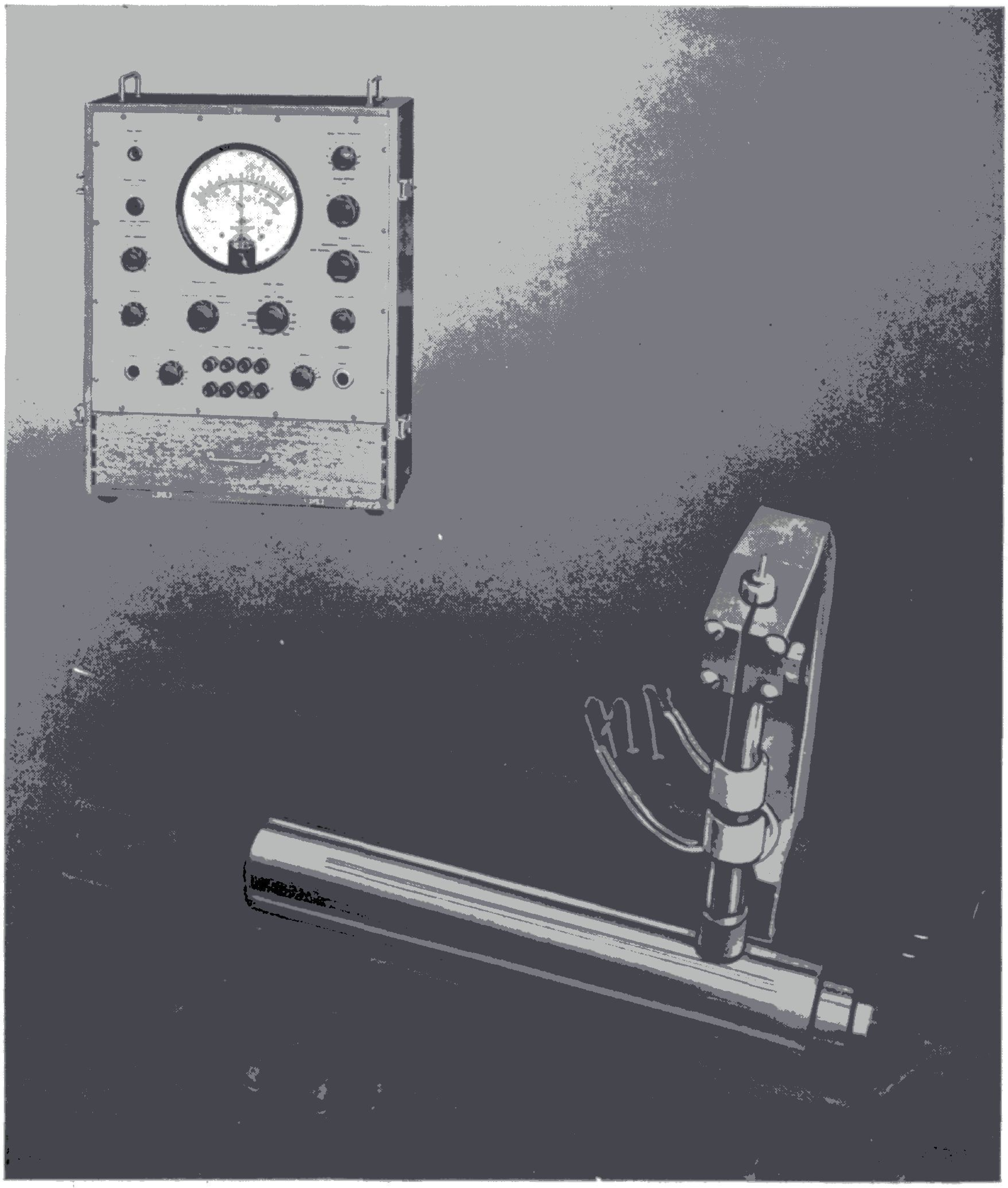
Brüel & Kjær

Technical Review

Teletechnical, Acoustical and Vibrational Research



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ANNOUNCEMENT

NEW RANGE OF GAUGE FACTOR ADJUSTMENT

Strain Gauge Apparatus Type 1516

In view of the relatively large number of strain gauges on the market which possess a gauge factor of less than 2, it has been decided to use a new range of Gauge Factor Adjustment in all Strain Gauge Apparatus Type 1516 subsequent to Serial Number 13885.

This new control range enables direct continuous adjustment to be made for strain gauges with gauge factors between 1.5 and 3.0.

All previous instructions for use, and information relating to the Type 1516 is valid for this later instrument, with the exception that where the gauge factor limits, multiples and sub-multiples are mentioned the values 1.5 to 3.0 should be substituted for the values 2.0 to 4.0.

The above substitutions apply to the articles in this Technical Review where relevant.

Use of Resistance Strain Gauges to determine Friction Coefficients

by

William E. Green

Increased reliability of the resistance strain gauge, coupled with the development of versatile recording and measuring instruments has been responsible for the increase in the use of strain gauges. Each new type of application usually requires variation of technique, both in the manner of affixing the gauge, and of extracting and displaying the results.

As the measuring schemes become more ambitious the difficulties involved increase, and it is occasionally necessary to spend some little time developing suitable adhesive techniques. However, really difficult cases tend to be the exception and the resistance strain gauge will be found to be a relatively simple, and increasingly indispensable tool of the instrumentation and development Engineer.

From the Laboratoriet for Metallære, Danmarks tekniske Højskole (Metallurgy Laboratory at the Technical University of Denmark), Copenhagen, comes an interesting example of strain gauge application and the use of the Strain Gauge Apparatus Type 1516 and Level Recorder Type 2304.

The various factors influencing the coefficient of friction existing between two sliding metal surfaces are being investigated. Considerable research has already gone into this problem, but the following is considered to be rather a novel approach.

A large number of factors will influence the friction coefficient existing, among these may be included the actual metals employed, the lubricant, the load (because this will vary the oil film thickness), the temperature and in some cases the humidity. Strangely enough, it would seem that the initial condition of the surfaces does not play a very important rôle, because in a test of any appreciable duration the sliding member, in travelling to and fro, will wear a track, the surface of which is peculiar to the two materials involved. The coefficient of friction will thus reach a value which is independent of the initial surface roughness.

The operating conditions of particular interest to the investigator are those encountered with slow bearing speeds and high loads, or with lubricants of low viscosity. Under these conditions "boundary friction" is experienced, the materials on each side of the oil film being of great importance. When hydrodynamic lubrication is employed the choice of mating materials is far less critical.

In order that the requisite loads could be produced without employing enormous test apparatus the experiments were carried out with one of the bearing materials in the form of a cylindrical specimen ca. 1″ diam. and the other in the form of a ball of ⅜″ diam, locked in position. The material from which the bar was made would normally form the static surface and the ball the moving surface. As may be seen from the drawing in fig. 1, the cylindrical test specimen is mounted between centres and the ball moved back and forth along the cylinder surface, parallel to its axis.

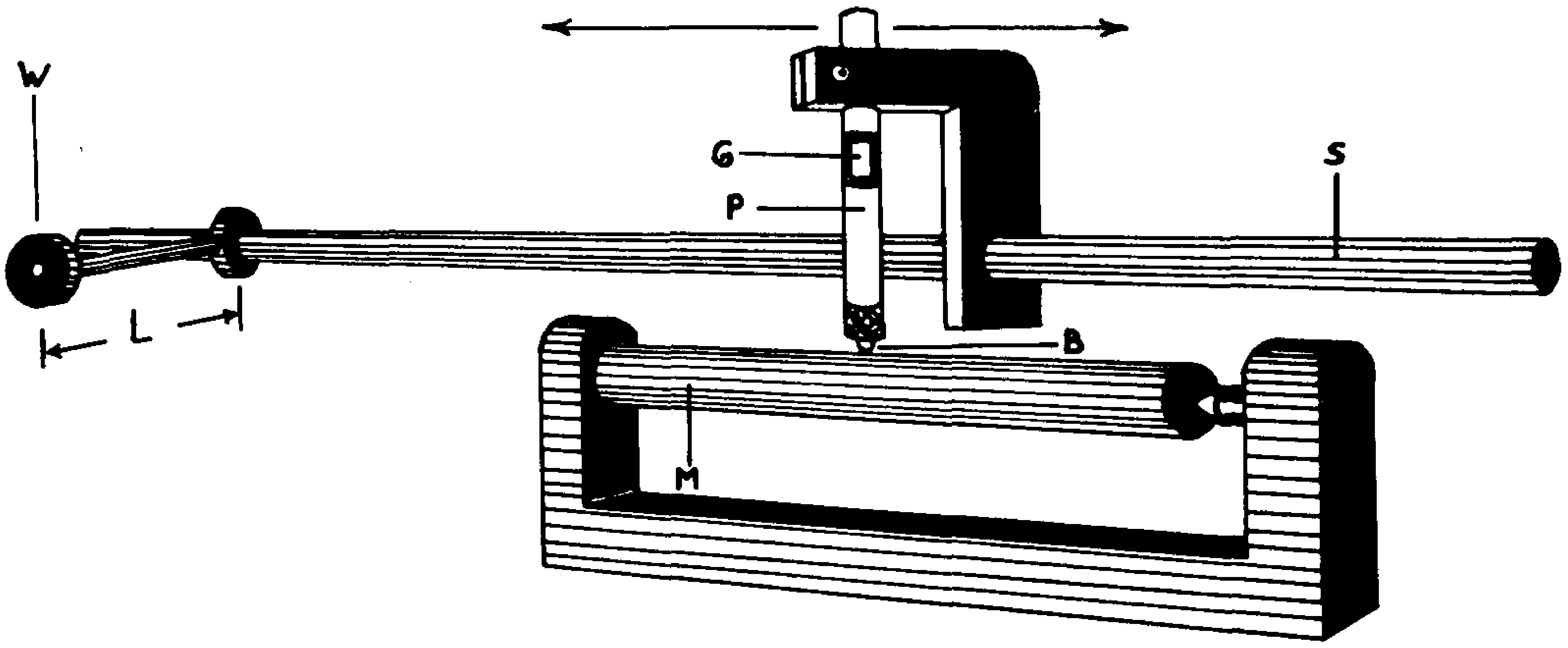


Fig. 1. Basic arrangement of friction rig.

The normal load between the ball and the cylindrical specimen is achieved by applying a load "W" (see fig. 1) at a point along the arm "L". This load is transmitted through the shaft "S" and appears as the normal load between the ball "B", mounted at the end of probe "P", and the cylindrical test specimen "M".

The shaft "S" is caused to move in a horizontal direction along its own longitudinal axis. In this way the ball "B" traverses specimen"M". This movement is derived from a speed controlled electric motor and transmitted through a crank to the shaft. It will be appreciated that both velocity and contact pressure may be readily changed. Provision is also made for immersing the two contacting components in oil, a simple bath being used, the type and temperature of the oil can be changed as required. (See fig. 4).

The frictional resistance to motion is measured by applying strain gauges "G" to the probe, the probe being considered to operate as a cantilever. Calibration of the probe is achieved by removing the ball and replacing it with an adaptor "A", which permits a horizontal force "F" to be applied to the normal point of contact. Fig. 2 shows the simple calibrating system.

In order that a study might be made of the effects of humidity on "dry" or partially self-lubricating surfaces, a plastic cover was made which encloses most of the apparatus and enables measurements to be carried out under varying atmospheric conditions. The photograph shown in fig. 3 is a general view of the test apparatus and the measuring equipment. The large metal disk "D" is used to support the plastic cover (not shown). Figures 4 and 5 give close ups of the probe and specimen, in fig. 4 the specimen is immersed in oil, and in fig. 5 may be seen quite clearly the tracks formed on the specimen "M" by the ball. As has been previously stated the material of which "M" is made would normally form the static bearing surface; some typical materials tested were aluminium alloys, bronzes, and tin and lead bearing metals. Balls made of hardened steel, soft steel, chromium plated steel or nickel were used.

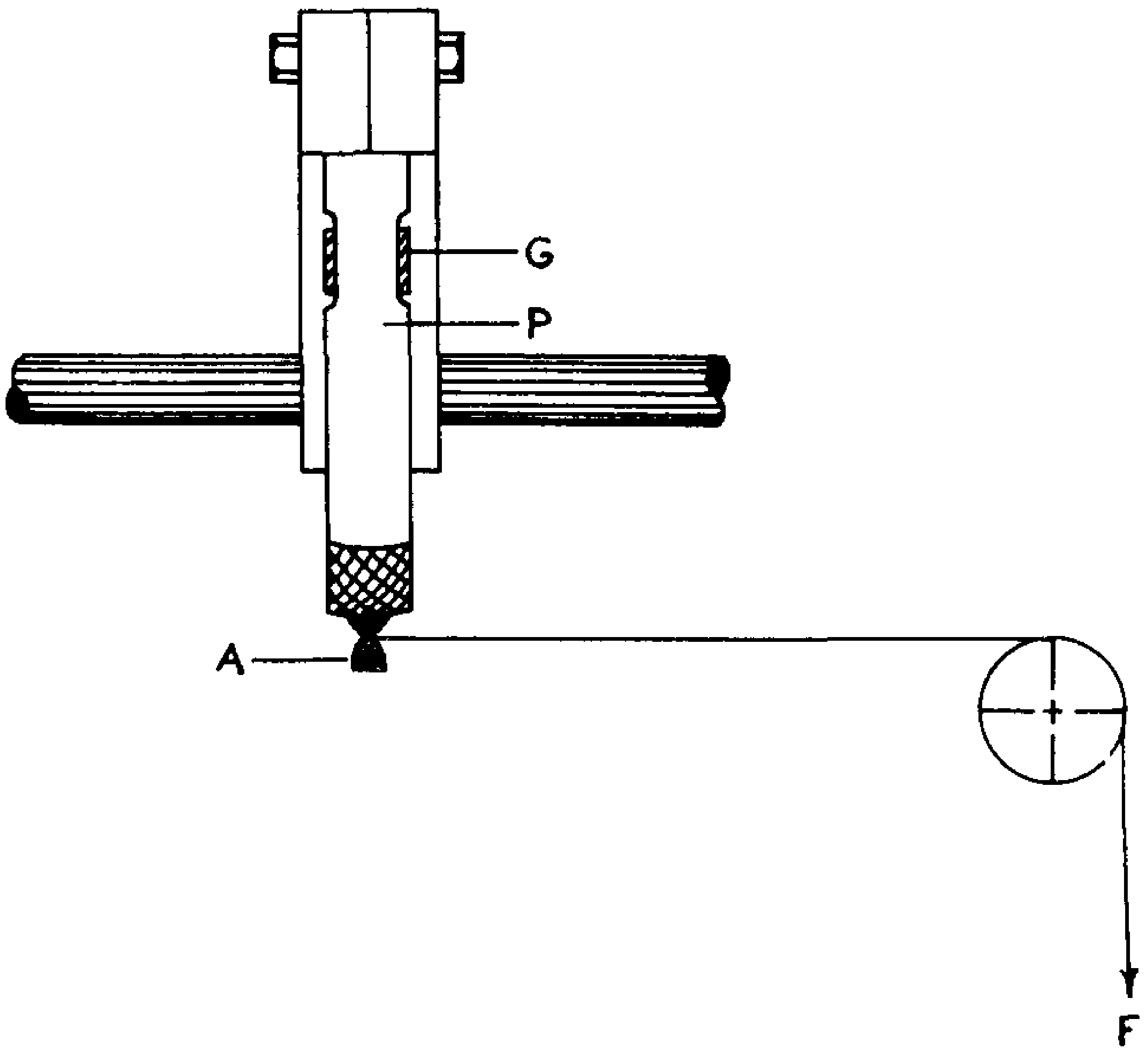


Fig. 2. Probe calibration.

When no lubrication was employed "M" was made of cast iron and the ball of Tungsten Carbide.

The normal load applied through "B", fig. 1, is ordinarily 1 kg but may be varied between 0.5 and 5 kg. Because the object of the work is to investigate the special conditions of boundary lubrication, coefficients of friction between 0.04 and 0.2 have been encountered with a resulting frictional drag of 40—200 g. In order to obtain the maximum sensitivity over the whole range three interchangeable probes "P" were fitted with strain gauges "G". In view of the wide range of the Type 1516 it would at first seem unnecessary to employ three probes to accomodate the range of loads encountered. However, it was found advisable to remove the minimum of material from the probe root in order to prevent vibration of the probes and false results. As an example of the probe stiffness a reading of 80 μstrain could be obtained from probe "I" with a tangential load of 1000 g, applied as in fig. 2.

The use of two strain gauges on each probe gives twice the sensitivity of one gauge, in addition to which the proximity of the gauges to each other ensures good temperature compensation, which is most essential in view of the small signals being measured.

The gauges used are Philips type PR9214 with a nominal resistance of 122 Ω, a gauge factor $k = 1.88$ and a temperature coefficient $\alpha t = -(23 \pm 2) \cdot 10^{-6}\ \Omega/\Omega^\circ C$.

The gauges were applied with ethyl-ketone and cellulose-acetate, the drying time and temperature being 24 hours at 30—40° C.

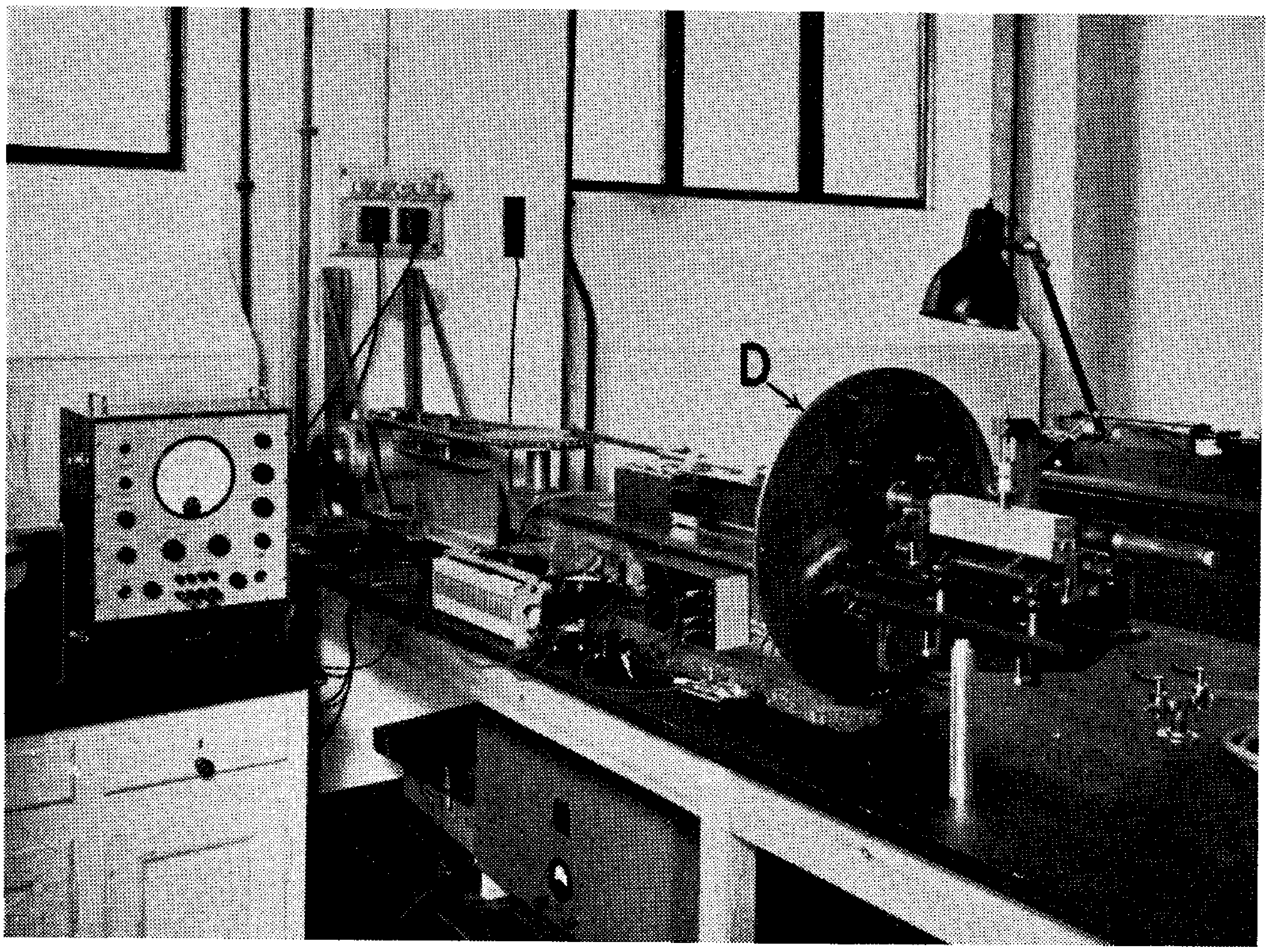


Fig. 3. General view of rig with B & K apparatus.

Although the gauge installation has given trouble free operation for more than one year, some misgivings have been felt with regard to the inadequacy of protection provided for the gauges. It is suggested that the use of Araldite resin "D" and hardener 951 might be considered, both to apply the strain gauges and to provide a water and oil proof coating. To obtain the best results, the adhesive should be thermally cured at 80°—100° C for a period of 20—30 minutes. In order to ensure that the gauge remains in position whilst being "cured", and that the minimum thickness of adhesive exists between gauge and probe, a small pad of P.T.F.E. should be placed on top of the gauge and weighted down. The P.T.F.E. will not stick, and upon its removal, after the gauge has adhered, a coating of Araldite may be applied over the gauge and the curing cycle repeated. Care must be taken to ensure that the metal surface is clean before the adhesive is applied.

In order to obtain a permanent record of the results observed a Level Recorder Type 2304 was used, this apparatus when fitted with a Linear Poten-

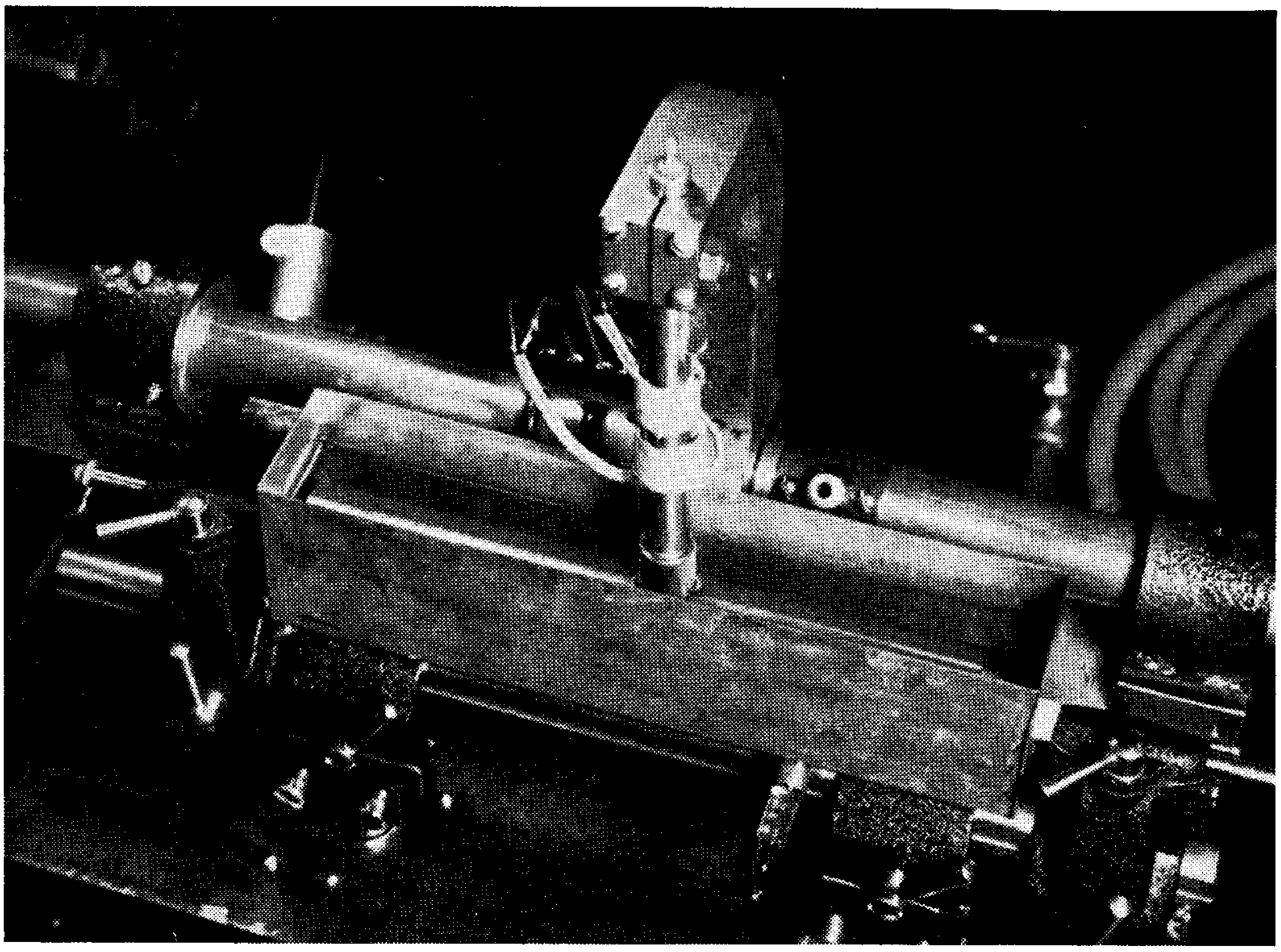


Fig. 4. Close up of probe and oil bath.

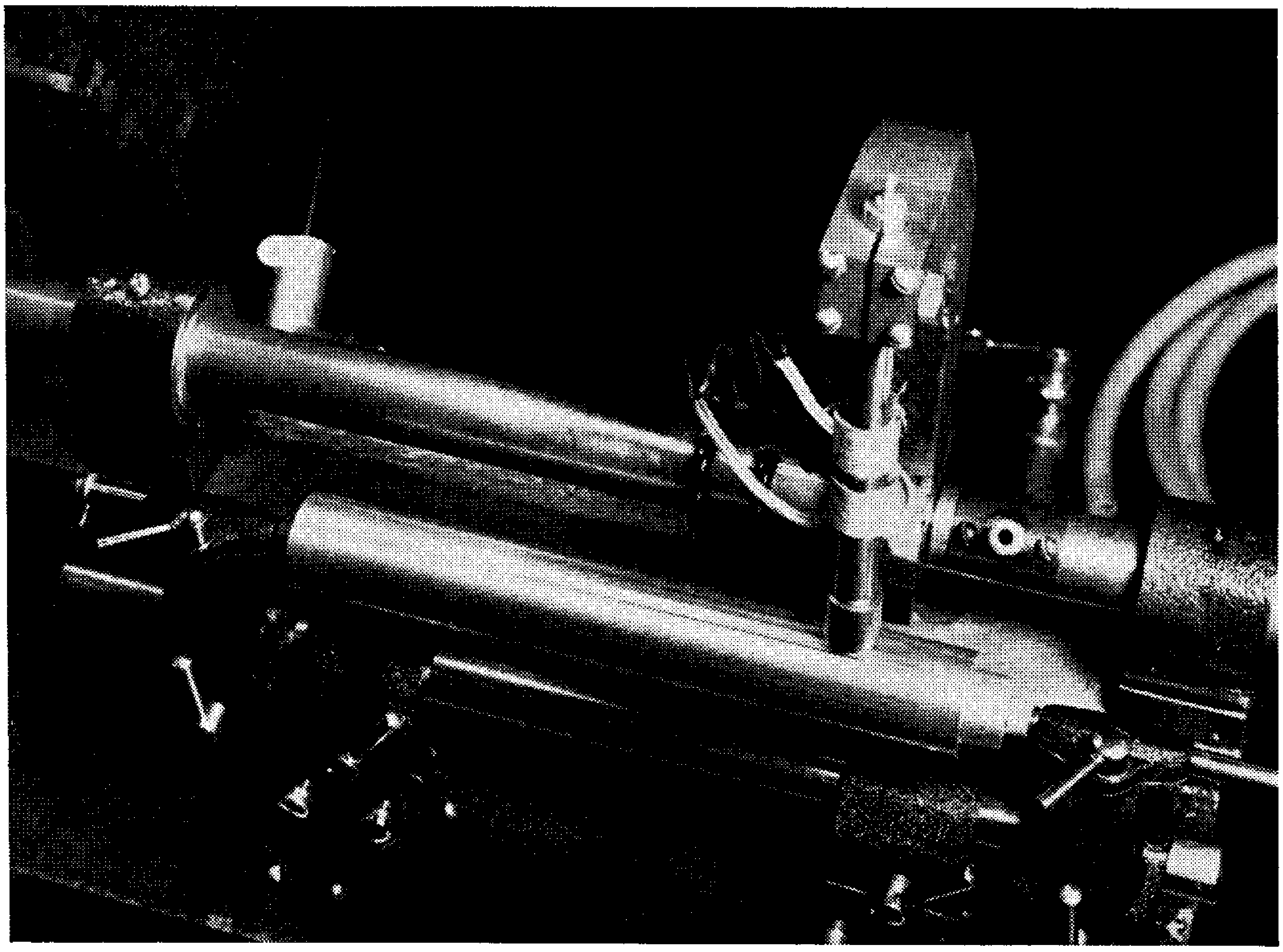


Fig. 5. Close up of probe and cylindrical specimen.

tiometer Type 2343 records directly from the Type 1516. For full details on the use and application of Brüel & Kjær apparatus the appropriate instruction manuals should be studied, copies may be obtained on request. Connection between the units should be made as shown in fig. 6.

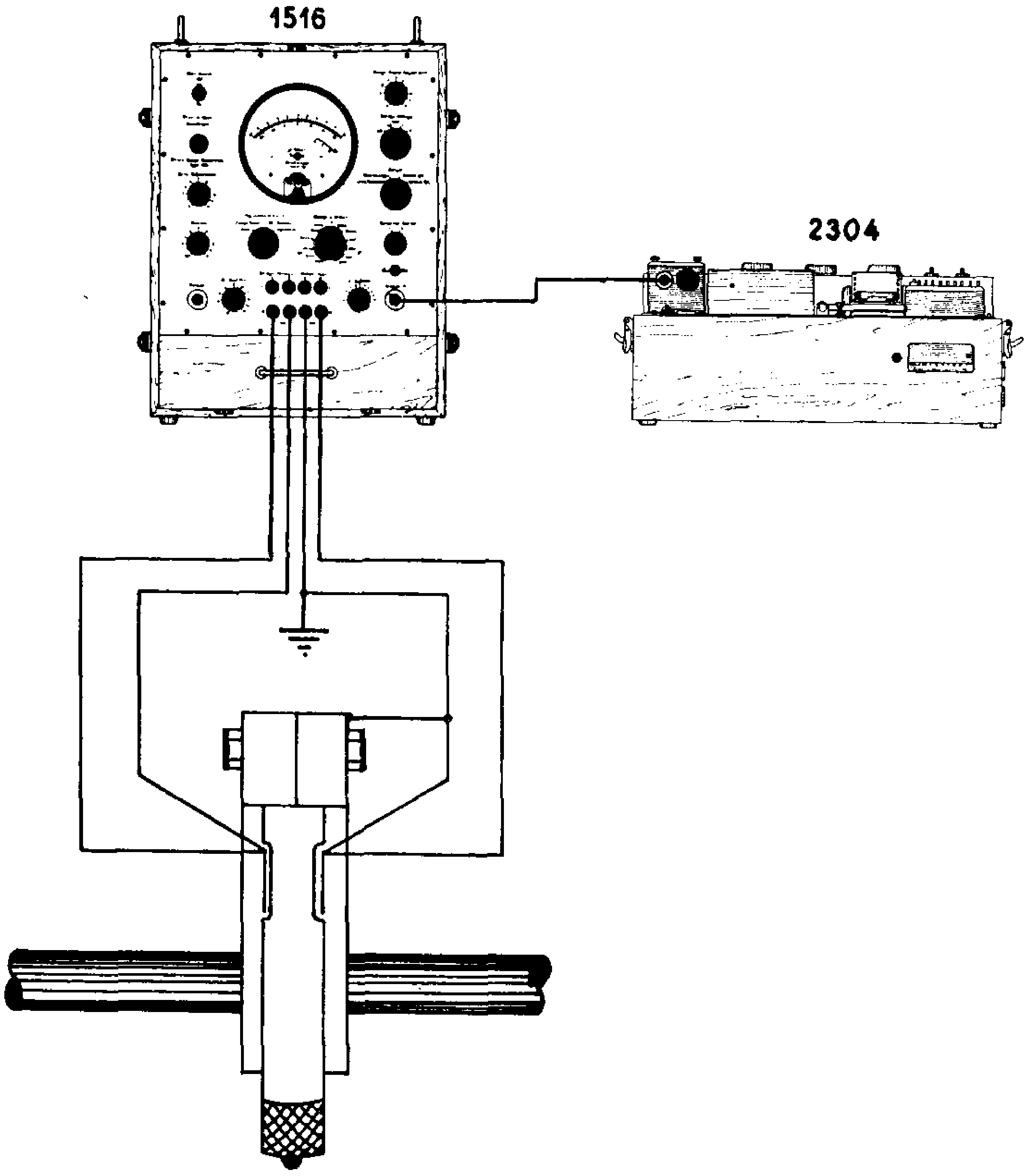


Fig. 6. Circuit diagram.

A typical low speed recording is shown in fig. 7a. The length of stroke was maintained constant and the number of strokes per minute varied from 1 to 6. The writing speed of the Level Recorder was set to a maximum value of 500 mm/sec. and two different paper speeds were used, 1 mm and 10 mm/sec.

From the explanatory diagram 7b, may be seen the idealised curves for such a measurement.

Comparison of the theoretical curve and the recording shows a close similarity, it is interesting to note, that certain peaks may be observed for each stroke, indicating that some irregularity exists on the track. This is particularly true at one end of the stroke, where there is a pronounced deflection of short duration caused by seizure or sticking through the protecting oil film.

The experiment described is a typical example of the application of strain gauges and strain measuring equipment. It shows that use of strain gauges is not confined to structural measurements and that the technique may be applied to problems where the measured strain has been produced in order that some other phenomena may be studied. Fig. 8 shows the two instruments employed, the B. & K. Strain Gauge Apparatus Type 1516, and the Level Recorder Type 2304.

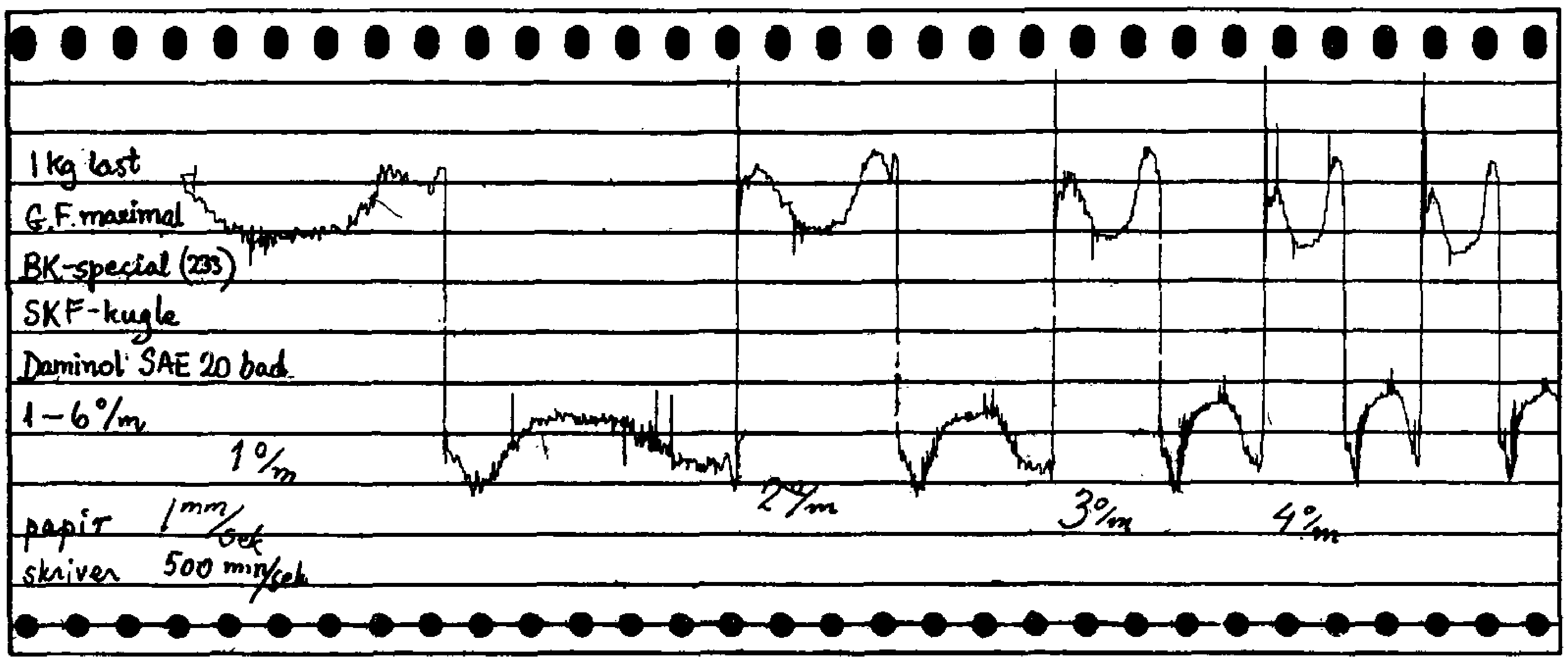


Fig. 7a. Recorded curves.

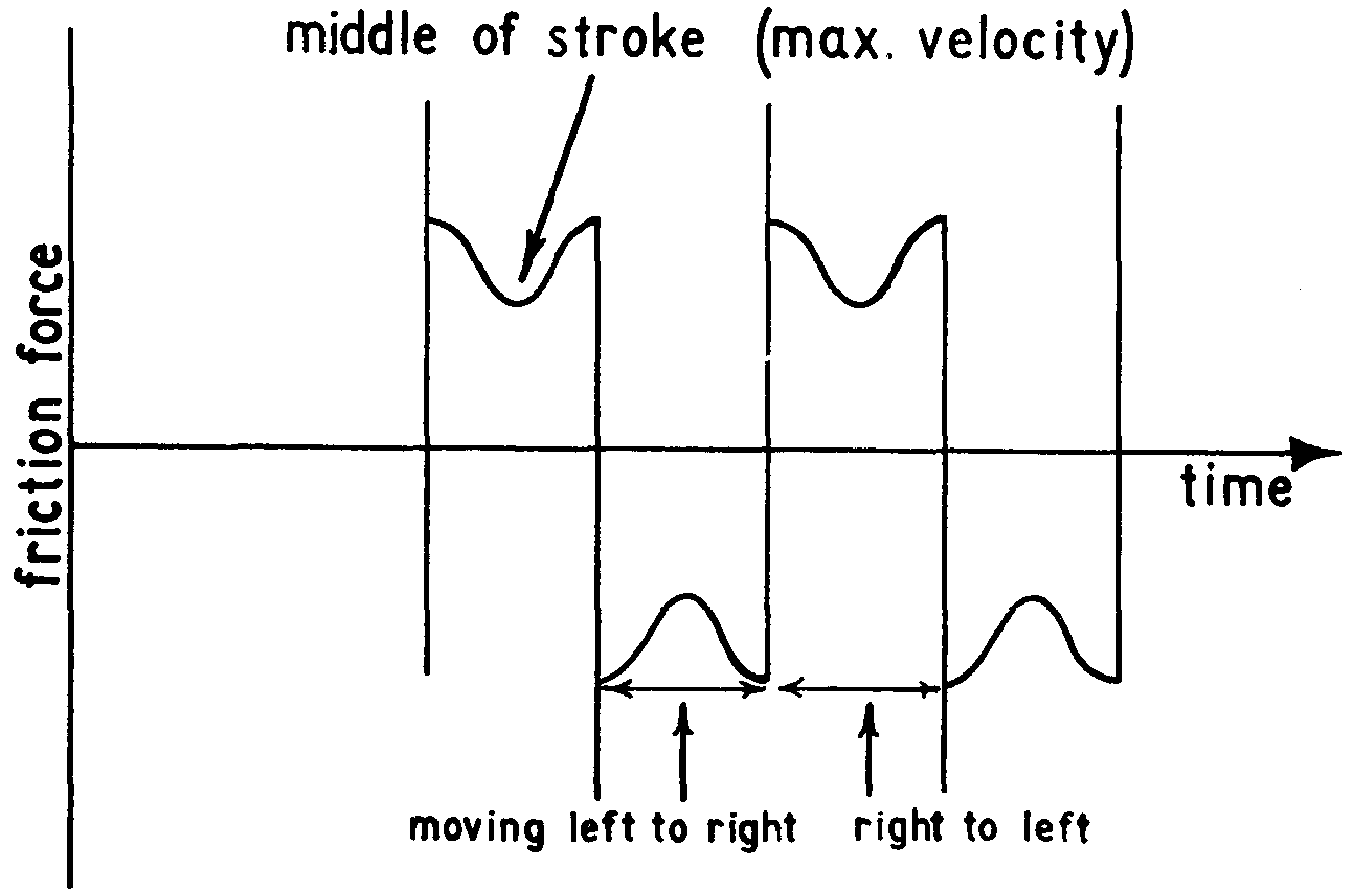


Fig. 7b. Idealized curves.

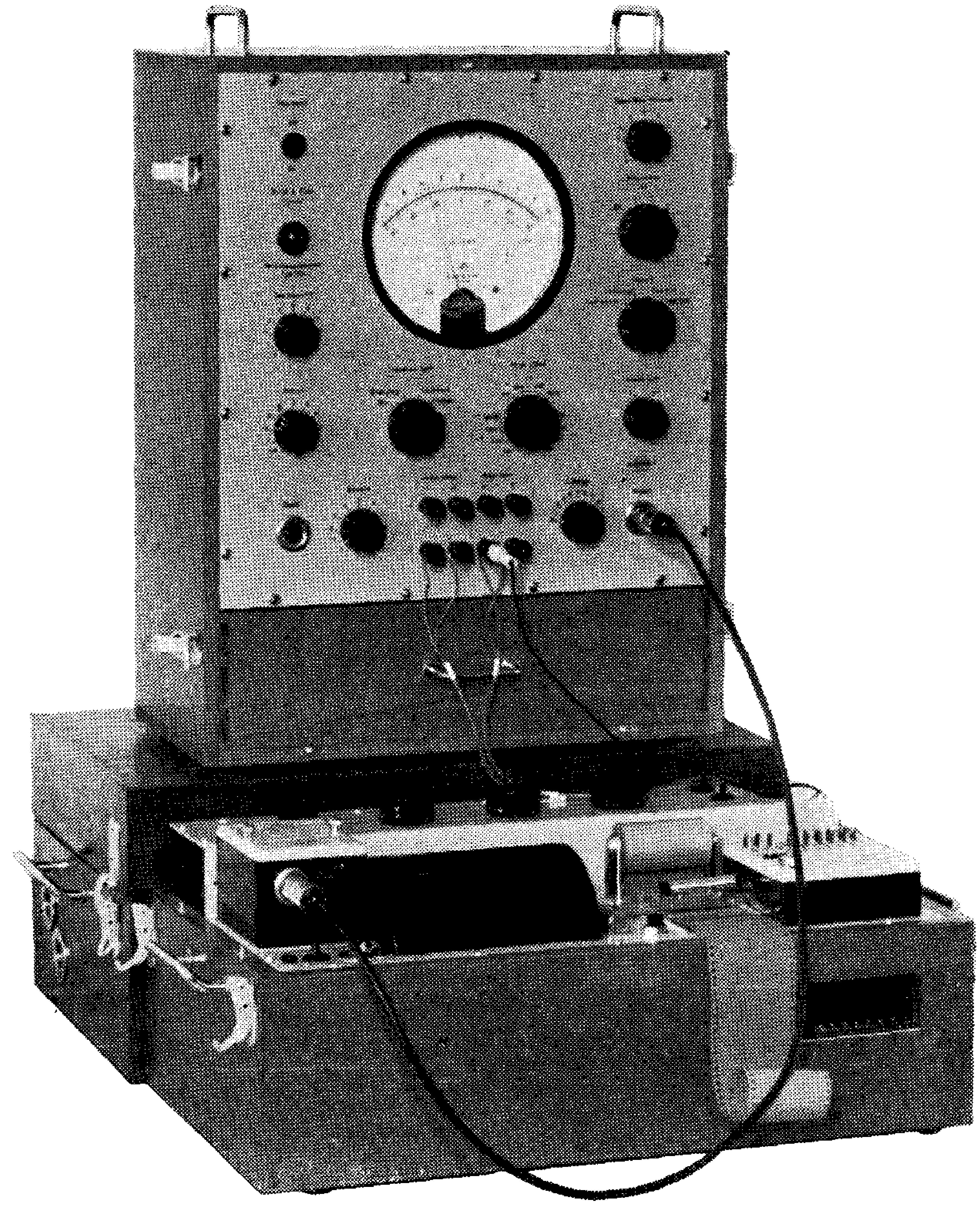


Fig. 8. Photograph of 1516 and 2304.

Acknowledgements.

Work on this project is being done by Civilingeniør Vagn Fabritius Buchwald, under the leadership of Prof., Dr. Techn. E. Knuth-Winterfeldt and Manager, Dr. Techn. Børge Lunn. Thanks are due to all parties for permission to publish this article and in particular to V. F. Buchwald for his willing co-operation.

A COMPENSATION CURVE FOR USE WITH THE STRAIN GAUGE APPARATUS TYPE 1516

by

William E. Green

It may be quite safely stated that in the majority of applications strain gauges with resistance values in the range of 50—250 Ω will be employed. A further analysis of the range would show that a very large percentage of these gauges would be grouped around 120 Ω.

In all bridge balancing systems where the balance components constitute an integral part of the bridge, the effectivity of the components will be governed by the values to be balanced. In an effort to obtain a reasonable compromise in the Strain Gauge Apparatus Type 1516, each instrument scale is individually calibrated at the factory with precision resistors of 100 Ω. The internal shunt balancing components being in the circuit at the time of calibration. After initial zeroing of the Type 1516, the calibrating resistors which shunt one arm of the calibration bridge, are switched in and the scale recorded.

The values of resistive balancing components must be such that they accommodate the normal manufacturing tolerance that manufacturers ascribe to their gauges, and a reasonable amount of out-of-balance introduced by asymmetrical wiring resistance. Herein then lies the basic problem, the balancing component must be able to influence the bridge balance and, at the same time, have no adverse effect on the measuring accuracy. Obviously both conditions can not be satisfied over a wide range of gauge resistance, because of the shunting effects.

An inspection of the theoretical diagram showing the balancing circuit, fig. 1, reveals what appears to be a solution to the problem. The circuit alteration would involve shunting the fixed 100 Ω resistors instead of the gauges, however this remedy would only be effective for a two gauge bridge.

In some special applications, such as the strain gauging of revolving shafts, the supply to the gauge bridge, and the output signal are conducted through slip rings. Owing to the resistance variations that occur between the slip rings and brushes it is advisable to use high resistance strain gauges. It is quite obvious, that if it is found necessary to use gauges possessing resistances between 250—5000 Ω, some form of compensation is required.

Fortunately, in the Type 1516 this is a simple matter, because the bridge voltage may be varied with the gauge factor control.

The actual loss of accuracy involved as the nominal value of the gauge resistance increases may be readily found as follows:

For simplicity only one gauge will be considered, this gauge having a resistance "r", is shunted by a resistance "R", where "R" is made up of the fixed shunt 10 KΩ and part of the variable 5 KΩ resistor. Fig. I.

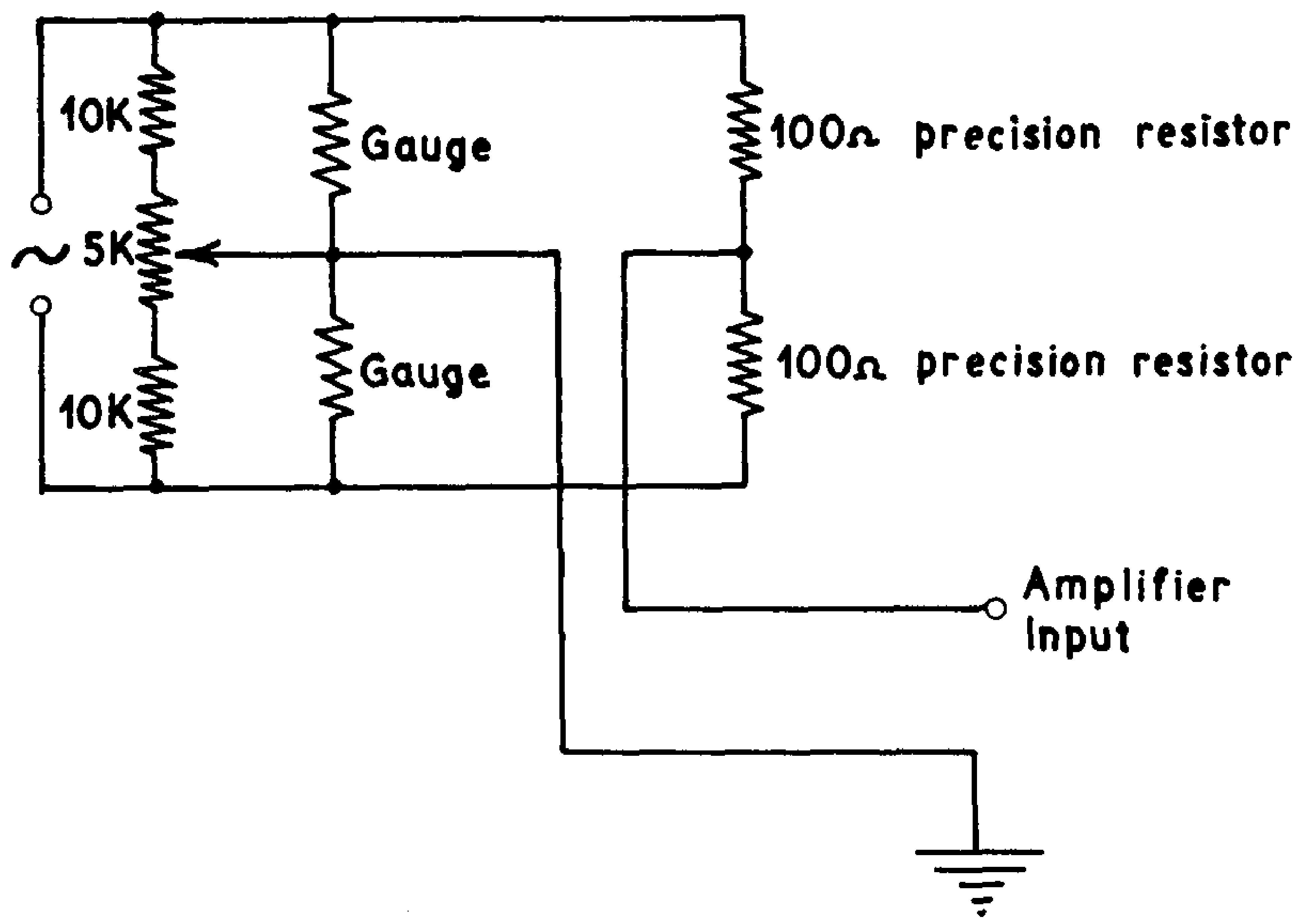
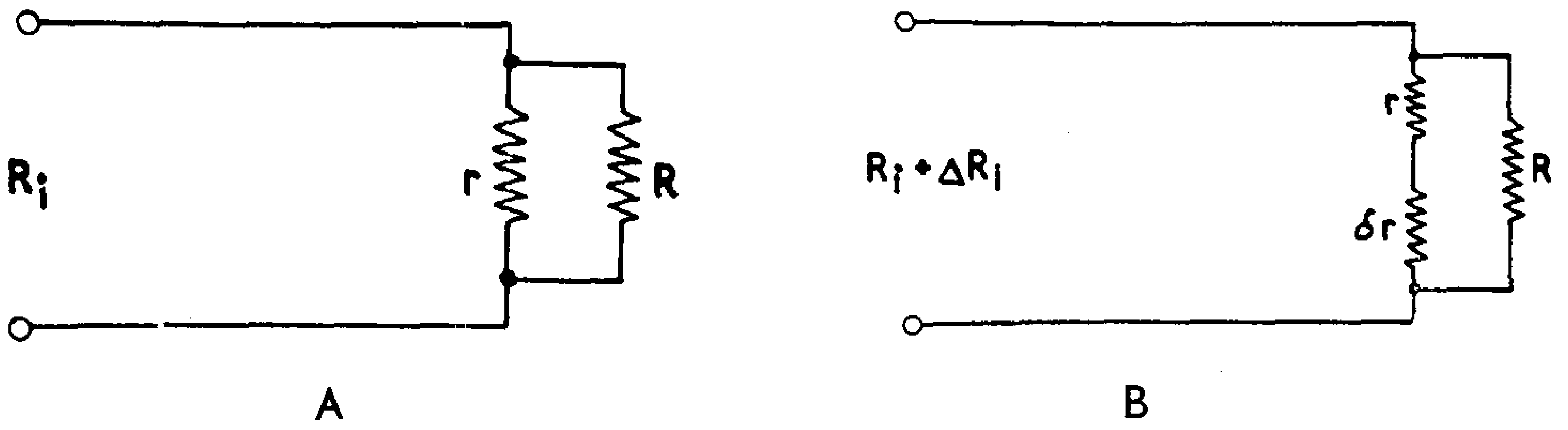


Fig. 1. Basic diagram of balancing circuit.



This combination is equivalent to some resistance R_i,

$$\text{where } R_i = \frac{R \times r}{R + r}$$

If now, due to an applied strain, gauge "r" experiences an increase in resistance δr, we have

$$R_i + \Delta R_i = \frac{R\,(r + \delta r)}{R + r + \delta r}$$

and the actual change in the combination, as a fraction of R_i

$$\Delta = \frac{(R_i + \Delta R_i) - R_i}{R_i}$$

$$= \frac{\dfrac{R\,(r + \delta r)}{R + r + \delta r} \qquad \dfrac{R_r}{R + r}}{\dfrac{Rr}{R + r}}$$

$$= \frac{R\,(r + \delta r)\,(R + r)}{(R + r + \delta r)\,R_r} - 1$$

$$\Delta = \frac{R\,(r+\delta r)\,(R+r) - (R+r+\delta r)\,R}{(R+r+\delta r)\,R_r}$$

$$= \frac{R^2\,\delta r}{(R+r+\delta r)\,R_r} = \frac{\delta r}{r} \cdot \frac{R}{R+r+\delta r} \qquad \text{— — — —} \quad (1)$$

If $\frac{R}{r} = M$, (1) becomes

$$\frac{\Delta R_i}{R_i} = \frac{\delta r}{r} \cdot \frac{M_r}{M_r + r + \delta r} = \frac{M}{M + 1 + \frac{\delta r}{r}} \cdot \frac{\delta r}{r}$$

because $\delta r << 1 < M$ we may write

$$\frac{\Delta R_i}{R_i} = \frac{M}{M+1} \cdot \frac{\delta r}{r}$$

Thus it may be seen that for values of $M >> 1$

$$\frac{\Delta R_i}{R_i} \simeq \frac{\delta r}{r}$$

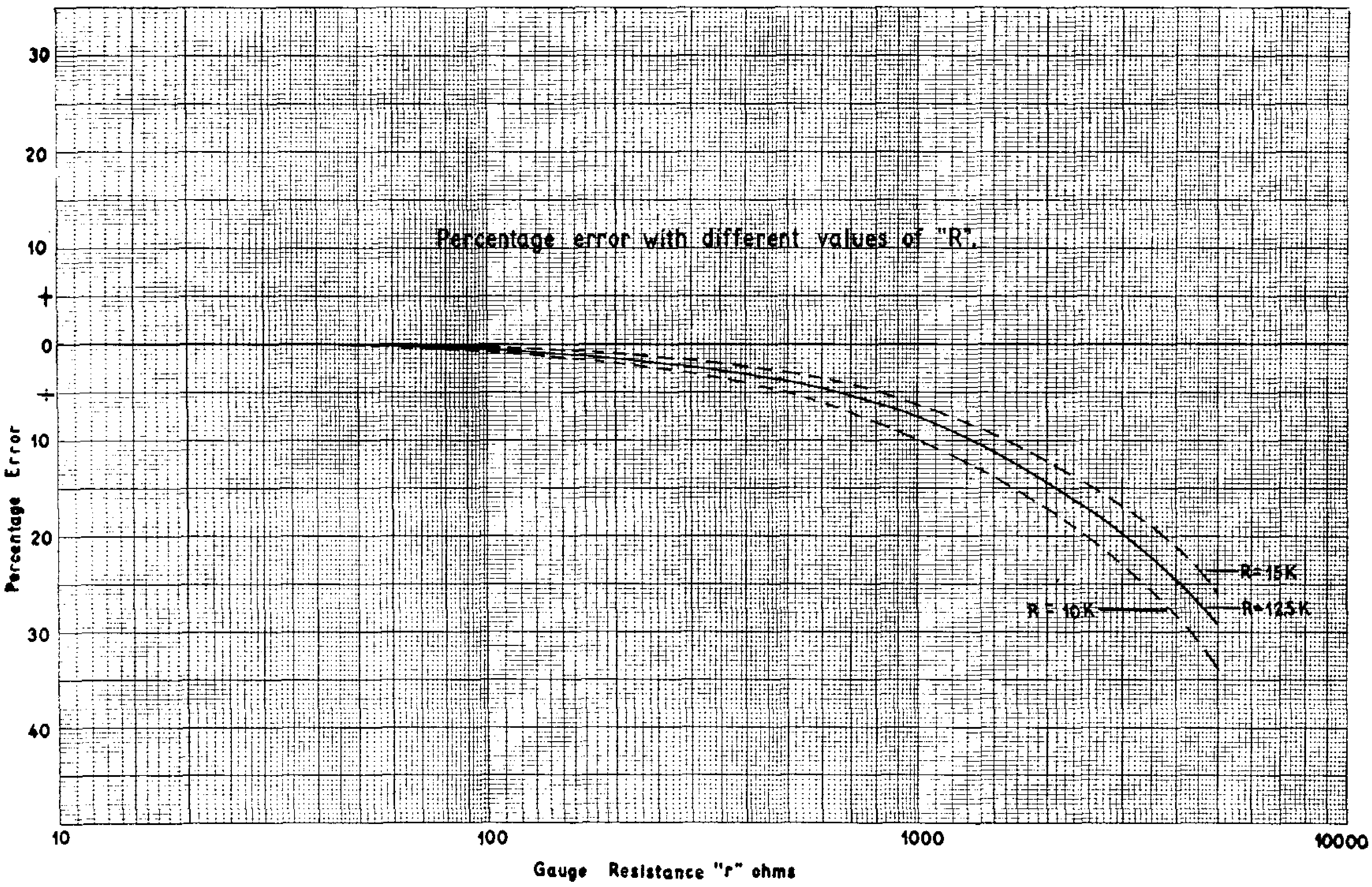


Fig. 2. Percentage error as a function of Gauge Resistance.

The curve fig. 2 shows the actual percentage error which will exist for various values of gauge resistance.

Only the three most important values of R have been considered. The actual value of R will of course depend on the closeness of the tolerance of the external gauges.

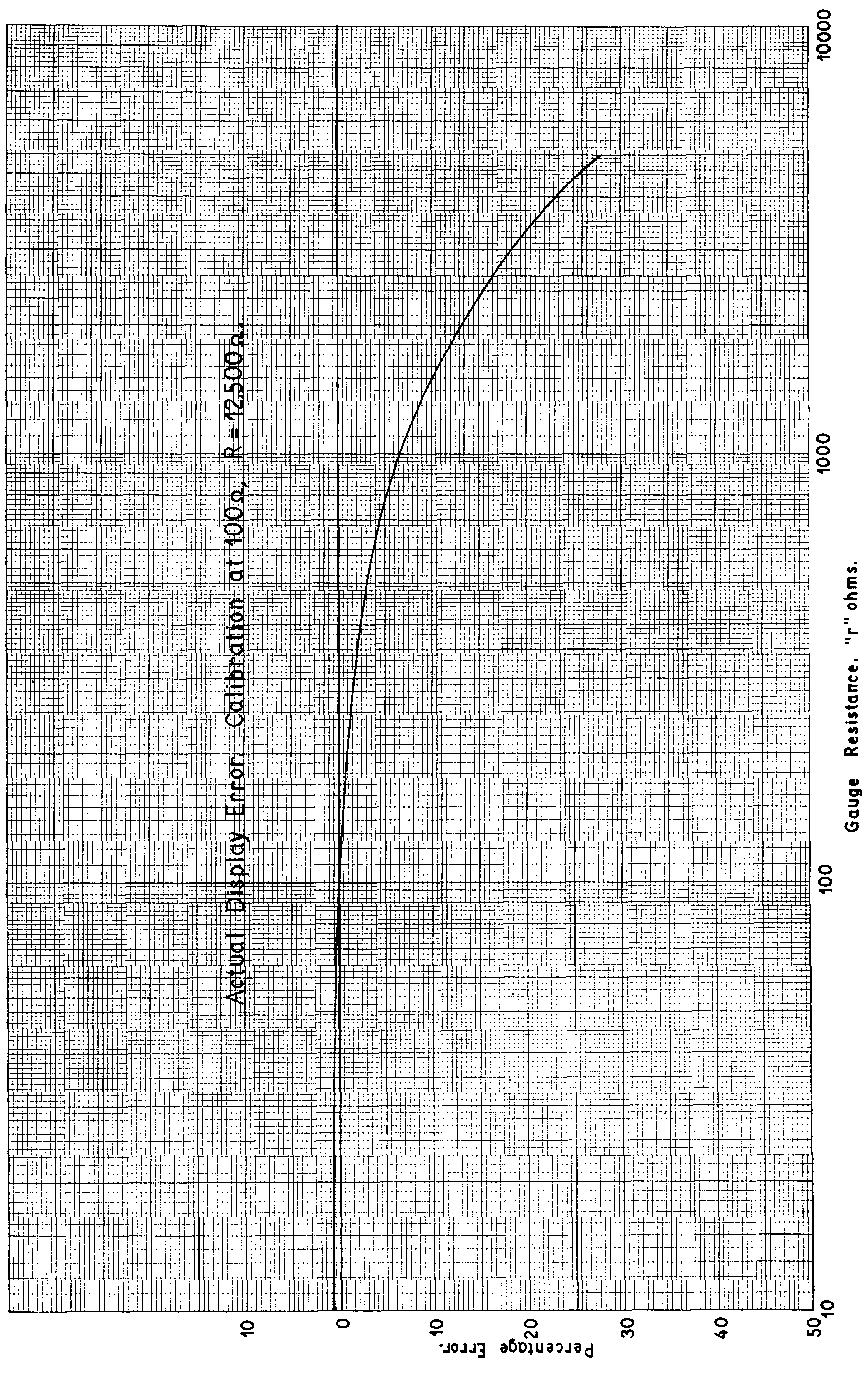


Fig. 3. Curve showing the display error for different values of Gauge resistance.

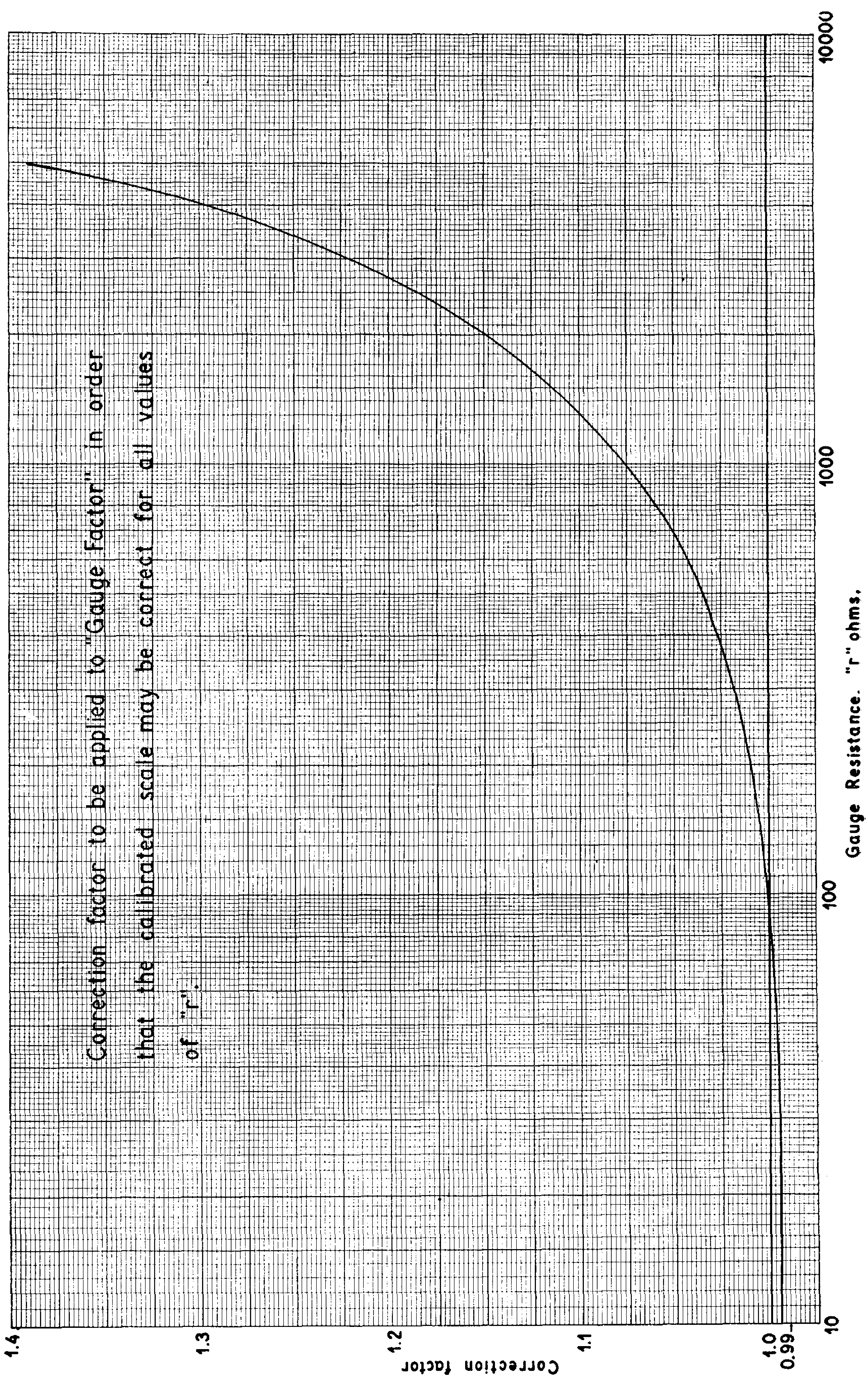


Fig. 4. Error compensation through Gauge Factor adjustment.

The actual display error is shown in fig. 3, this curve assumes that

$$R = 12.5\ K\Omega$$

the calibration having been made with an "r" value of 100 Ω, as previously stated.

The compensation curve shown in fig. 4 enables the appropriate factor to be determined for any gauge resistance value "r", between 10 ohms 5000 ohms.

A simple example is the best way to illustrate the application.

Let the resistance of the gauges	"r" = 750 · 0 Ω
the gauge factor	K = 2.2
Number of active gauges	= 1

The setting up instruction in the Type 1516 manual should be followed, but in the "Gauge Factor" position of the "Adjustment Switch" the gauge factor should be set to a value G.F'.

$$\text{when GF'} = \frac{\text{actual gauge factor}}{\text{correction factor}}$$

which in the above example would be $\frac{2.2}{1.053} = 2.09$

The effect of reducing the gauge factor setting is to raise the bridge voltage, which automatically compensates for loss of sensitivity.

In the event of GF having a numerical value less than 2 the setting should be multiplied by 2 and also the meter reading.

Ex.

The gauge resistance "r"	= 1000 Ω
The gauge factor	= 2.0
Number of active gauges K	= 1.

From the compensation curve the correction factor is found to be 1.0725

$$GF' = \frac{2.0}{1.0725} = 1.865$$

Actual setting on GF scale = 1.865 × 2 = 3.730

The strain reading read off the μ Strain scale must now be multiplied by 2

The above may be summarized by saying the following:

Condition a)

1 active strain gauge

$1 < GF' < 2$

Actual setting on GF scale = GF' × 2.

The meter reading must be multiplied by a factor of 2.

Condition b)

1 active strain gauge

$2 < GF' < 4$

Actual setting on GF scale = GF'.

The reading from the meter is then correct.

SHUNT BALANCING OF BRIDGE CIRCUITS

by

William E. Green

It follows from the preceding discussion that the ability of a shunt balance system to accomodate differences of resistance in a strain gauge bridge will depend on the relationship of balancing resistor resistance to gauge resistance.

The case will be considered when two strain gauges are used with the Strain Gauge Apparatus Type 1516. Under these circumstances the other two arms are made up of 100 Ω wire wound precision resistors.

In order to determine the "effectivity" of the balancing controls the gauges will be assumed to have some nominal resistance 'r', due to manufacturing tolerances one gauge is in excess of 'r' by a percentage 'α' and the other gauge is below 'r' by a similar factor.

The effectivity of the balance control may be defined as the largest value of 'α' which may be compensated. This is obviously a limiting condition and will be determined for various values of 'r'.

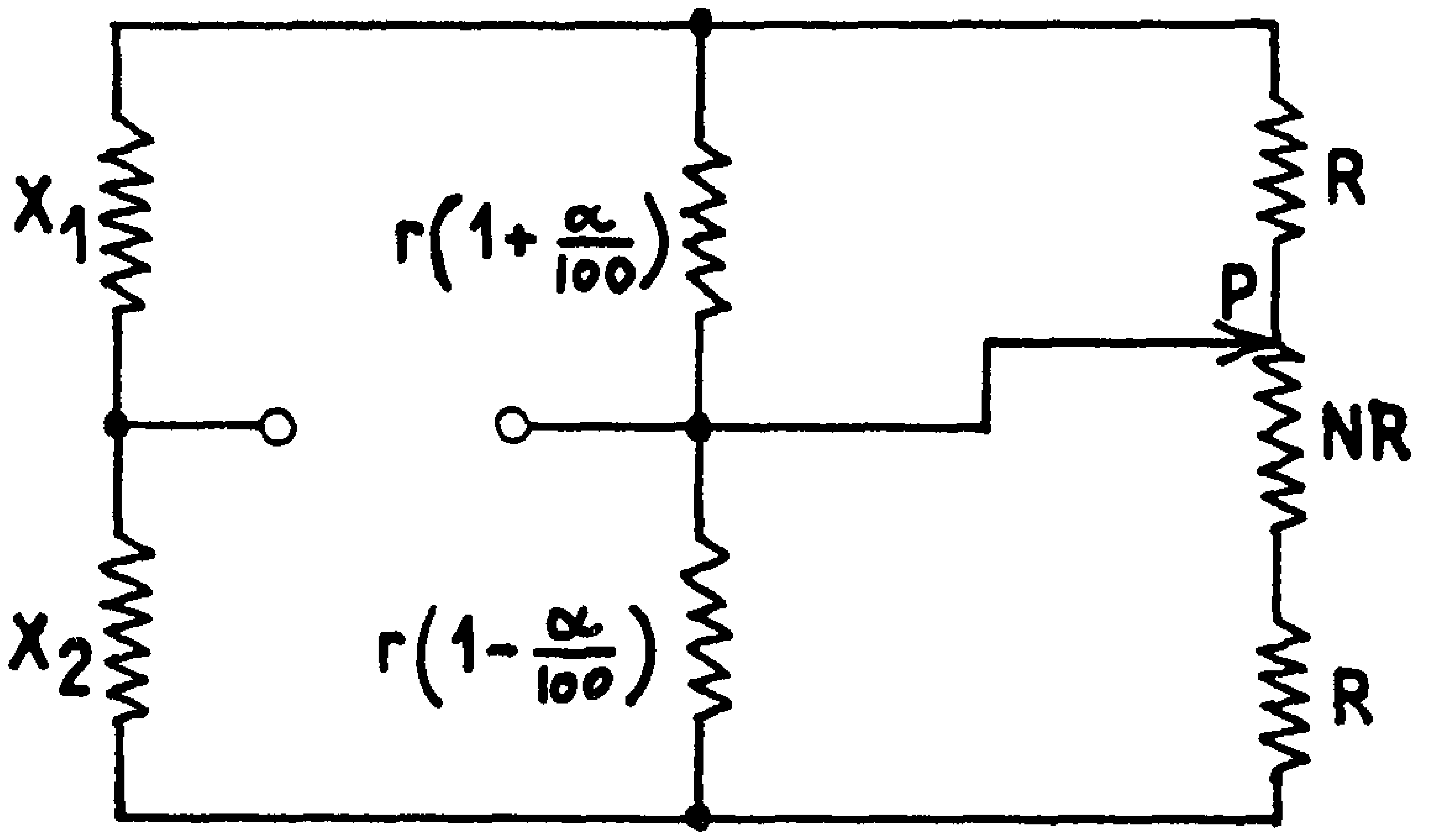


Fig. 1. Theoretical circuit.

The diagram in fig. 1 is the theoretical circuit for the condition as described, resistors x_1 and x_2 may be assumed equal.

Because the condition of interest is the limit, tap 'P' will be at the top of NR.

$$\text{Let } \frac{\alpha}{100} = T.$$

For balance then

$$\frac{1}{r(1-T)} - \frac{1}{R} = \frac{1}{r(1-T)} - \frac{1}{R(1+N)}$$

$$\frac{R}{1} - \frac{1}{R\,(1+N)} = \frac{1}{r\,(1-T)} - \frac{1}{r\,(1+T)}$$

$$\frac{R\,(1+N) - R}{R^2\,(1+N)} = \frac{r\,(1+T) - r\,(1-T)}{r^2\,(1-T^2)}$$

$$\frac{Nr}{2\,R\,(1+N)} = \frac{T}{(1-T^2)}$$

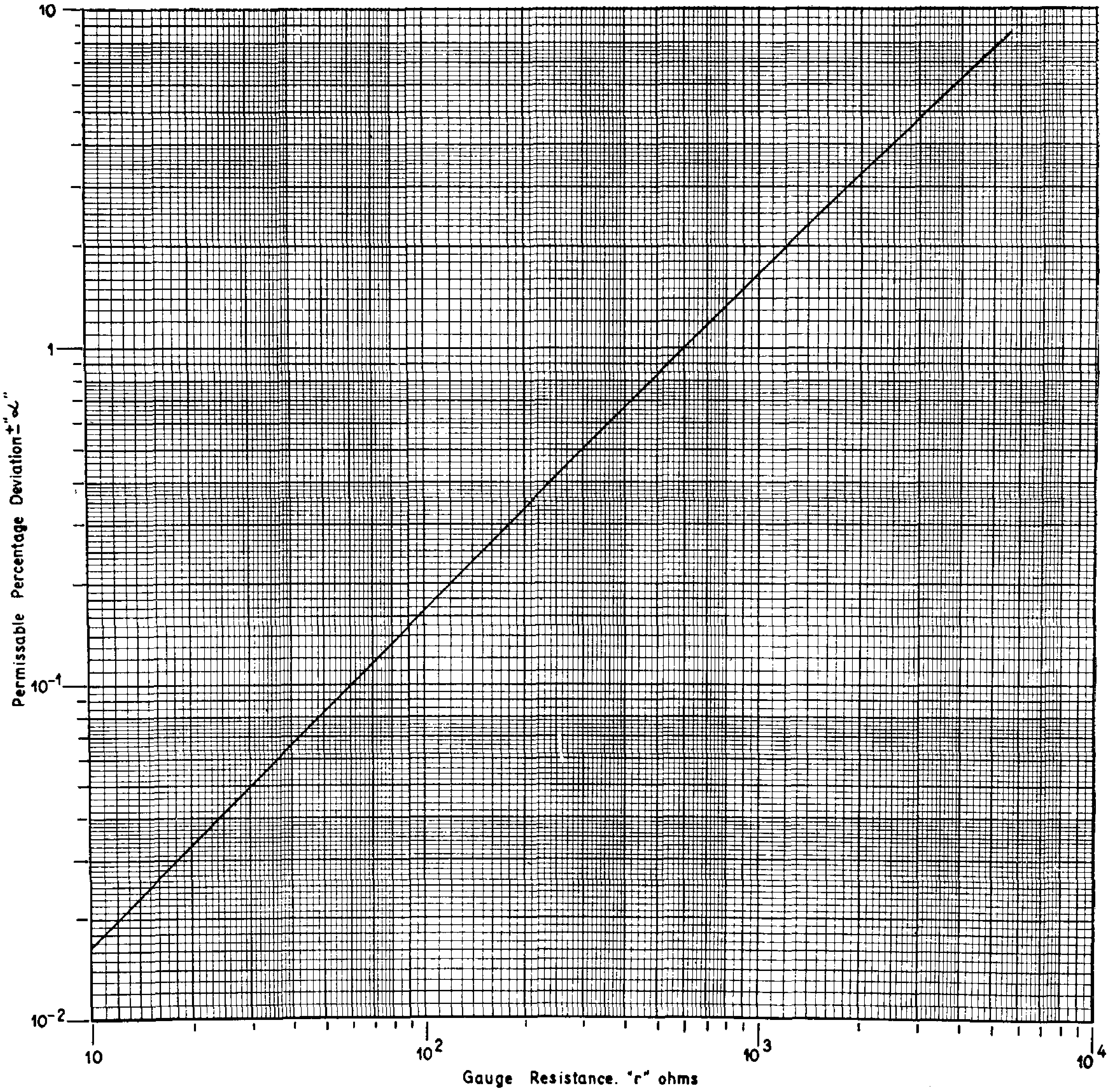


Fig. 2. Curve showing the relationship between "α" and Gauge resistance for the Strain Gauge Apparatus Type 1516.

If $T << 1$, it may be ignored.

$$\text{and } \alpha = \frac{100\,N \cdot r}{2R\,(1+N)} \quad - - - \qquad (1)$$

Now for a particular instrument N is constant, therefore the values of 'α' which can be accommodated for various values of $\frac{R}{r}$ may be found, and a graph plotted, fig. 2.

In the 1516, 'N' has a value of 0.5 and (1)

therefore becomes $\dfrac{50}{3 \times \frac{R}{r}} = \alpha$, for small values of T.

r ohms.	10	50	100	250	500	1000	5000
$\frac{R}{r}$	1000	200	100	40	20	10	2
α % deviation	1.67×10^{-2}	8.33×10^{-2}	1.67×10^{-1}	4.165×10^{-1}	8.33×10^{-1}	1.67	7.82

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