.C. power, at approximately 1,000 c.p.s., supplied by an electron tube circuit for converting D.C. to A.C. (known as an oscillator), is supplied to the bridge and the voltage due to unbalance, amplified, is applied through an output transformer to two opposite terminals of a group of four rectifiers connected in a ring. Power, directly from the oscillator, is applied to the other two terminals. If the bridge is adjusted through balance, the phase of the bridge unbalance voltage with respect to the oscillator output voltage will change by 180 degrees. A meter is so connected to the rectifier that this change of phase causes the D.C. passing through the meter to reverse, and the operator then knows in which direction to adjust the bridge in order to obtain a balance. This would not be the

(Procedure, cont'd) -

case if the output current were merely rectified and passed through the meter. To the first order of approximation, if the bridge is balanced there will be no output voltage from the bridge, none from the amplifier, and no deflection from the meter.

The vertical amplifier of a DuMont 208-B C.R.O. was connected through a G.R. 830-R 500-1000 c.p.s. band-pass filter to the secondary of the output transformer of the strain indicator. The vertical width of the trace was then proportional to the out-of-balance voltage from the bridge and therefore to the load on the weighbar. The horizontal sweep frequency of the C.R.O. was adjusted approximately equal to the frequency of oscillation of the machine. The six C-10 gauges, with a total resistance of 6,000 ohms, were connected in series with a 6,000-ohm resistor to a 45-volt battery. Changes in the resistance of the gauges due to varying stress in the bar caused a similar variation of the current flowing through the gauge and resistor, and the A.C. voltage, of wave form identical with that of the dynamic component of the tension of the weighbar, appeared across the resistor. This voltage, amplified by a Ballantine Model 300 voltmeter acting as an amplifier, was applied to the input terminals of the horizontal amplifier of the C.R.O. The upper horizontal amplifier terminal was connected to the external synchronization terminal of the C.R.O. By turning off the linear time-base, the horizontal deflection of the electron beam could be brought into phase with the variational load component of the machine. By using the output of the C-10 gauges to synchronize the linear time-base sweep, an absolutely stationary pattern with a linear time-base could be obtained.

It will be recalled that the frequency of the

(Procedure, cont'd) -

oscillator of the strain indicator is 1,000 c.p.s., while the frequency of variation of load in the Avery machine is 45 c.p.s. Therefore, all components and circuits of the strain indicator will behave instantaneously, as if static loads were being studied. Therefore, with the Avery machine running and all electrical equipment operating, the vertical width of the trace on the screen of the C.R.O. will pass through zero if, and only if, the strain on the weighbar passes through the unique value that will cause its strain gauges to assume such a resistance that the strain indicator is balanced. If the strain indicator be set at the highest reading at which the amplitude of the trace on the C.R.O. is seen to pass through zero at some point of the cycle, and then to the lowest reading at which amplitude of the trace is seen to pass through zero, the difference between the two readings is the dynamic range of strain of the weighbar under the existing conditions.

In practice, certain difficulties were encountered. The weighbar was placed in the Amsler machine, its 120-ohm strain gauges were connected to the strain indicator, the 6,000-ohm group to a Wheatstone bridge, and a Martens extensometer was applied to the bar. The Martens extensometer can be readily calibrated by measurements of distance, and as set up could be read to ±1 micro-inch. This permitted readings obtained by the electric strain gauges to be directly checked against those of the optical-lever type, which are assumed to be correct. The results indicated that the electrical strain gauges gave readings about 8 per cent too high. For this reason, the deflections of the strain indicator for each 5,000 pounds up to 30,000 pounds of load were observed. It was found that throughout this range the strain indicator deflection was one micro-inch per inch for each 31.2 pounds

(Procedure, cont'd) -

of load. This calibration was made using the null meter of the strain indicator.

Another difficulty was found in balancing the strain indicator using the C.R.O. as a null indicator. It was found that when the dial was adjusted through the position of balance as indicated by zero current in the meter, the amplitude of the out-of-balance voltage passed not through zero but through a fairly large and indecisive minimum. This was attributed to phase shift in the two bridge arms contained in the instrument, due to different amounts of distributed capacity. A variable capacitor consisting of 100 m.m.f. fixed and 35 m.m.f. variable connected in parallel across the compensating gauge permitted the 1,000-c.p.s. voltage to be adjusted to zero. However, it was then discovered that there was a fair amount of second harmonic of frequency 2,000 c.p.s. arising from distortion in the oscillator which, due to the presence of capacity, did not balance out at the same settings as balanced out the 1,000-c.p.s. voltage. This rendered achievement of a C.R.O. trace with zero amplitude impossible. This trouble was overcome by placing a General Radio Company 500-1,000 c.p.s. band-pass filter, terminated with a 50,000-ohm resistor, in the line from strain indicator to C.R.O. vertical amplifier input. This eliminated all difficulty from this cause. A schematic diagram of the circuit is given in Figure 2, and a photograph of the apparatus used appears in Figure 3.

It was suspected that connecting 135 m.m.f. across the compensating gauge might alter the calibration. Theoretically this should not be the case, for such a capacitor should have a reactance at 1,000 c.p.s. of 1.4 megohms which, remaining constant, would have negligible effect. It was found that if the capacitor were suitably adjusted at one value of static load on the weighbar and the load increased by steps, the

(Procedure, cont'd) -

minimum width of the C.R. Tube trace gradually increased to a fairly large value, and that to get zero amplitude a slight readjustment of the condenser was necessary - probably of the order of a few m.m.f. To see whether adjusting the capacitor so as to produce exact balance at each setting would result in an altered characteristic, the following test was made: The weighbar was placed in the grips of the Avery machine and all connections made. Load was applied, in 7 steps, up to about 82,000 pounds. At each step the strain indicator reading was taken under three different conditions: (a) With the null-meter at zero, capacitor was removed; (b) capacitor connected and adjusted to give zero width of C.R.O. trace; and (c) capacitor present and adjusted as stated but null meter set to zero. In the majority of cases the readings by methods (a) and (c) were the same, within the error of observation (1 micro-inch). Method (b) gave readings usually differing by about +4 micro-inches from the other two. This is probably due to a slight dissimilarity of the rectifiers which causes the null meter to give a deflection corresponding to a strain of 4 micro-inches when the bridge is balanced.

While these tests indicate that deflections measured with the C.R.O. and null indicator with a capacitor across the compensating gauge to give phase balance are the same as those measured without capacitor, it was found, later, that much higher loads must be used for the tests. In order for the method to be reliable, the strain-indicator with capacitor and C.R.O. must behave normally as regards deflections when loads sufficient to cause a deflection of 1,000 micro-inches per inch are applied to the weighbar. These tests were done, using methods (a) and (b) as detailed. However, instead of using method (c), the bridge was balanced without

(Procedure, cont'd) -

using a capacitor. The reading of the meter was then zero. Reading the meter (calibrated in micro-inch) with the capacitor connected, then gave a more exact idea of how much the circuit was disturbed by adding it. Similarly, to see how uniformly the instrument operated with various strains, using the C.R.O. as a null indicator, it was balanced with the C.R.O., the capacitor removed, and the dial read.

Table I gives strain gauge readings taken during calibration of the weighbar. Tables II and III give strain readings obtained by methods mentioned above. They show that the calibration of the SR-4 strain indicator and weighbar is not affected by addition of the capacitor for loads up to 30,000 pounds.

TABLE I. - Reduction of Data from Weighbar Calibrator.[1]

(Loads in units of 1,000 pounds.)

Load, kilo-pounds	Strain-indicator Deflection	Range of Values of Defl'n	Range of Defl'n[2] if worst omitted	Calc. Load, kp (Deflection x 31.2 plus 0.10)
0.10	0.00	0	0	
5.00	158	2	1	5.03
10.00	317.7	1	0	10.01
15.00	478	2	1	15.01
20.00	639	2	2	20.04
25.00	799	1	1	25.03
30.00	959	4	2	30.02
25.00	800	3	2	25.06
20.00	638.5	3	2	20.02
15.00	478	2	1	15.01
10.00	317	3	2	9.99
5.00	158	3	1	5.03
0.10	000.0	0	0	

1. Summarized from readings obtained during 8 cycles of loading.

2. The value lying furthest from the average omitted.

Conclusion:

Load range = 31.2 ±0.1 x strain-indicator deflection.

(Procedure, cont'd) -

TABLE II.

Comparison of Strain Indicator Readings and Deflection.
(a) With null meter of strain indicator set to zero; no capacitor.
(b) Capacitor in parallel with compensating gauge, adjusted to zero vertical deflection of C.R.O.
(c) Capacitor adjusted as for (b) but null meter set to zero.

Method (a) Strain Indicator			Method (b) Strain Indicator			Method (c) Strain Indicator		
READING	DEFLECTION		READING	DEFLECTION		READING	DEFLECTION	
	Increment	Total		Increment	Total		Increment	Total
1574	97	706	1578	96	707	1573	96	706
1477	102	609	1482	103	611	1477	104	610
1375	98	507	1379	97	508	1373	96	506
1277	105	409	1282	104	411	1277	105	410
1172	95	304	1178	97	307	1172	96	305
1077	100	209	1081	101	210	1076	102	209
977	109	109	980	109	109	974	107	107
868			871			867		

(Table III appears on Page 11.)

The method of using the calibrated weighbar, strain-indicator and C.R.O. to measure dynamic loads is as follows. With the weighbar fastened in the grips and all electrical equipment operating, the dynamic load was applied and, after the machine had "steadied down,"* the reading of the dynamometer microscope was observed. The strain indicator was then adjusted to the lowest reading at which the C.R.O. trace could be seen to pass through zero amplitude. The difference between this reading and that for zero load indicates the minimum load during the cycle. In a similar way the strain indicator was set to the highest reading for which the trace had, at some point, zero amplitude, the capacitor being adjusted if necessary. The difference between this reading and the zero load reading gives the maximum load during the cycle. The difference between the two readings gives the range of load to which the weighbar was subjected.

(Continued on Page 12)

* The machine was left running for an hour before tests were attempted.

TABLE III. - Investigation of Effect on Calibration of Strain Indicator Caused by Connecting 135 m.m.f. across Compensating Gauge Terminals.

Method (a) Strain Indicator READING	Method (a) DEFLECTION Increment	Method (a) DEFLECTION Total	Method (b) Strain Indicator READING	Method (b) DEFLECTION Increment	Method (b) DEFLECTION Total	Change in meter reading. Balanced by meter without capacitor; capacitor then added. (Micro-inch)	Meter reading when adjustment made to CRO null and capacitor removed. (Micro-inch)	CRO Null Deflection (Total) minus - Meter Null Deflection (Micro-inch)
888		0	894		0			+2
	76			78				
964		76	972		78			0
	77			77				
1041		155	1049		155			-1
	156			154				
1197		309	1203		309	06L		+1
	76			77				
1273		385	1280		386	06L		-1
	63			62				
1336		448	1342		448	06L		0
	77			77				
1413		525	1419		525	05L		+1
	77			78				
1490		602	1497		603	07L	01R	-2
	77			75				
1567		679	1572		678	05L	01R	+2
	73			75				
1640		752	1647		753	05L	0	0
	80			80				
1720		832	1727		833	05L	0	0
	68			68				
1788		900	1795		901	05L	0	-2
	90			88				
1878		990	1883		989	04L	01R	0
	37			37				
1915		102[illegible]	1920		1026	06L	0	

(Procedure, cont'd) -

A series of dynamic calibrations was carried out in this manner using different preloads, 0.57, 10.83, 13.4, 15.2 and 16.9 kilopounds. The results are shown in Figure 4, in which the load range is plotted against the band-width seen in the microscope minus 8 divisions, the static band-width.

Analysis of Results:

It has been shown by D. G. Sopwith, in N. P. L. Engineering Division Report No. 151/45, that if the relation between the applied load and the corresponding microscope scale reading is linear, the relation between the load range and the scale reading will be the same; if the former relation is parabolic, the scale reading will be approximately proportional to the load range, but the constant of proportionality will vary with the preload. Within the limits of experimental accuracy, the static calibration can be expressed as a parabola:

$$X_p = 2.89 P + 0.005 P^2$$

where X_p = scale reading for load P (in kilo pounds).

This gives the following relation between the load range (R) and the corresponding band-width (X), ignoring terms involving R^3:

$$X = R(2.89 + 0.01 M)$$

where M = the preload in kilopounds.

On the basis of these relations, straight lines were fitted to the series of points obtained in the dynamic calibration with different preloads. It was found, as with the similar N.P.L. machine, that the best-fitting straight lines did not pass through the origin, but gave a small positive load range for zero true band-width. The equations

(Procedure, cont'd) -

obtained for these lines are given below,

$$M = 16.9 \; : \; X = 3.20\,R - 0.8,$$
$$M = 15.2 \; : \; X = 3.24\,R - 1.0,$$
$$M = 13.4 \; : \; X = 3.25\,R - 1.6,$$
$$M = 10.83 \; : \; X = 3.18\,R - 0.8,$$
$$M = 9.57 \; : \; X = 3.08\,R - 0.3,$$

M and R being in kilopounds, X in scale divisions.

Plotting the constants (slope and intercept) in these equations against M and using the method of least squares, it was found that they could be represented approximately by:

$$X = (2.98 + 0.016\,M)\,R - 0.06\,M.$$

Lines calculated from this equation are drawn in Figure 4 and can be seen to fit reasonably well to the plotted experimental points. The term 0.06 M, representing the (negative) scale difference for zero load range, has been suggested by D. G. Sopwith as due to some defect in the microscope system; for the N.P.L. Pulsator machine the corresponding term was 0.09 M. Neglecting this term, the relation between X, R and M is equivalent to a parabolic static calibration given by:

$$X_p = 2.98\,P + 0.008\,P^2.$$

The scale readings for various loads as calculated from this equation are given in Table IV, together with the corresponding readings obtained from the derived static calibration curve.

(Table IV follows)
(on Page 14.)

(Procedure, cont'd) -

TABLE IV.

Load, Kilopounds	SCALE READING, IN DIVISIONS From Static Calibration	From "Equivalent" Static Calibration	Difference, per cent
2	5.8	6.0	3.5
4	11.6	12.1	4.3
6	17.5	18.2	4.0
8	23.4	24.4	4.3
10	29.4	30.6	4.1
12	35.4	36.9	4.2
14	41.5	43.3	4.3
16	47.6	49.7	4.4
18	53.8	56.2	4.5
20	60.0	62.8	4.7

It will be seen that there is a 4 per cent difference between the two sets of readings. This is greater than the corresponding figure for the N.P.L. Pulsator machine, in which the dynamic calibration was carried out by a somewhat different electrical method. It is intended to continue with further investigation of this point.

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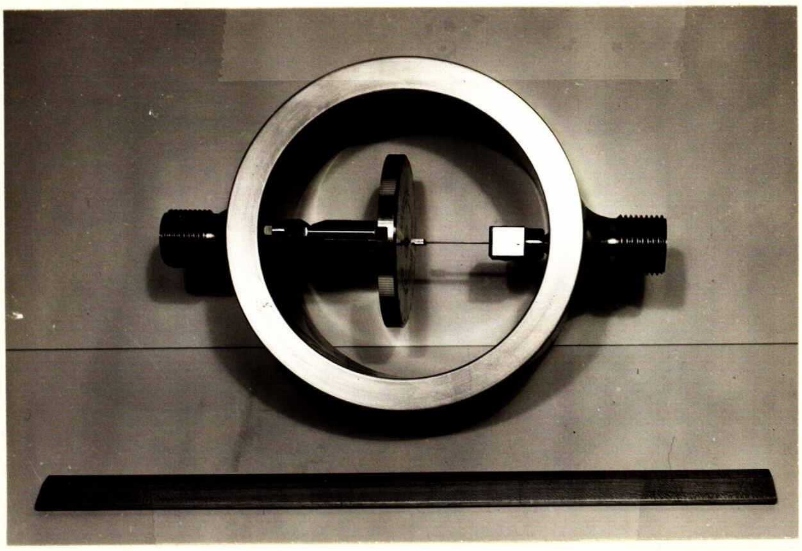
JW:RT:TWW:LB.

(Figures 1 to 4 follow,)
(on Pages 15 to 17.)

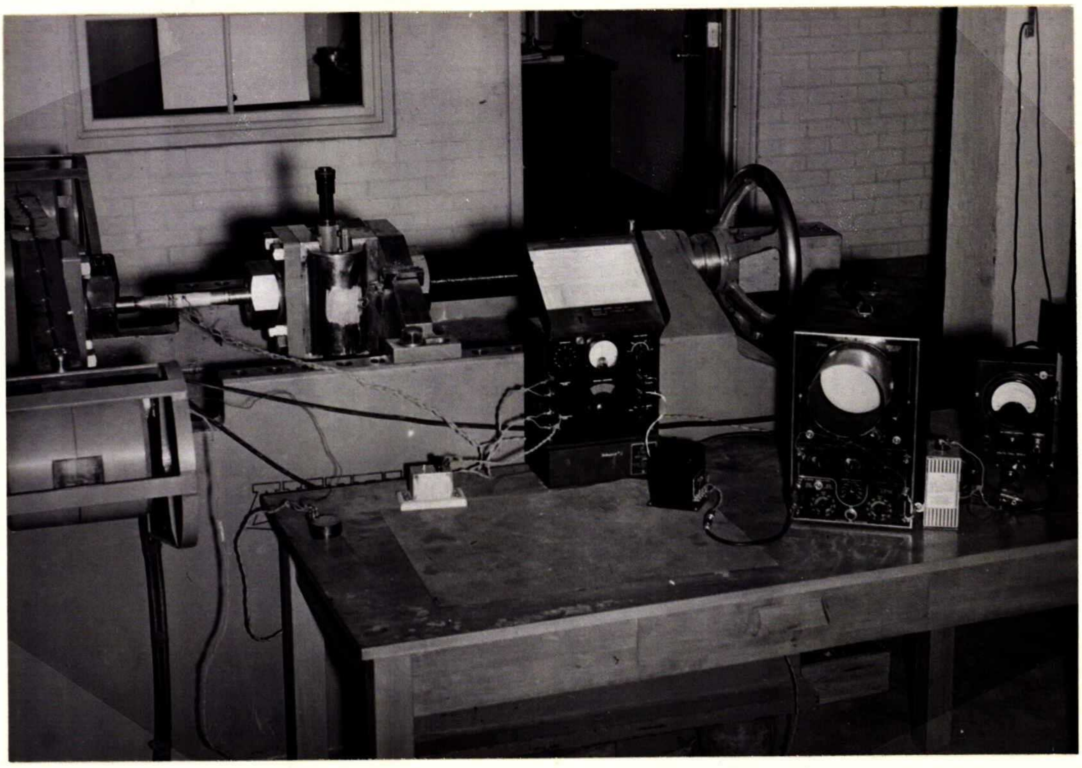
Figure 1.



50,000-POUND MOREHOUSE PROVING RING.

-

Figure 3.



APPARATUS USED FOR THE DYNAMIC
CALIBRATION WITH STRAIN GAUGES.

-

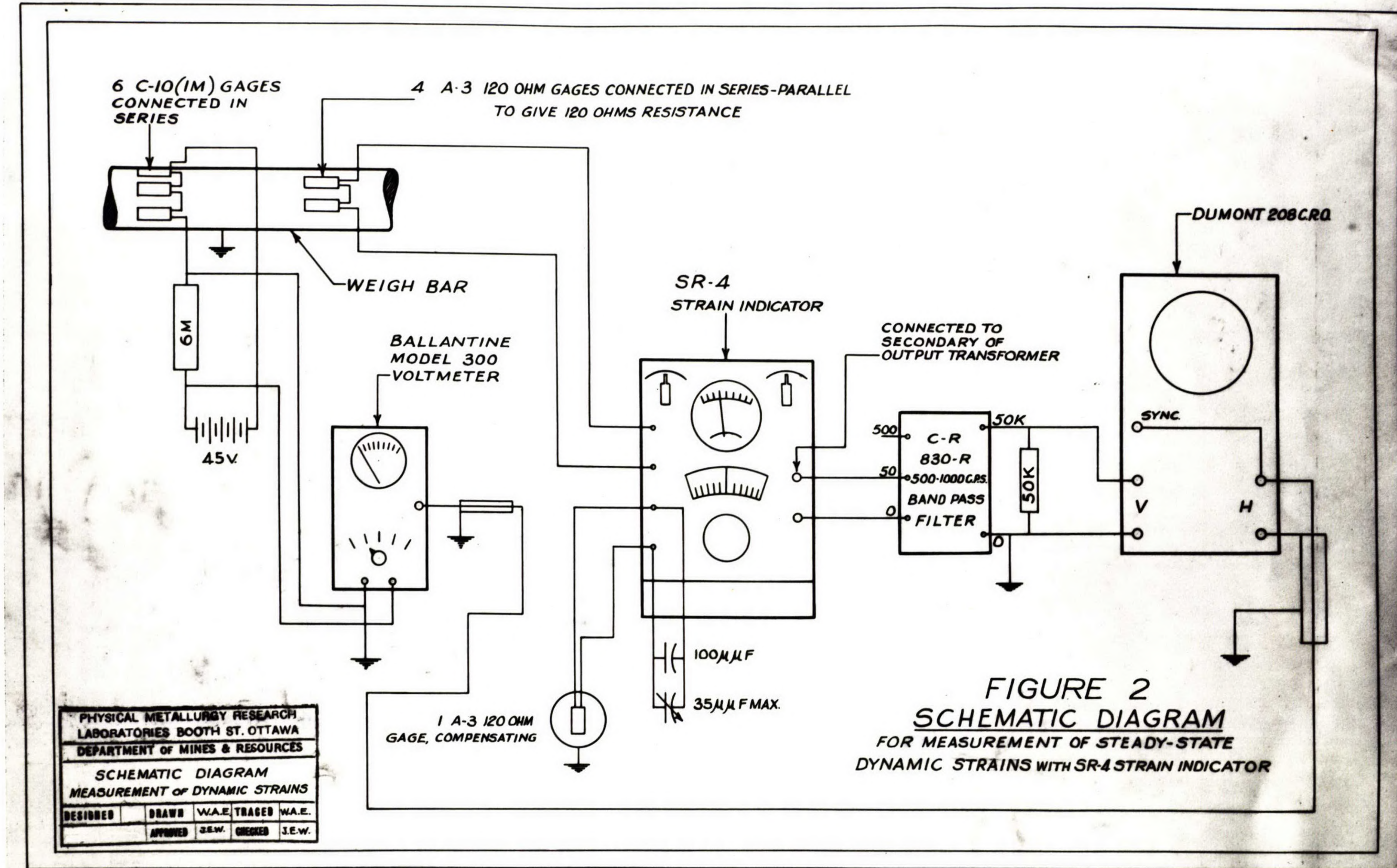


FIGURE 2
SCHEMATIC DIAGRAM
FOR MEASUREMENT OF STEADY-STATE DYNAMIC STRAINS WITH SR-4 STRAIN INDICATOR

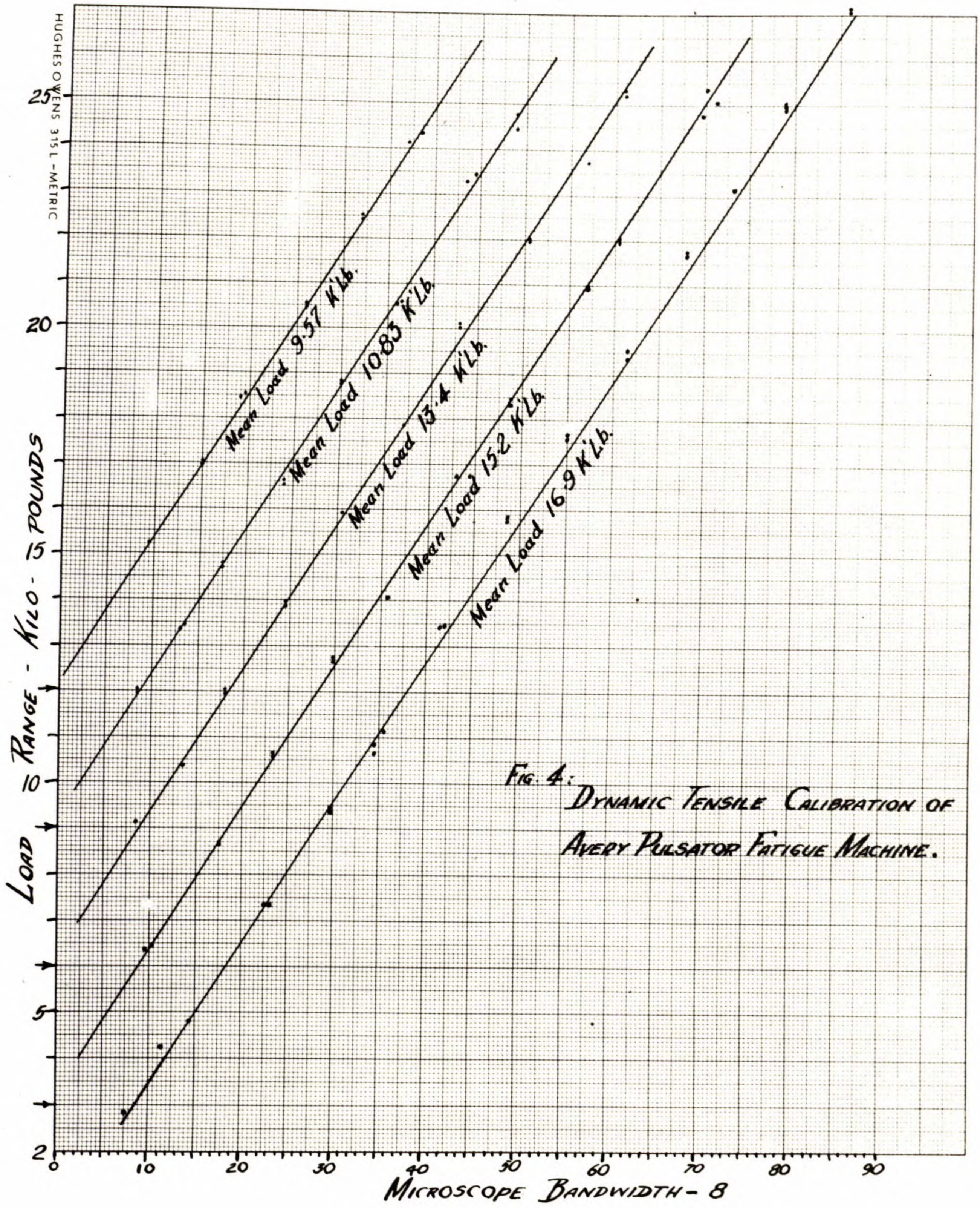


FIG. 4: DYNAMIC TENSILE CALIBRATION OF AVERY PULSATOR FATIGUE MACHINE.

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JW:RT:TWW:LB.