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LARGE SCALE METROLOGY

A.J. Scarr D.Ae; D.C.Ae; A.M.I.Mech.E;
A.M.I.Prod.E; A.F.R.Ae.S.

INTRODUCTION

It has been recognised in industry that the measurement of large components to high orders of accuracy presents a particularly difficult problem. This fact has been emphasised by a survey carried out by the N.P.L. (Ref. 1) in which a number of engineering firms in Great Britain were asked to declare the size of several prepared test pieces ranging in diameter from 15 inches to 80 inches.

In general terms the result of this investigation showed that, under industrial conditions using conventional equipment, it was not possible to declare the size of large components to an accuracy of better than - 30 parts in a million under workshop conditions and - 15 parts in a million under inspection conditions. The survey also showed that above 20 inches the accuracy of determination of internal diameters was somewhat higher than for external diameters.

The purpose of this paper is to indicate the main problems associated with measuring large sizes and to describe the experimental work undertaken at the College of Aeronautics in the design and testing of a new type of stick micrometer for internal diameters and micrometer frame for external diameters.

PROBLEMS ASSOCIATED WITH MEASURING LARGE SIZES

These may be classified under three broad headings:

1. The influence of temperature on the measurement
2. Problems associated with the stiffness of the measuring equipment
3. The elimination of operator feel.

1. The influence of temperature

In considering the result of variations in temperature from 20°C it is important to remember that both the workpiece and the measuring equipment is subject to its effect. As far as the measuring equipment is concerned the most likely sources of heat input are from the handling of the equipment and from ambient temperature differences from 20°C. The workpiece is also affected by ambient temperatures and may also be subjected to considerable heating during machining operations.

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- Let t_1 = temperature of workpiece
 t_2 = temperature of measuring equipment
 α_1 = coefficient of expansion of workpiece
 α_2 = coefficient of expansion of measuring equipment
 δt_1 = temperature difference from 20°C of workpiece ($t_1 - 20$) $^\circ\text{C}$
 δt_2 = temperature difference from 20°C of measuring equipment ($t_2 - 20$) $^\circ\text{C}$
 L = length being measured

The error in measurement δL caused by the temperature differentials δt_1 and δt_2 is given by:

$$\delta L = L (\alpha_1 \delta t_1 - \alpha_2 \delta t_2)$$

It can be seen from this equation that where the coefficient of expansion of both the measuring equipment and workpiece are the same then provided that they are both at the same temperature, regardless of whether this is 20°C or not, a correct determination of size will be obtained. Where, however, the workpiece has a different expansion rate to that of the measuring equipment then they must both be at 20°C to obtain a correct result.

The particular problems associated with temperature in the measurement of large sizes may be illustrated by reference to fig. 1. This shows the effect of variations in the temperature of steel components with respect to the Fundamental Tolerance value established in the British Standard on 'Limits and Fits for Engineering' (BS 1916). The particular case illustrated is for a 3°C difference in temperature between the component and measuring equipment expressed as a percentage of the manufacturing tolerance grade IT6. The coefficient of expansion for steel has been taken as 11 parts in a million $/^\circ\text{C}$.

It can be seen from fig. 1 that in the smaller sizes up to say 10 inches the percentage of the tolerance taken up by the 3°C difference in temperature remains relatively small, but with increase in size the effect of temperature becomes increasingly significant, until at 100 inches 82% of the tolerance grade has been consumed.

Further problems occur on large components where the time taken for their temperature to stabilise after, for example, machining operations may be prolonged. Professor Sawin (Ref. 2) suggests that the time necessary to reduce a temperature difference from $T^\circ\text{C}$ to $t^\circ\text{C}$ for a steel component may be calculated from the relationship

$$Z = 31.3 \frac{G}{F} \times \log \frac{T}{t}$$

- where Z = time in minutes to cool from T to t
 G = component weight in grammes
 F = component surface area in cm^2



For components weighing 1000kg the time taken to reduce the temperature difference to 0.2°C may be more than two days.

With regard to the measuring equipment an anomaly arises in that it needs to be insulated from the effect of body heat whilst it is being handled and yet it is desirable that it should be able to follow changes in ambient temperature. Reference will be made to this when dealing with the Cranfield stick micrometer.

2. Stiffness of the measuring equipment

Appreciable errors may arise due to the lack of stiffness in the measuring equipment in the measurement of both internal diameters with a stick micrometer and external diameters with a micrometer frame.

In the case of the stick micrometer the position of the supports is important and should be placed so as to give the minimum shortening of the bar. This relationship, originally determined by Sir George Airy is given by $\frac{L}{\sqrt{n^2 - 1}}$

where L = total length of the bar
n = number of supports

It can be shown that the number of supports may be reduced to two with negligible effect on the overall length, when the spacing becomes $\frac{L}{\sqrt{3}}$.

In the case of the micrometer frame the calibration of the micrometer, against a standard such as end bars, should take place in the same plane as the measurement. In industrial applications it is a common practice to calibrate in the horizontal plane and then measure in the vertical plane. This will introduce errors into the measurement due to the deflection of the micrometer frame and should be avoided if at all possible.

3. Elimination of operator feel

It is considered to be essential that some form of fiducial indicator is incorporated in the measuring equipment to avoid introducing errors due to the 'feel' of the operator.

The operation of the fiducial indicator may be mechanical, pneumatic or electrical, each system offering certain advantages. However, recent developments in the application of transistorised techniques have enabled battery operated electrical transducer units to be produced. These, in addition to providing high magnification over an appreciable range have the added advantage of being self contained and independent of an external power supply.

Stick micrometer for internal diameters developed at the College of Aeronautics.

Figure 2 shows the basic measuring element of the stick micrometer. This consists of a $7/8$ inch o.d. x 18 s.w.g. steel tube, with solid threaded anvils at each end. The end faces are lapped flat and parallel to one another, and the units may be joined together in combinations via the threaded connection. The steel tube is surrounded by a 2 inch o.d. x 0.1 inch thick fibre glass tube, with the annulus between filled with a foamed resin. The fibre glass tube, plus foamed resin, has the two fold effect of firstly insulating the steel measuring element when handled by the operator, and secondly serves to stiffen the steel tube and prevent error due to deflection of the stick micrometer. This basic measuring element is made in a variety of lengths enabling combinations to be made up in increments of one inch.

The fiducial measuring element is shown separately in fig. 3 and consists of a pneumatic sensing unit and meter display. The measuring element is fitted into a body which enables adjustment to be made over a range of one inch. A direct reading may be made from the meter to .0001 inches over a range of $\pm .002$ inches.

Experimental results were obtained to determine the accuracy of this equipment under both inspection and workshop conditions. The same standard test pieces were used in this investigation as those used in the N.P.L. survey and the relative results may be considered comparable. Under inspection conditions an accuracy of ± 4 parts in a million may be obtained with the Cranfield equipment compared with ± 15 parts in a million from the N.P.L. survey. Under workshop conditions the comparable values are ± 7 parts in a million as against ± 30 for the N.P.L. survey. The accuracies quoted above are for the absolute determination of size; the repeatability of the stick micrometer was found to be ± 2 parts in a million.

The insulation properties of the stick micrometer are such that holding the unit in two hands in an ambient temperature of 20°C for 20 mins gave an extension of 10 parts in a million. As mentioned earlier the insulation required to minimise the effect of heat from handling is in conflict with the desirability of the stick micrometer responding quickly to changes in the ambient temperature. In the test on the insulation properties it was found that drilling a $1/8$ inch dia hole through the fibre glass and inner steel tube reduced the time necessary for the bar to return to ambient conditions from 125 minutes to 50 minutes.

The stiffness is such that the difference in length when supported horizontally at the Airy points and supported at positions to give maximum deflection, results in a change in length of 1 part in a million.



Micrometer frame for external diameters developed at the College of Aeronautics

The micrometer frame * shown in fig. 5 is a composite construction consisting of 24 s.w.g. steel side and channel members stabilised with a light alloy honeycomb structure, the whole being bonded together with Redux.. The particular advantage of this type of construction is the high rigidity obtained combined with lightness in weight, thus enabling the micrometer to be easily manipulated in practice.

The maximum capacity of the micrometer illustrated is 24 inches and the frame plus measuring head and anvil weighs 3 lb. This is appreciably less than the weight of a conventional micrometer of this capacity whilst the stiffness is well within the requirements called for in the current British Standard BS 870.

The fiducial measuring head is again pneumatic in operation although, as indicated earlier in this paper, subsequent experience would suggest that an electronic transducer unit could offer advantages particularly if it were battery operated and self contained.

Experimental work under both inspection and workshop conditions indicates that the accuracy of determination using the micrometer corresponds closely to that obtained with the stick micrometer namely - 4 parts in a million under inspection conditions and - 7 parts in a million under workshop conditions.

Conclusions

By the use of measuring equipment such as has been described in this paper and with an awareness of the precautions which are necessary with regard to temperature effects, it is considered that a substantial improvement in the accuracy of determining large size may be obtained compared to those which are currently achieved in industrial practice using conventional equipment.

References

1. Harrison P.W. 1955 Proc. Inst. Mech. Eng. vol.169 p.977.
2. Sawin N.N. 1953 Engineering Dimensional Metrology Symposium vol.II p.495 H.M.S.O.
3. Jolly T.P. 1962 The Accuracy of Industrial Measurement of Length and Diameter Symposium p.143 H.M.S.O.

* A patent application (17641/65) has been filed for the micrometer frame through the National Research Development Corporation of Great Britain.

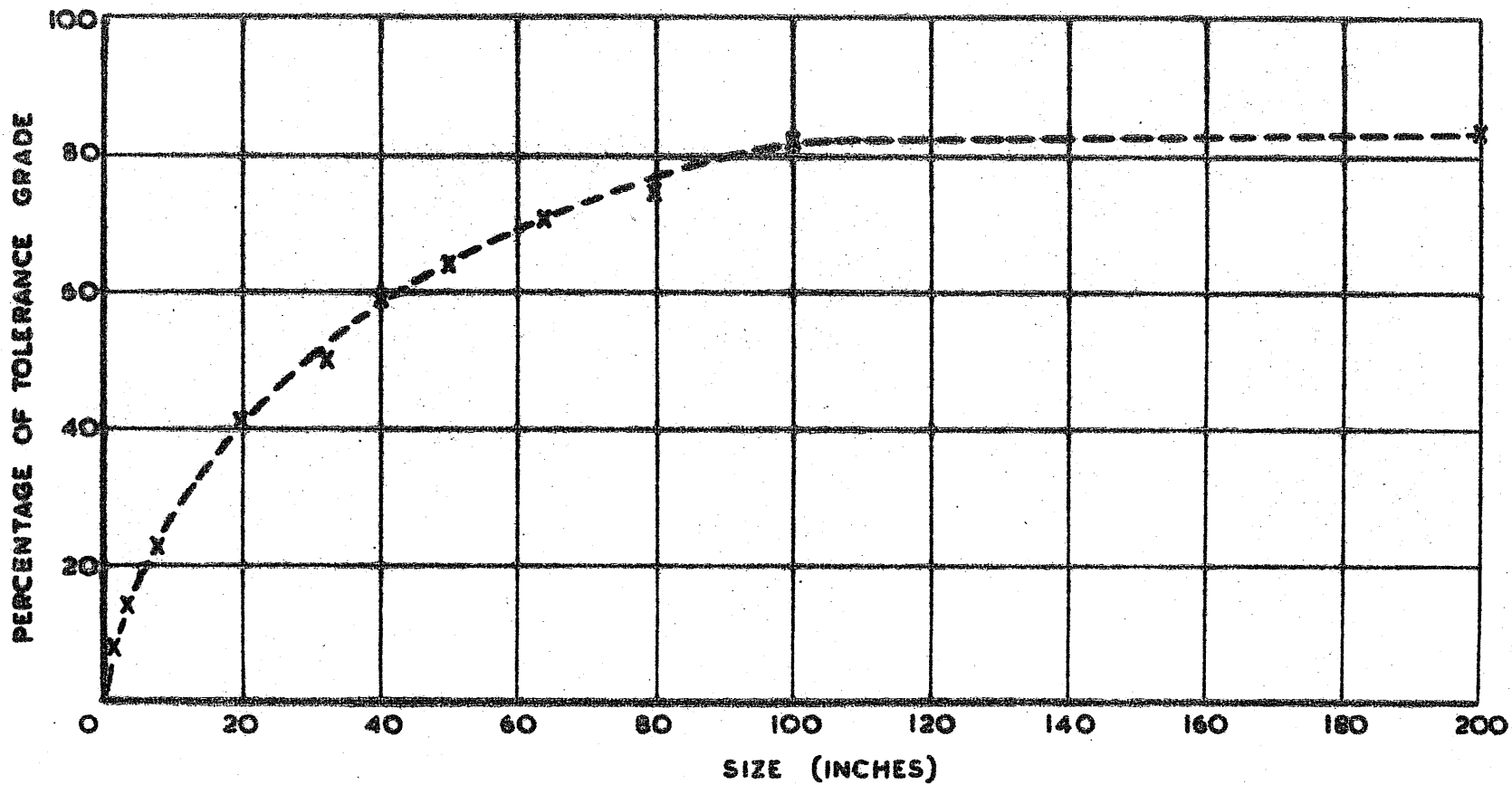


FIG.1. PERCENTAGE OF TOLERANCE GRADE IT6 TAKEN UP BY A 3°C RISE IN TEMPERATURE ON A STEEL COMPONENT.

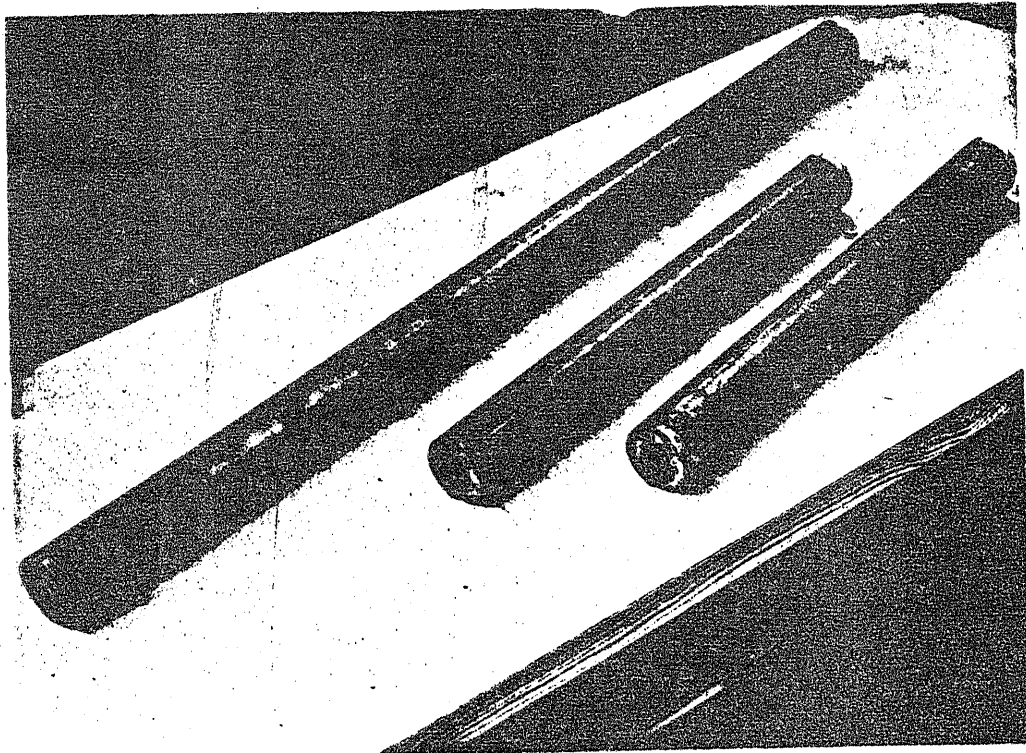


FIGURE 2.

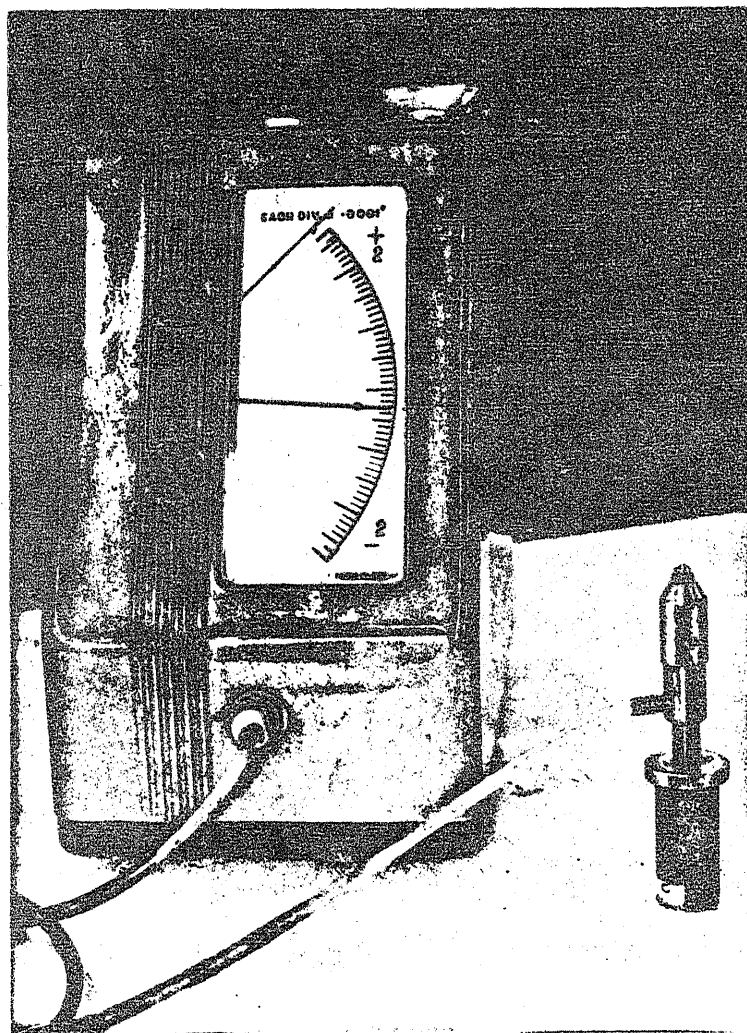


FIGURE 3.





FIGURE 4.

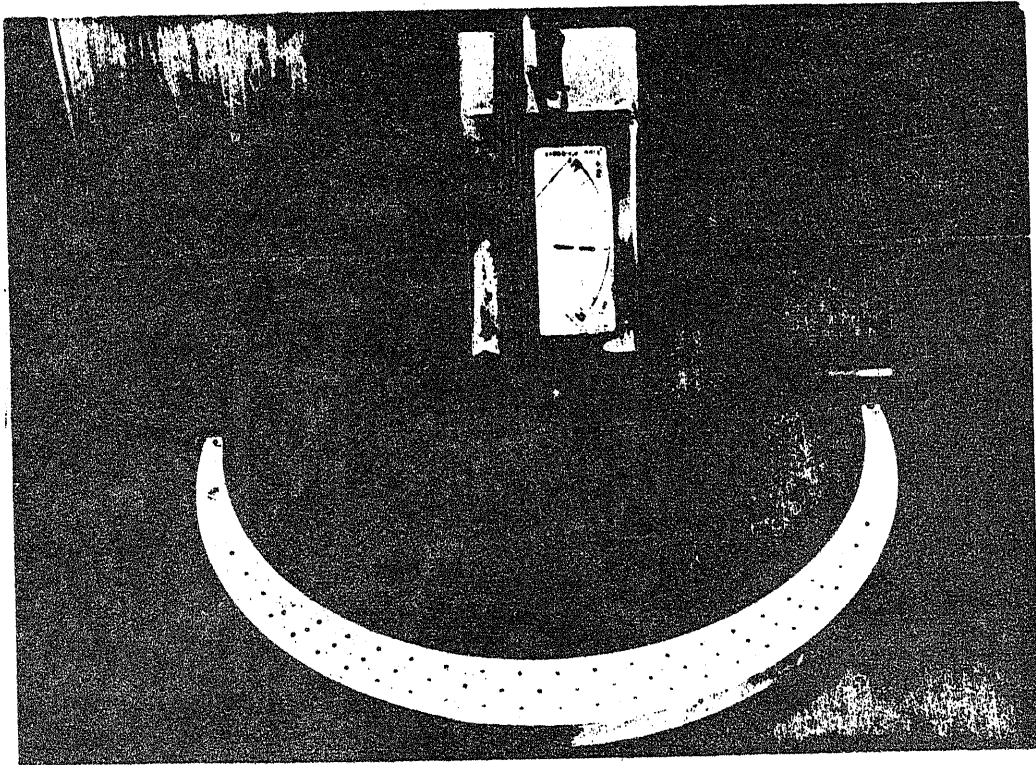


FIGURE 5.

