LECTURE BY MR. J. H. HOBBS.

Mr Chairman and gentlemen,

It is with considerable pleasure that I received your invitation to come here this evening to talk to you for a brief time on Precision Measurement.

It does, perhaps, seem rather presumptuous that I should come to Coventry, which after all is recognised as one of the homes of Precision Engineering, to talk to you about 'precision'. I do trust, however, that you will bear with me and I hope during the course of this talk to provide you with something of interest.

Any study of precision measurement should be prefaced by a consideration of what is meant by 'precision' and where the use of specially designed instruments is necessary when precision measurements have to be made.

Most measurement today is comparison against known standards of length, these standards usually take the form of what are known today as 'Slip Gauges'. These slip gauges are made in fractional parts of the inch, and in increments of the inch, in the case of English measurement, and likewise in units of the centimeter in regard to metric measurement.

However, before even these Slip Gauges can be produced, a standard unit of length which would not vary, had to be employed. There is the well-known story of a little girl who found a long worm on the garden lawn, she was asked by her mother to say how long it was, whereupon the following reply was forthcoming, "Oh, it was as long as a piece of string". Now that reply, although it would hardly be accepted as an estimate of length, was nevertheless quite correct. What was faulty was the unit of length which the little girl depended upon. A piece of string is not always standard length but is variable.

In the past man experienced exactly the same difficulty and was forced to find some unit of length. The most obvious and the most convenient was rather naturally some part of the body, since any unit based on the body could be carried out with him wherever he went. One unit of length which is still in use today is the hand, which is used for giving the height of a horse and which is now

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accepted as being four inches, although it does not usually find a place in any tables of length.

Another common practice is the measurement of a piece of cloth by stretching it between the nose and the outstretched arm, while even today a quick call for an inch measure will often bring into play the distance between the top of the thumb and the first knuckle. In these two cases also, however, the unit of length is obviously too variable for accuracy, since it depends on the individual characteristics of each person adopting it.

The necessity for devising some standard unit of length which could be accepted by everyone engaged in commerce was realised as time went on, and the original yard which was adopted is said to have been the length of the arm of King Henry first. The earliest authentic standard yard, was made in 1496 in the reign of King Henry seventh, and this is still preserved, with another made in Elizabeth's reign, by the Board of Trade.

The Imperial Standard yard, which is now the basic unit of length in this country, was not made until some two hundred years later, in 1760. The standard yard was represented by the distance in a straight line between the centres of two dots marked on gold studs inserted in a brass bar.

By an act of Parliament of June 1824, this distance when measured at a temperature of 62^{o} Fah. was declared to be the Imperial Standard Yard. This original standard was unfortunately lost in a fire which destroyed both Houses of Parliament on October 16, 1834, but fortunately for posterity some copies had been made, and it was decided to make a new standard by reference to these.

The man entrusted with this work was Sir Francis Bailey, who decided to make the new standard yard from a bronze alloy consisting of copper - 16 parts, tin - 2.5 parts, zinc - 1 part. He died before the completion of the work, which was finally completed by the Rev. Sheepshanks, the metal having been cast in 1845.

At about the same time, four copies were made of this new Imperial Standard yard, which is the working standard of the Board of Trade, the fifth was cast in 1878.

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These original copies are designated 'Parliamentary copies', numbers 2, 3, 4, 5 and the last No. 6. These yard standards are one inch square sections and 38 inches long. One inch from each end gold plugs are inserted, and across each plug three transverse lines, spaced about 10 thou. of an inch apart, are marked, and the Imperial Standard yard is the distance in a straight line between these two central engraved plugs, measured when the bar has a temperature of 62° Fah. The engraved faces of the plugs are half an inch from the top face of the bar at the centre of the one inch centre at, what is known as, 'the neutral plain'.

This is the plain in which the fibres of the metal of the bar remain unstretched and change from compression to tension when the bar is supported on two rollers placed equi-distant from each end, spaced at .577 of the length of the bar apart. The bar is supported at this particular distance, known as the 'airy points of support', because when a bar is supported in this manner the minimum deflection or sag takes place at the centre of the bar, the ends remaining perfectly horizontal. The 'airy points' were so-named after Sir George Airey, who proved that condition. The standard, and one copy, are held by the Board of Trade Standards Department, and one contemporary copy each by the Royal Mint, the Royal Society and the Royal Observatory. The fifth copy is immured within the Palace of Westminster.

With the exception of this immured copy they are inter-compared every ten years by the National Physical Laboratory at Teddington, who themselves have their own working copies of the standard.

The Limitations of Precision Measuring Instruments.

Let us now proceed to determine what is understood by the term 'Precision Measuring Instrument'. Such an Instrument may perhaps best be defined as one having the ability both to give an accurate measurement and to repeat that measurement.

A Precision Measuring Instrument today is generally considered to be one which will measure by direct reading to at least one ten thousandth part of an inch in linear measure, or to at least thirty seconds of arc in circular measure.

Some indication of the fineness of these limits will be gained when it is remembered that the finest feeler gauge usually on sale to the public is two thousandth of an inch in thickness or twenty times thicker than the limits down to which the modern precision linear measuring instrument is expected to measure. No instrument, however, is accurate in an absolute sense, and it should be clearly understood that there is no such thing as absolute accuracy of measurement. Error must always be present depending on such variable factors as suitability of the instrument to repeat readings, the inherent inaccuracy of the instrument, reliability of the observer and small variations in the physical quality of the specimen being measured, such as caused by temperature change and the possible deformation of the specimen under the measuring load of the instrument, as for example, the elastic compression of metal which occurs when measuring small spherical objects.

To enlarge upon these factors which can produce errors, it is obvious that an instrument must be chosen which is suitable for measurement to the extreme accuracy required. The instrument must also be in a suitable condition to give this accuracy and to repeat its readings, which will depend to a great extent on the inherent accuracy built into the instrument during its manufacture.

The accuracy of the observer is not always given the attention it deserves. The observer should be reasonably conversant with the mechanism of the instrument in order that he may be guided in his manipulation of it, and that he may be prepared to take some precautions against making incorrect readings due to faulty manipulation.

After these precautions are taken there are accidental errors which the observer can make, such as misreading the graduations of the scale of the instrument, incorrect entry of the value read, failing to take precautions against such variables as a temperature change between the instrument and the specimen being measured, and failure to perform some necessary manipulation before taking a reading. After these possibilities of error creeping in, such as carelessness in interpretation, and the tendency to read the scale either slightly high or low. This means that, when a 'so-called' precision

GAUGES AND GAUGING

May I now take a little more of your time to consider the question of gauging work.

In the past it has generally been customary for the machine operator to attempt to produce with the aid of limit gauges, and for the setter to employ his mics. verniers, calipers etc. in an endeavour to set-up for a production run and to produce parts which conform to requirements.

This has often given rise to controversy due in the main to what is, after all, a human element; the differences in '<u>feel</u>' of the users of such tools as the micrometer-caliper; or to the fact that whilst the setter has had to rely on his micrometer etc. the inspection department have used comparators for measuring the same part.

In my humble opinion the time is long overdue, when the operators should be provided with a suitable form of comparator for checking his job and should not have to rely on limit gauges etc. By being enabled to know the exact size of any particular part, as you do by using comparators, much valuable information can be obtained which will prove a boon to the production department; as by analysis of results obtained such things as the ability of the machine to produce within certain limits; tool wear etc., can be determined and the manufacturing programme can be planned accordingly.

Where the type of production does not, for one reason or another, lend itself to the use of comparators in the shop, then it is all the more important for the inspection department to approve the first off, and not just by saying it is 'O.K.', but by giving the setter or operator precise information as to its size etc., do much to promote a run of good work.

In the detail inspection limit gauges can be used to a great extent, as at this stage it is usual only to satisfy oneself that parts are within a specific tolerance.

In the final inspection either functional gauging or in some mechanisms, examination of the completed job and a check on its satisfactory performance are the essentials.

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3. Pneumatic.
4. Optical.

Another method of obtaining linear measurement and one which does enjoy a very great degree of success is that form of measuring known as 'Interferometry'. It is now possible to determine linear measurement to within one milionth of an inch by using the wave length of different types of light as a standard for fine measurement. Interferometry is, however, at the moment more suitable for use in the laboratory and where almost absolute control variable, such as temperature etc. can be established, and it is doubtful whether it will ever play a direct part in obtaining measurement under normal shop or standard room condition.

Whilst on the subject of interferometry, I would like to mention the one particular Optical Measuring Instrument which relies purely on optics for means of measurement. I refer, of course, to the Optical Flat or proof plain, as it is called. These proof plains are generally made of either glass, sillica, quartz or crystal quartz, and are polished until they are almost perfectly flat. Flatness is to one millionth part of the inch and are usual on master flats and the method of using these particular checking flats for the testing of small highly finished flat surfaces is by the use of interference ridges, which are commonly called 'Newton Rings' so names after the gentleman who first introduced this form of measurement, Sir Isaac Newton.

When these flats are applied to a highly finished surface under normal lighting conditions, a number of bands are observed, these generally, due to the normal lighting conditions or electric lighting being of spectrum colours. By reference to the disposition and the shape of these bands, both the shape of the surface and its deviation from true flatness can be measured. A distance between each recurring dominant colour band of the spectrum colours represents the thickness of air between the optical flat and the surface to be tested, which is approximately 100,000 part of an inch. The contours and errors of the tested surface are indicated by the manner in which the colour band ends, because each colour band will follow an air gap of constant thickness, By counting the number of times one particular colour is repeated or by noting the amount of bending of one particular band, the deviation of the tested surface from true flatness can be accurately determined. By using the luminant of one length of light only such as cadmium or mercury vapour lamp and a suitable filter, one colour only is seen instead of the spectrum colours. This type of illuminant, is preferable, if very accurate work is undertaken. With this type of illuminant the wave length of the light is of course first accurately known and the distance between each recurring colour band represents an air gap of one half of this bright wave length. Should the bands appear to be straight spherical bands, it indicates that the surface under test is flat, but when a wedge of air is present and by counting the number of these bands one can accurately determine the thickness of this wedge of air at its thickest part.

When the surface to be tested and the optical flat are in actual optical contact, and should both surfaces be flat, then one colour only is clearly distinguished over the whole of the surface under test.

These bands do represent what is in effect a contour of the surface to be tested and by noting their disposition and by applying slight pressure, it is possible to determine the exact shape of the particular surface to be tested, and of course the amount by which the surface deviates from true flatness. Should the surface be a spherical surface, that is either concave or convex the bands will assume a circular form, and pressure lightly applied to the centre of the optical flat will indicate at once whether the surface is concave or convex, on the same principle that the water always runs towards the lowest point, in the same way that water should flow downhill, so that, should the surface be low in the centre and high at the edge, the bands will run away from the point of pressure, in exactly the same way, should the surface be cylindrical or eliptical that condition too can be assured.

Optical flats may also be used as a means of comparing the size of one slip gauge against another of the same nominal size.

Gentlemen, having dealt with linear measurement and possibly diametrical measurement, I would now like to call your attention to circular measurement. One of the most used types of instruments used for this particular measurement is, of course, the Dividing Table and Dividing Head. These are generally either of mechanical or optical design.

The mechanical design depends in the main for its accuracy upon a worm and wormwheel, and therein of course does lie the restriction to its accuracy.

The optical type of table relies mainly upon a circular scale made of quartz upon which are engraved the 360° divisions. This scale is accurately sensed to the axis of rotation of the Optical Dividing Table and Head and by this suitable optical system of magnification within the instrument, any circular movement of the table can be read directly either through an eye piece, which itself has an additional scale for direct readings to at least 30 seconds of arc or, as on the latest type, where the scale is projected on to a screen and an optical vernier, which again is dependent on the mechanic for its accuracy, enables you to take direct readings to within the order of two seconds of arc. An Auto-Collumator is another instrument which, when used in conjunction with precise angular slip gauges or master polygons, can also be used to determine circular measure.

For the measurement of surface flatness over fairly large areas, such as the surface plate or machine tool slideways, an instrument which is very reliable and much used, is the Precision Level. These precision levels are made in various degrees of accuracy where one division on the vial equals the tilt at the base of the level of 5 seconds. This in fact means that if the base of the level is 10" long and one end of the level is inclined a matter of approximately three tenthousandths of an inch, it will cause the bubble in the vial to one fault division. The level of such sensitivity is thus easily capable of indicating to the observer the rise on the tested surface of less than one tenthousandth of an inch. Observation of the movement of the bubble in the vial enables accurate readings to be made and any inaccuracies of the surface if the bubble is moved over. These readings can be plotted in graph form, and an accurate picture of the contours of the surface under examination thus recorded.

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Another type of instrument used for a similar purpose is, of course, our old friend the auto-collimator, which measures optically the angle of tilt on a small flat surface, reflecting the face which is moved over the surface to be tested. This angle of tilt is converted mathematically into actual measurement of the irregularities of the tested surface. This instrument is invaluable when testing the straightness of vertical surfaces and inclined surfaces.

Another type of precise measurement which is very much to the fore these days for the measurement of surface finish . Instruments used for measurement of surface finish fall generally into a class known as 'Recording Types', which consist essentially of a stylus passing over the surface to be tested.

This stylus is free to move up and down on the surface irregularities. In appearance and action it is somewhat similar to the pick-head in a radiogramophone, the stylus replacing the needle. Extremely small movements of the stylus are very considerably magnified, usually by electrical means, or in the earlier types magnification was effected mechanically, and the magnified movement is often recorded on graph paper by means of mechanical pens.

The modern electrical instrument used for surface finish measurement usually has a magnification of about 40,000:1 and small scratches of the surface being tested of say two millionths of an inch, appear on the record as a vertical distance of more than 1/16 of an inch, the standard generally adopted for a surface finish is referred to as 'the micro-inch', that is one millionth of an inch.

At this stage, gentlemen, if you will bear with me, I would like to make brief mention of the problem associated with the measurement of the Gas Turbine Blade as fitted in Aero Engines today. This blade itself, of course, being three-dimensional and presenting a very real problem of measurement. I will now, with your permission, describe one particular means of measuring these blades which has had very considerable success.

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In conclusion gentlemen, may I say that I regret that at the time at my disposal it has only been possible to give a very brief outline of each subject, but I trust that what I have said has been of interest.

May I thank you most sincerely for your kind attention.