THE INSTRUMENT MANUAL

THIRD EDITION

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INTRODUCTION

General

"The pace of British instrument development is such that on each of the sections in this work a text-book could be written, and in many cases this has been done. It is manifestly impossible to include the equivalent of twenty-five text-books in one volume, and, as the editing proceeded, it became apparent that the task was becoming one of deciding more what was to be left out rather than what was to be included."

These words are quoted from the Introduction to the second edition, published in 1953. They apply to an even greater degree to the present edition. There is little need to comment on the pace of development since 1953. A new coined word has appeared—Automation—and whilst not a little dislike has arisen to its use, it does, at least, describe a field of operations in which instrumentation plays a leading role. Included under this general heading are automatic control and data processing. In both of these spheres, deciding what to include was a major problem, as the extremely fluid situation could well render much of the printed material obsolescent before it was published. Particularly does this apply to digital and analogue computers. Many discussions were held to decide whether these two subjects could be presented in a concise manner to be of value to readers, and yet not encroach on the space available as a whole. In the end, it was felt possible to include a section on analogue computers, but, somewhat reluctantly, digital computers had to be omitted. Again, it seemed to the editor that some fields of measurement and control of physical conditions had been undeservedly neglected in the past. One of these certainly has been viscosity, and the opportunity has been taken to enlarge considerably this section by a specialist in the field. This practice of inviting specialist authors to contribute has been followed in the more important sections. A list of the authors is given overleaf.

Another field in which considerable developments have been made is, of course, nucleonics. The division of this section into reactor control instrumentation, health instrumentation, laboratory instrumentation and industrial instrumentation may seem arbitrary, but does illustrate an approximate picture of the nucleonic instrumentation activities at the present time.

The general scheme of the third edition of the *Instrument Manual* follows that of the second edition. One section has been omitted—Navigational Instruments—and this has been replaced by one on Analogue Computers. The original optical section has been dispersed. Microscopy has now been alloted a section to itself, and the analytical pattern of optical instruments has been included in the section Analytical Instruments, which also includes all relevant material (revised) from the section called Instruments for the Determination of Compositional Quality in the second edition. Smoke Density Measurement proving a little difficult to include logically in any section has an individual section. The titles of some sections have been modified to indicate their contents more accurately.

In revising such a work as this, it must not be forgotten that much basic instrumentation is relatively unchanging, having been well proved in practice. One need only instance orifice, nozzle and venturi flow meters to emphasise the point, and material relevant to this class of instrumentation must be retained if the book is to present a balanced appearance. In spite of this much revision has been necessary even here.

General Acknowledgments

Where illustrations supplied by individual firms have been used these have been acknowledged in the text. If any material or figures have been inserted without permission, it is purely accidental and not deliberate. The editor would here like to thank the many firms who have helped in a most generous manner in supplying details of their equipment.

General Editor

J. T. Miller, B.Sc., F.Inst.P.

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	Part dealing with Flaw Detection by Magnetic Particle Testing	D. W. Tasker
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OTHER PUBLICATIONS

Instrument Practice Automation & Electronics, a monthly journal covering the whole field of Instrument Technology and Instrumentation, price 50s. per annum, post free.

Automation and Automatic Equipment News, a monthly journal devoted to the subject of automation, covering latest news and developments in this field, price 42s. per annum, post free.

A Course in Industrial Instrument Technology, by J. T. Miller, B.Sc., F.Inst.P., 140 pp., price 20s. post free.

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CONTENTS OF SECTION

Introduction

APART from increasing output, efficiency and economy, the essential aim of modern methods of mass production is to produce component parts which are interchangeable in assembly and readily replaceable after assembly. Whereas the craftsman of former days worked on the individual system, making each part and then assembling the various parts himself—re-machining if they did not fit—men and machines have become specialised for the performance of single operations, and the work of assembly has also been specialised into a separate operation. Thus in the mass-production methods of interchangeable manufacture it becomes essential to ensure that the finished parts are always of the correct dimensions to effect a satisfactory mating, no matter when, where, and by whom they are made.

Clearly the mating of component parts can only be ensured if they are made under a system of dimensional control and afterwards checked under a system of dimensional inspection.

If each part had to be machined to a very high degree of accuracy, involving extremely fine measurements, the cost factor would be prohibitive. Moreover, the attainment of absolute uniformity is impracticable, as there will always be some degree of size variation arising from imperfections of workmanship and the variations associated with materials and machines. Fortunately, it is not necessary for components to be absolutely accurate in order to obtain a sufficiently high level of uniformity and to ensure that they shall always fit. A certain amount of error is permissible, and still the parts will mate satisfactorily in an assembly. So long as each component falls within certain limits of size all is well. In other words, it is possible in practice to *tolerate* a certain amount of deviation from a certain *basic size* representing the theoretically perfect size of that part. The range between the upper and lower limits of size permitted is known as *tolerance*. This tolerance concept provides the basis for the system of dimensional control and inspection employed in mass production and in workshop practice generally.

Limits and Fits

The British Standard Specification

The specification B.S. 1916 : 1953, superseded the earlier specification B.S. 164 : 1924. The new specification is based on the Continental ISA system and its tables are direct conversions from the metric dimensions in ISA Bulletin 25. There are sixteen grades of tolerance, each covering a range of size from 0·04 in. to just under 20 in. These grades are combined in various ways to provide twenty-one classes of fit, ranging from extreme clearance to extreme interference. A much wider selection of fits is possible by combination of various hole and shaft grades, and either the hole basis or shaft basis may be used. The unilateral hole basis is, however, strongly recommended.

The following definitions relate to essential features in the specification. They were included in the earlier B.S. 164 but are not in B.S. 1916, as they will appear in a new specification entitled "Definitions for use in mechanical engineering."

DIMENSION : A dimension is a feature of any piece of work, such as a length or a diameter, of which the size is specified.

NOMINAL SIZE : The nominal size of a dimension or part is the size by which it is referred to as a matter of convenience.

BASIC SIZE : The basic size of a dimension or part is the size in relation to which all limits of variation are assigned. (The nominal and basic sizes are often the same.)

ACTUAL SIZE : The actual size of a dimension or part is the measured size of that dimension.

LIMITS (OF SIZE) : The limits for a dimension or part are the two extreme permissible sizes for that purpose. (The high limit is the largest size permitted for that dimension, while the low limit is the smallest.)

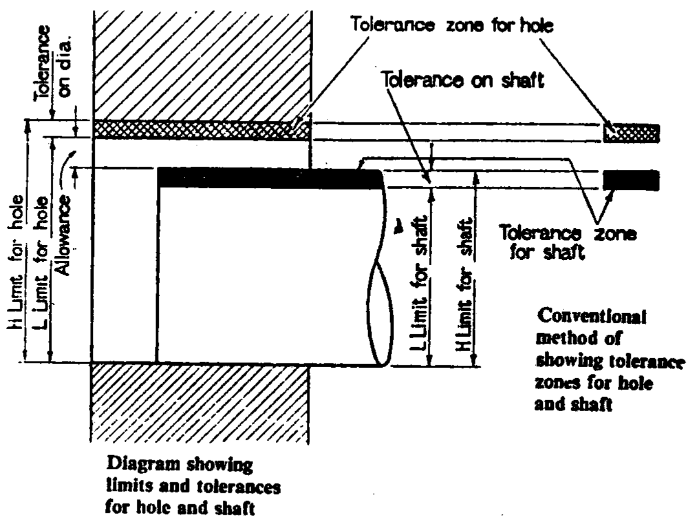

Fig. EP1

Note.—The left-hand portion of this diagram illustrates diagrammatically the limits and tolerances for a hole and its mating shaft. It will be noted that the hole and shaft are drawn in contact at the bottom so that the whole of their tolerances are shown at the top. These tolerances are shown by the cross-hatched and the black regions for holes and shafts respectively.

In diagrams used to illustrate limits and fits, it is customary and convenient to use only the upper portion of such a "limits diagram," and to confine them to the tolerance bands, or tolerance zones as they are called, for the mating members. Such diagrams thus become reduced to the form shown on the right-hand side of the above diagram.

Diagrams of this type are used later to illustrate the positions of the tolerance zones for "go" and "not go" workshop and inspection gauges in relation to the tolerance zones for the hole or shaft, as the case may be.

TOLERANCE : The tolerance on a dimension is the difference between the high and low limits of size for that dimension ; it is the variation tolerated in the size of that dimension to cover reasonable imperfections in workmanship.

LIMITS OF TOLERANCE : The limits of tolerance are the differences between the two limits of size (limits) and the basic size of a dimension.

(1) Each limit of tolerance should be associated with its appropriate sign.

(2) The difference between the limits of tolerance of a dimension is equal to the tolerance on that dimension.

ALLOWANCE : Allowance is a prescribed difference between the high limit for a shaft and the low limit for a hole in order to provide a certain class of fit.

(1) An allowance may be either a positive or a negative amount according to the type of fit in view. A positive (or plus) allowance results in a clearance fit and a negative (or minus) allowance in an interference fit.

(2) Tolerance and allowance are two separate and distinct things.

FIT : The fit between two mating parts is the relationship existing between them with respect to the amount of play or interference which is present when they are assembled together.

There are three principal classes of fit :

(*a*) *Clearance Fit :* where there is a positive allowance between the largest possible shaft and the smallest possible hole.

(*b*) *Interference Fit :* where there is a negative allowance (obstruction) between the largest hole and the smallest shaft, the shaft being larger than the hole.

HOLE BASIS* : A limit system (recommended by B.S. 1916) is said to be on a hole basis when the hole is the constant member and different fits are obtained by varying the size of the shaft.

SHAFT BASIS* : The shaft is the constant member, and the hole is varied.

UNILATERAL SYSTEM : When the lower limit of the hole is equal to the basic size of the hole.

BILATERAL SYSTEM : When the limits for the basic member are disposed one above and the other below the basic size for that member.

* The term "hole" and "shaft" are used not only to denote cylindrical components but to indicate any internal or external dimension respectively.

Newall System

Mention must be made of the Newall system of limits. This is extensively used in this country. In brief, it includes two classes of holes with bilateral tolerances and six grades of shaft tolerance. These allow clearance, transition, and interference fits for dimensions up to 12 in., or 300 mm.

Dimensional Gauges

Gauges are simple devices that can be applied with the minimum expenditure of time and skill to ascertain whether the dimensions of a part are within specified limits (hence the term "limit gauges"). Gauges do not usually possess a graduated scale and "fixed gauges" do not require to be adjusted. By means of a gauge, the machinist can very quickly determine whether the part is too big or too small, or whether it meets requirements by coming within the limits of tolerance permitted.

A *comparator* is an instrument for comparing the dimensions of a work-piece with those of a master part or a standard dimension consisting of a combination of slip gauges. The comparator magnifies the small difference which exists between the part and the standard of reference, and the magnitude of this difference may be read on a dial scale, or the instrument may merely indicate by signal lights or other means whether the dimension is within the limits of tolerance.

The instruments used in engineering workshops for *direct measurement* range from non-precision tools, such as the steel rule, which can measure down to 64ths or 100ths of an inch, with the aid of skill and good eyesight, to precision instruments, such as interferometers, slip gauges and measuring machines, which are capable of measuring in hundred-thousandths and millionths of an inch. In between are many types of precision instruments which can measure in thousandths and ten-thousandths of an inch. For example, the production inspector can measure halves and quarters of thousandths with a micrometer, and with a vernier micrometer he can measure in ten-thousandths of an inch.

End Gauges

Slip Gauges

Slip gauges (known as gauge blocks in America) are rectangular steel blocks having two end-measuring faces which are flat and parallel, and which are separated by a distance guaranteed to be accurate. They are hardened against wear, heat-treated to dissipate internal stresses, ground and lapped to the required dimensions.

Slip gauges constitute the practical basis of all accurate measurements in engineering laboratories, toolrooms and factories. They are primary standards against which secondary or ordinary working standards (such as limit gauges, comparators and measuring instruments) can be accurately calibrated. Thus they provide the necessary basis for the economic attainment of that degree of accuracy and uniformity required in modern interchangeable manufacture.

The British Standard for slip gauges, B.S. 888 specifies four grades of accuracy :

(*a*) workshop,
(*b*) inspection,
(*c*) calibration,
(*d*) reference.

The following table gives the maximum permissible errors in millionths of an inch at 68° F. of the length of the smaller gauges (up to 1 in.) :

Workshop	$+ 10 - 5$
Inspection	$+ 7 - 3$
Calibration	± 5
Reference	± 2

Tolerances on larger gauges are in proportion.

Recommended sets are 28, 35, 41, 49, and 81 in number for English units, and 50, 78, and 105 for the metric system.

Before it goes to the user, each block is inspected for size, flatness, parallelism, stability, surface finish, wearing qualities, hardness and workmanship. Flatness, parallelism and length are tested by optical methods.

Combinations of blocks are built up by simply bringing their surfaces together—an operation known as "wringing." Owing to the perfection of the surfaces, they adhere tenaciously, so that a holding device is not required. Slip gauges from a standard set can be used for lengths up to about 6 in. Combinations of greater length become unwieldy, and use may be made of end bars.

Various accessories are available which extend the range of application of slip gauges, such as adjustable holders, master flat, master parallels, straight edge, scriber, calliper jaws, centre points, vernier gauge blocks. As a protection against wear, protector slips (or wear blocks) are available, consisting of a pair of slip gauges, 0.1 in. thick, made of stellite or hard steel. These are wrung on the outside of the slip gauge assemblies.

Common applications of slip gauges are as follows :

(*a*) For the checking of working gauges, such as plug, ring and snap gauges, used in the factory, and the setting of dial indicators and comparators.

(*b*) For checking parts while in process of manufacture, and also when they are finished, either directly or by working gauges and instruments which are themselves checked by gauge slips.

(*c*) For setting machine tool cutters.

(*d*) For checking dies, tools, jigs and fixtures to ensure that the part produced by them will be within the required tolerances.

(*e*) For use in conjunction with the sine bar in the setting up and measurement of angles and tapers.

B.S. 888, which was drawn up in collaboration with the National Physical Laboratory, users and manufacturers, gives recommendations as to material, dimensions, finish, accuracy, marking, etc., and particulars of accessory measuring jaws, holders, and base. Notes are also included on the care and use of slip gauges.

Reference should also be made to the remarks on slip gauges given in *Notes on Gauge Making and Measuring*, issued by the Metrology Division of the National Physical Laboratory and published by H.M. Stationery Office.

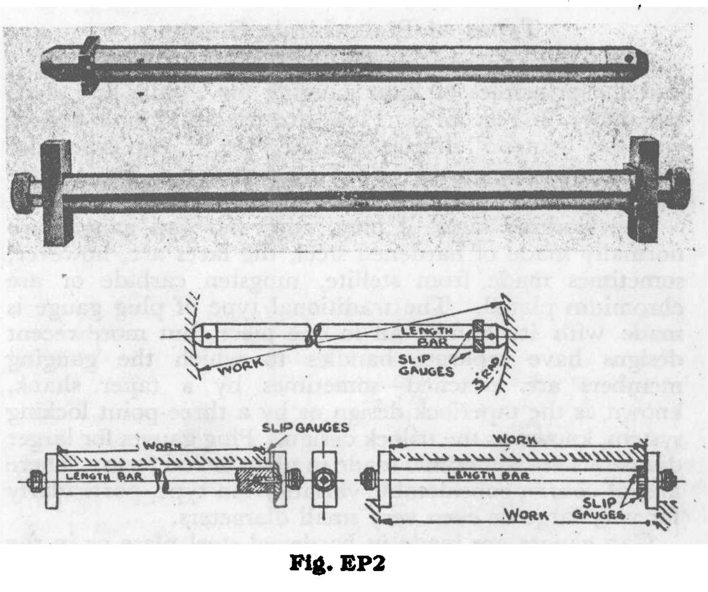

Fig. EP2

Length Bars (Combination End Bars) are used to extend the range of slip gauges. They are round bars, about $\frac{7}{8}$ in. diameter, with lapped end faces. Central tapped holes and studs enable bars to be screwed together so that their lapped faces wring. Sets usually contain nine to twelve bars, and inch lengths up to about 39 in. are obtainable. By adding slip gauges, fractions are obtainable. Various accessories are available, *e.g.* a stand to hold bars vertically, end jaws, etc. Fig. EP2 shows the bars arranged to measure internal and external dimensions.

Limit Gauging

The use of limit gauges is, as the name implies, to gauge between limits. From the ideas of tolerance and limits already discussed it will be clear that, for normal inspection purposes, it is only necessary to ensure that a dimension on a component lies between the permitted limits. Its actual size is not usually required.

The extremes of size correspond to what are known as the maximum and minimum metal conditions. These terms apply equally to external and internal dimensions, *i.e.* shafts and holes. The minimum metal condition on a shaft or external dimension is the minimum size, but on a hole or internal dimension it is the maximum size. The maximum metal condition is, of course, the opposite in each case.

Limit gauges for a plain dimension—a circular hole, for example—consist of two elements known as "Go" and "Not Go" gauges. They are made in such form that they will mate or assemble with the component, *e.g.* cylindrical plugs for gauging a hole. The "Go" gauge must be able to pass into or over the component (if it is within its limits) and therefore must be made to correspond to the maximum metal condition; in the case of the hole it is the minimum diameter. The "Not Go" gauge must not enter or assemble with the component and must therefore correspond to the minimum metal condition, the maximum diameter of the hole.

Gauges for a shaft or external dimension are in the opposite sense, *i.e.* "Go"—maximum diameter (maximum metal condition) and "Not Go"—minimum diameter (minimum metal condition). Gauges for cylindrical shafts may be in the form of rings or, more usually, of the gap or caliper type.

Types of Plain Limit Gauges

Plug, ring and gap gauges are illustrated in Fig. EP3, and the principles of limit gauging for a hole and shaft are shown in Fig. EP4. Plugs are usually double-ended, with the "Not Go" shorter than the "Go." This is because there is less wear on the "Not Go" end, as it does not enter the component except when the hole is oversize.

The working faces of plug, ring and gap gauges are normally made of hardened steel, the faces are, however, sometimes made from stellite, tungsten carbide or are chromium plated. The traditional type of plug gauge is made with its handle all in one piece, but more recent designs have separate handles to which the gauging members are attached—sometimes by a taper shank, known as the taperlock design or by a three-point locking system, known as the trilock design. Plug gauges for larger diameters are sometimes made in plate or rod form. There are, of course, considerable variations in type, particularly for very large or even very small diameters.

Gap gauges are made in hardened steel plate or in the form of cast or forged caliper frames with inserted adjust-

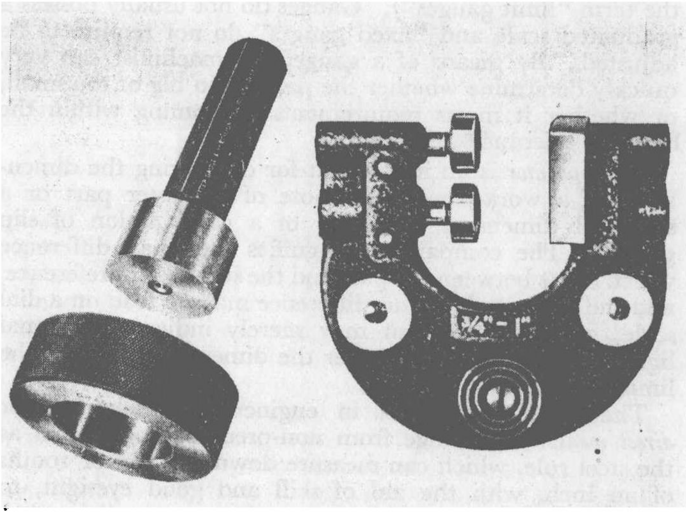

Fig. EP3

able units for the gauging faces. Ring gauges are also made in hardened steel and are of an annular form. It is important in ring gauges that the cross section of metal should be adequate to withstand, without undue distortion, the considerable forces which may be present if a component is forced into a gauge. For the gauging of circular shafts, the ring gauge has very largely given way to the gap or caliper gauge. Many designs of caliper gauge are made adjustable; this means that gauges can be made in standard sizes, each covering a fairly wide range of dimensions and, furthermore, each gauge when no longer required for one dimension or component can be re-set for another within its range, perhaps to entirely different tolerances. It will be seen later, however, that in theory, the ideal gauges for

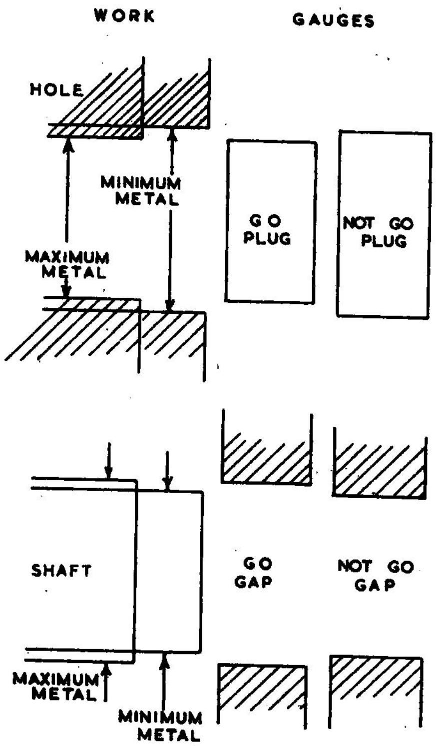

Fig. EP4

shafts are a "go" ring and a "not go" caliper. This arrangement is, however, seldom used and under properly controlled manufacturing conditions is not really necessary.

Specifications of design and dimensions of gauges are given in B.S. 1044. The N.P.L. publication, *Notes on Gauge Making and Measuring*, contains some useful information on the manufacture and checking of various types of gauges.

Gauge Tolerances

Just as a manufactured component has to be given a tolerance to allow for inevitable variations and imperfections in manufacture, so gauges also have to have tolerances on their dimensions. Naturally, the gauge tolerances are much smaller than the tolerances on the corresponding components and in general are about 10 per cent of the component tolerance. This means that if the component tolerance is 0·001 in., each part of the gauge, "go" and "not go," will have a tolerance of about 0·0001 in. The direction of the gauge tolerance is most important. If the gauge tolerance is applied in one direction it will encroach on the work tolerance and give the gauge maker less latitude, but if applied in the other direction it will allow work to be passed which is outside the strict work tolerance. Gauge tolerances can therefore only be a compromise.

From the time of the First World War until 1953, a system of gauging was in force using two categories of gauges, workshop and inspection. The principle adopted in this system was that workshop gauges, which were intended for use by the operator in the manufacture of components, had tolerances which encroached slightly on the work tolerance. Inspection gauge tolerances, on the other hand, were placed just outside the work limits and therefore did not encroach on the work tolerance. This also meant that any work passed to the workshop gauges automatically passed the inspection gauges. The disposition of these gauge tolerances relative to the work tolerances for holes and shafts is shown in Fig. EP5. If this diagram is compared with Fig. EP1 it will be seen to show only the tolerance zones and not the full dimension of the component. It is, in fact, an exactly similar type of diagram except that the lower extremity of the component dimension is omitted. It will also be noted that a small allowance is shown for workshop "go" gauges. Such a wear allowance can be permitted only where the tolerance is fairly wide, as it adds to the encroachment of the gauge tolerance on the work tolerance.

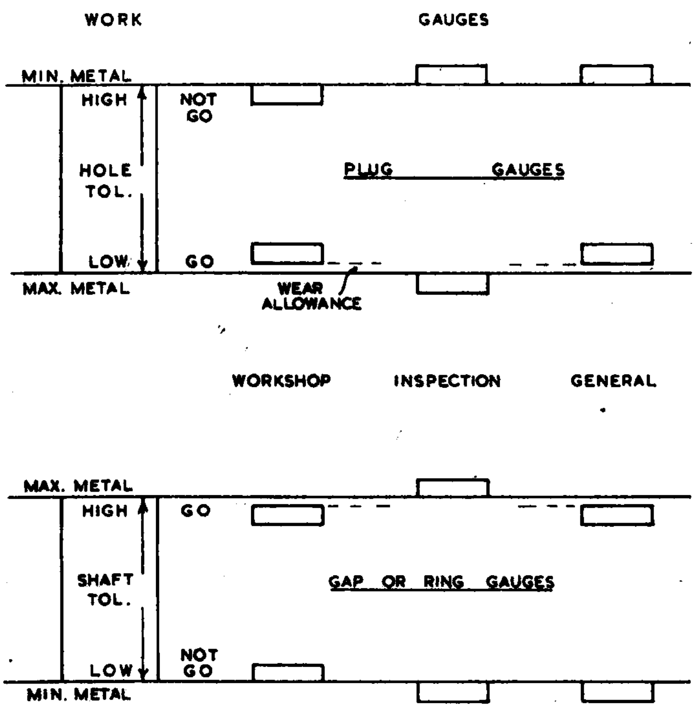

Fig. EP5

This system of workshop and inspection gauges was changed when the B.S.I. issued in 1953, a new specification, B.S. 969, on plain limit gauges, limits and tolerances. This standard specifies a single type of gauge, the General gauge. The disposition of the General gauge tolerances for holes and shafts is shown in Fig. EP5. From this diagram it will be seen that, in each case, the "go" gauge corresponds in disposition to the old workshop gauge but the "not go" gauge corresponds to the old inspection gauge. The principle behind this revision was that the "go" gauge checks the maximum metal condition which affects interchangeability and that, with the traditional inspection gauge, there was always the danger, in theory at any rate, that holes and shafts passed to inspection gauges may not assemble. The "not go" gauge, however, checks the minimum metal condition, and although work slightly outside limit in this direction may affect the grade of fit or may have some functional disadvantage, the effect is likely to be very small and, in any case, will not affect interchangeability.

Another new principle was introduced for the first time into B.S.969, 1953. This principle is that for larger work where fine tolerances are specified, limit gauges should not be used. The specification contains a table giving minimum gauge tolerances appropriate to type and size of gauge. The table shows, for example, that for a work size between 1 and 2 in. the minimum plug gauge tolerance should be 0·0001 in. for plug, bar and rod gauges, and 0·00015 in. for ring and gap gauges. This means that, for this range of sizes, if finer gauge tolerances than these are necessary due to the fineness of tolerance on the work, limit gauges are not satisfactory and some form of direct measurement, such as with an indicating comparator, should be used. There are three main reasons for these recommendations. Large diameter fine limit gauges are difficult to manufacture accurately, difficult to measure accurately and, probably worst of all, are difficult to use in the workshop. Slight temperature variations cause considerable trouble at all three stages, and in using such gauges, it is easy for errors to occur; for example, it is easy to force a "not go" gauge even when the component is slightly outside limit.

Other Forms of Limit Gauges

The foregoing principles have been described in terms of plain limit gauges; that is in general plug, ring and gap gauges intended to check simple diameters and linear dimensions. Similar principles can be applied to other forms of component although the more complex the shape, the more difficult it is to apply simple limit gauging. One or two examples will show how the principles can be applied. Fig. EP6 shows a flush pin gauge for measuring depths of holes or recesses (part sectioned). The pin slides in the gauge body and a step is cut in the top of the pin, the depth of the step being equal to the tolerance allowed on the component. When the top of the pin is flush with the top surface of the gauge body, the projection

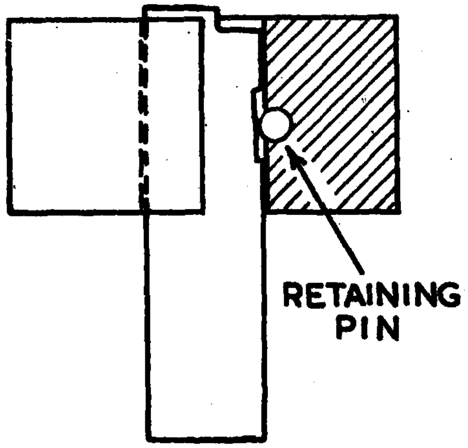

Fig. EP6

of the pin corresponds to the maximum permissible dimension. When the step is flush with the body the projection is on the lower limit. When checking a component, all the inspector has to do is to see that the top face of the body lies between the top of the pin and the step. A great many variations of this type of gauge are possible.

A similar principle can be applied to taper, plug and ring gauges, examples of which are shown in Figs. EP7a and 7b. (The ring is shown in section.) Here in a similar manner a step is cut at one end of the gauge ; it may be either at the large end or the small end of the taper. The position of the step is designed to match a suitable surface or shoulder on the component and the depth of step corresponds with the tolerance on the work. This type of measurement is, however, rather more complicated than the plain depth measurement; not only has the diameter of the work to be correct but its angle of taper has to be checked also. Strictly speaking, a single gauge of this type cannot check both dimensions and the gauge is, therefore, something of a compromise. The angle of taper is however quite often checked with the same gauge by applying Prussian blue or some other marking medium to the gauge and assembling it with the component. If the taper of the component is correct, the marking will transfer uniformly but this operation has to be carried out with a good deal of care and skill. It is very easy to rotate the gauge with the component and obtain what appears to be quite a good marking even though the angle of the component may be seriously in error.

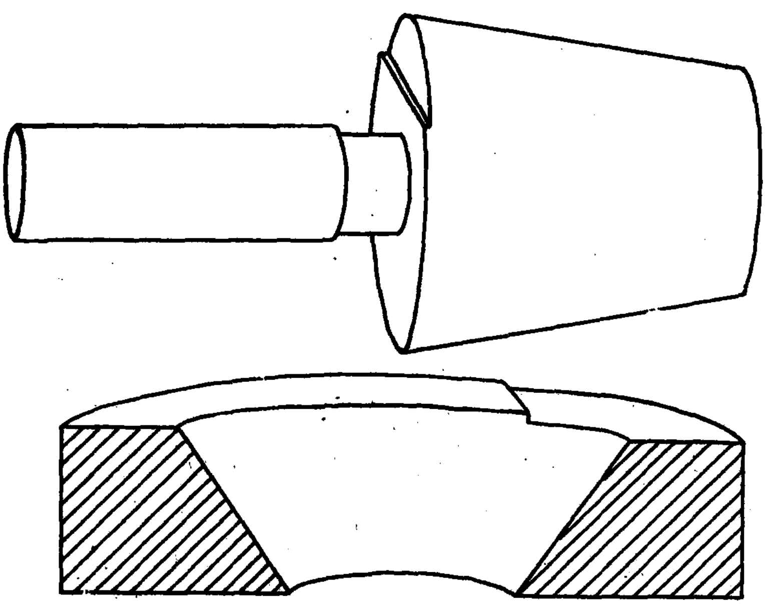

Fig. EP7a and 7b

The Taylor Principle

In 1905, William Taylor first enunciated the principle which requires that the "go" gauge shall have the full form of the mating component so that all elements of the work are gauged simultaneously for the maximum metal condition. On the other hand, the "not go" gauge which checks the minimum metal condition should check each dimension or element separately. According to this principle, a plug gauge should have the full length of the hole it has to check. This ensures that any errors of roundness or straightness do not exceed the maximum metal condition. On the other hand, a "not go" gauge for a hole should be short and should, in theory, be a pin gauge making contact across one diameter only.

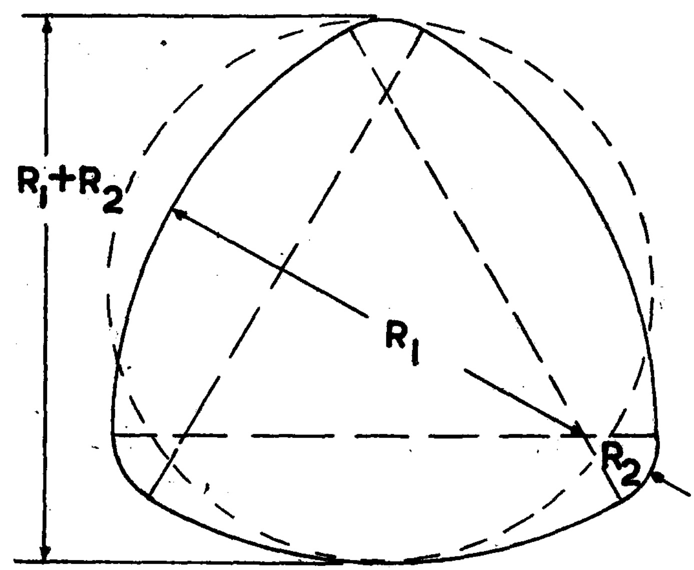

Fig. EP8

Similarly, the ideal gauges for a shaft would be a full length ring gauge for "go" and a calliper or gap gauge for "not go." In practice these conditions are rarely fulfilled, "go" plug gauges of less than full length being used for holes and "go" gap gauges being used for shafts. Such gauges are quite satisfactory in practice, provided the conditions of manufacture are under proper control and where it can be assumed that if one or two portions of a dimension are correct, then the complete dimension is satisfactory.

Under some conditions, however, this less-than-perfect gauging can be quite deceptive. Fig. EP8 shows a figure which is of uniform diameter as measured between parallel faces, *e.g.* a gap gauge or micrometer, and yet is far from being circular in section. If a shaft were in the form of such a figure it might measure perfectly on diameter, but would not enter a hole of the same diameter or even one appreciably larger. This effect is known as lobing and, while it does not occur frequently to a serious extent, it is sometimes met on components which are centreless ground. Holes bored in a component which has been gripped too tightly in a three-jaw chuck can also have this type of form.

Where the form of a component is complex, in a screw thread, for example, adherence to the Taylor Principle becomes very important. In screw thread gauging, the "go" gauge has the full form of the mating thread but several "not go" gauges are necessary to check each element separately. The gauging and measurement of screw threads will, however, be dealt with under a separate heading.

Linear Measurement

In checking components in production there are certain limitations to the use of limit gauges. There are also many operations such as the checking of gauges themselves where dimensions have to be measured direct. In many cases, particularly with large-scale, experimental or prototype manufacture, it would not be economical to design special gauges for each dimension. The checking of small variations such as eccentricities also involves direct measurement.

For these purposes some form of indicating comparator has to be used and this may take one of many forms. The commonest of these is probably the ordinary micrometer or micrometer caliper. Vernier calipers and height gauges are in the same category. Since, however, micrometers and vernier instruments are capable of measuring dimensions direct and not only small differences, they come into a slightly different category and will be dealt with under another heading.

Both dial gauges and comparators are instruments for comparing small variations which are amplified and indicated on a scale. They can be set and used in many different ways. The general principle of operation is to set the instrument first on a standard which may take the form of a special setting piece or be a combination of slip gauges or other basic standard gauge. The work is then applied to the instrument, or vice versa, and the difference in reading is noted. Since the size of the standard is known the actual size of the dimension on the component may readily be determined. In addition, any variations in the dimension can be detected.

Dial Gauges

Dial gauges, or dial indicators, are extensively used for determining whether the dimensions of a finished piece are within the limits of tolerance. They are primarily intended for use as comparators, and should not be used as direct measuring instruments owing to the fact that they lose accuracy over a large range of travel. It is therefore recommended that when any desired measurement is to be ascertained by the difference between two readings on a dial gauge, the difference should always be kept as small as possible. Over a long range, a dial gauge is inferior in accuracy to a micrometer, because the majority of dials depend primarily on racks and pinions. If a case should arise in which the use of a dial over a long range is necessary, a direct calibration from end to end of this range against slip gauges should be regarded as essential.

The dial gauge magnifies the linear displacement of the plunger and converts this movement into a magnified rotation of the pointer on the dial scale. A rack engages with a train of gears and pinions, so that movement of the plunger causes the rack to turn the pinion with which it is meshed. Any lost motion due to backlash when the motion is reversed is known as the hysteresis of the instrument, and is minimised by provision of a spiral spring. For rapid checking of parts, tolerance hands may be attached

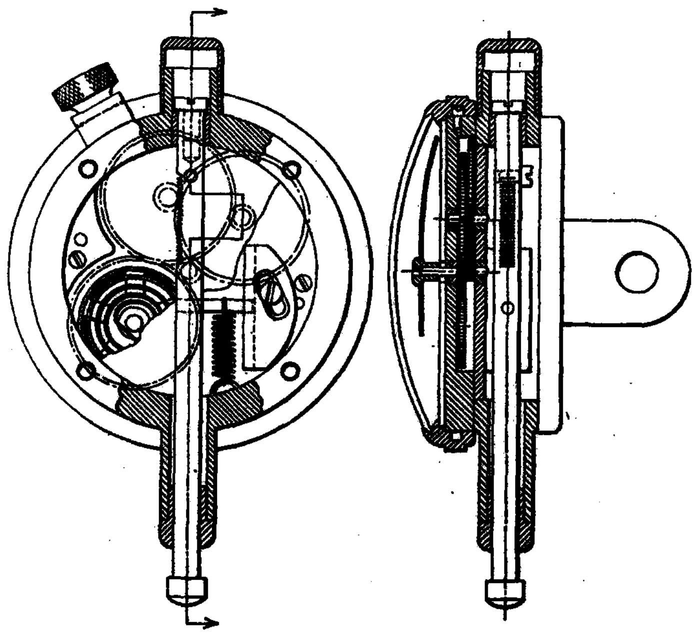

Fig. EP9

to the dial face, or shutters may be used to mask out the unessential part of the dial. (See Fig. EP9.)

A specification for dial gauges for linear measurement is given in B.S. 907. The specification applies to gauges with dials from 1½ in. to 2 in. diameter and having ranges of movement of the plunger up to ½ in. or 12 mm., and measuring by steps of 0·001 in., 0·0005 in., 0·0001 in., and 0·01 mm. The ranges of movement vary with the make and type of gauge; the purchaser should state any particular requirements as to range.

The specification makes recommendations for dimensions, and gives methods of testing, as well as advice on the care and use of dial gauges.

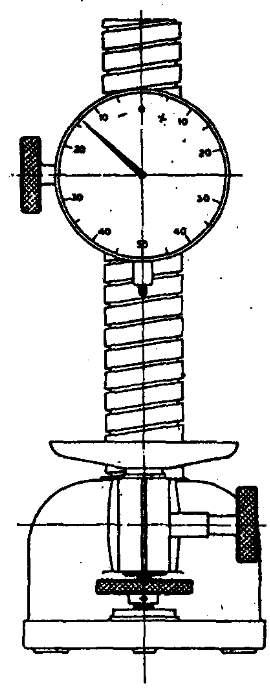

Fig. EP10

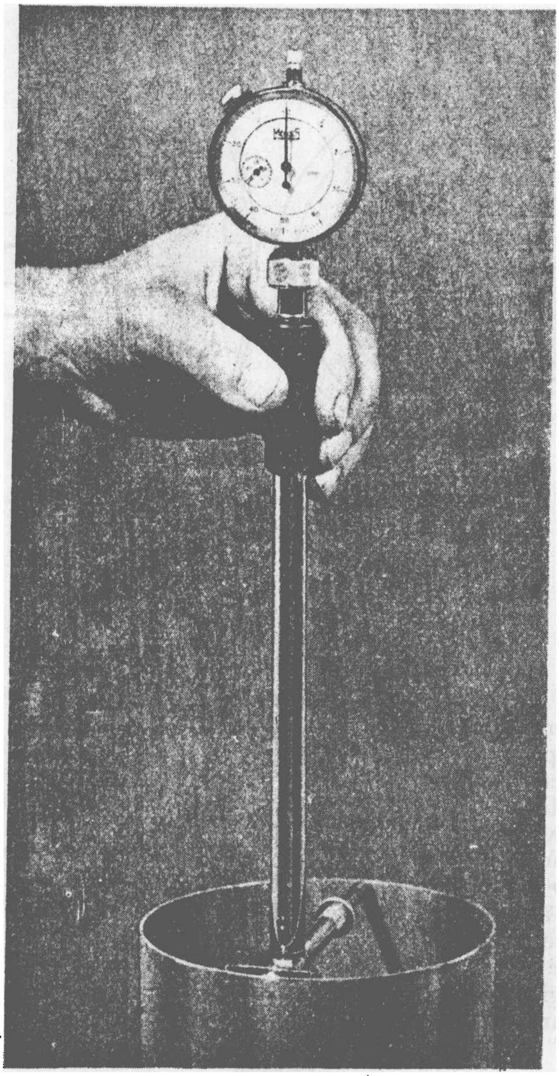

Fig. EP11

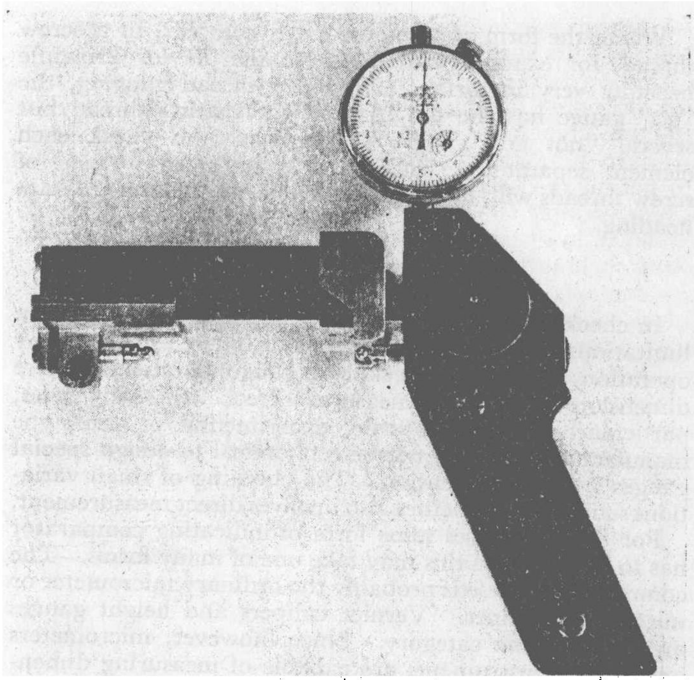

Fig. EP12

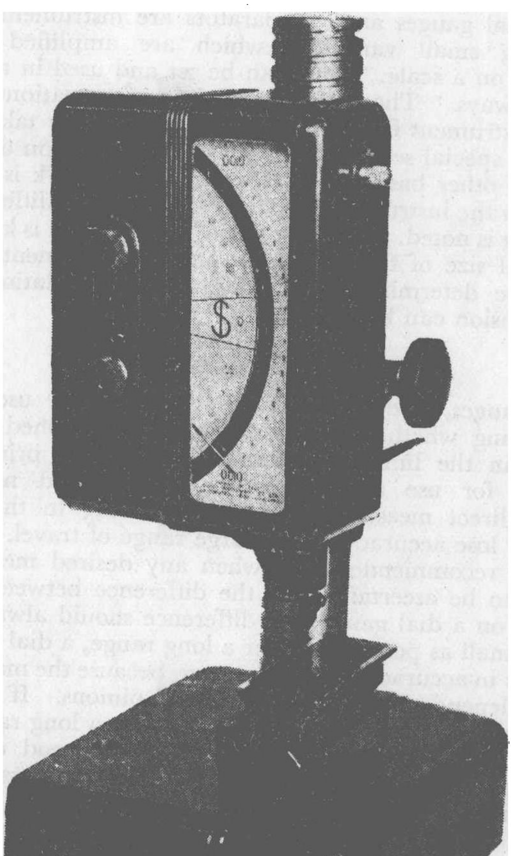

Fig. EP13

Dial gauges should be checked for calibration and general condition before being put into general use and periodically thereafter. This calibration can be done by mounting the gauge on a suitable rigid stand above a surface plate or other lapped table and putting slip gauges under the measuring plunger. For gauges graduated only to ·001 in., a micrometer head is often more convenient than slips, but it must be a good one which has itself been calibrated. Again the stand or other method of mounting must be quite rigid.

Dial gauges should be used carefully and treated with the same respect as a watch. They should be kept as free as possible from dirt, oil and grease, although this is not always easy under workshop conditions. Where gauges are exposed to arduous conditions, it is essential to service them regularly. In any case, they should be dismantled only by a competent instrument mechanic who has actual experience of this type of work. One of the worst mistakes frequently made is to oil the plunger. It must run absolutely dry or it will stick in the stem. If the gauge is clamped by the stem, great care is needed or the plunger will bind.

In addition to their use as simple comparators in the style shown in Fig. EP10, dial gauges are often incorporated in special gauging devices which include depth gauges, calipers, thickness gauges, bore gauges and so on. In addition, they are coming into more and more use as an integral part of specially designed gauges and gauging fixtures. These often take the place of limit gauges, particularly for large dimensions where tolerances are too fine to permit the application of fixed gauges.

An example of a standard type of gauge, the bore gauge, is shown in Fig. EP11. Such a gauge will cover a range of sizes, such as $\frac{3}{4}$ in to 2 in. and 2 in. to 6 in. Various measuring contacts which cover the range can be fitted. The gauge is, of course, used as a comparator and is set either on a gap made up with slip gauges or on a standard ring gauge.

One of the special gauges, made for gauging a particular dimension in quantity production, is shown in Fig. EP12. Such a gauge will often have its own setting master which is carefully calibrated for size, allowance for any difference from nominal size being made when the gauge is set to it. This utilises one of the most important principles of measurement ; that it is nearly always better to calibrate and allow for known errors than to attempt to make something "spot on." Some gauges of this type are quite complex and may incorporate several dial gauges, checking a number of dimensions at one time.

Comparators

Comparators may take a wide variety of forms and, as the name implies, are used to compare dimensions, usually

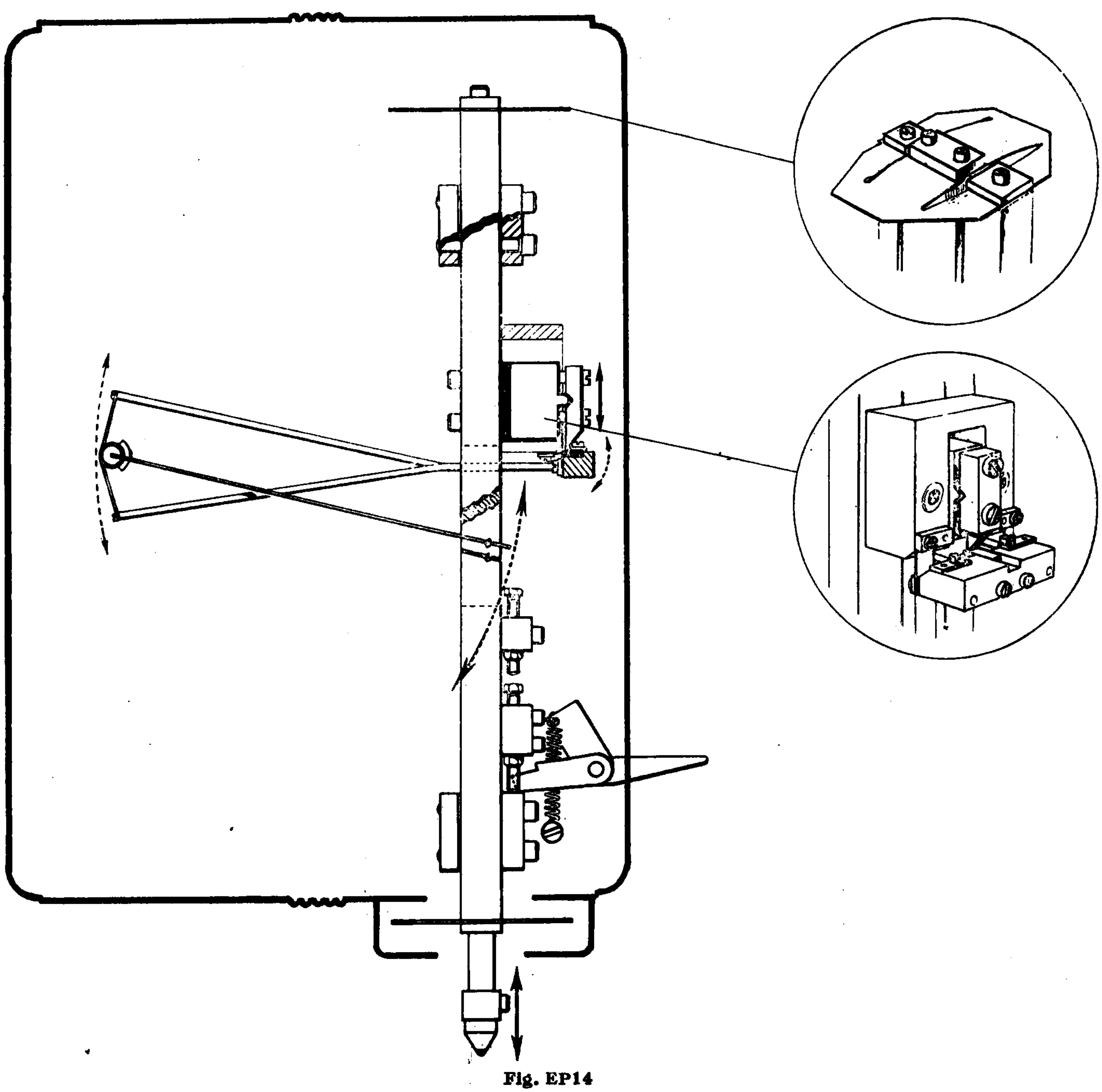

Fig. EP14

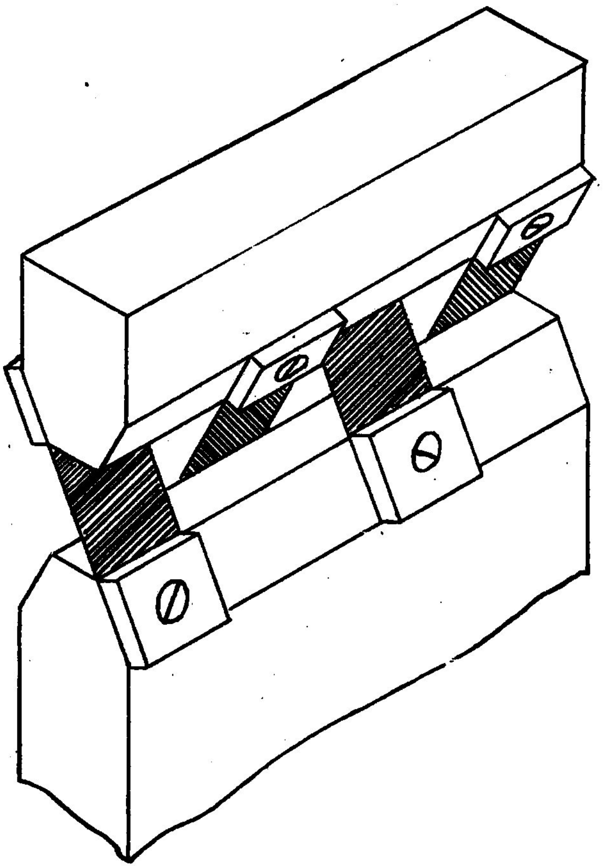

Fig. EP13

between a standard and the object to be measured. This may be a work-piece, gauge under test, a gear or other component. The standard usually consists of a set of slip gauges from which can be built up almost any size master required. Comparators of high accuracy are used in the gauge inspection department and standards room for checking inspection and workshop gauges and working standards.

In operation, the slip gauges are wrung on to the anvil of the comparator, and the gauge head is lowered and clamped in position when the pointer is at rest on zero. The slips are removed and the work-pieces presented to the gauge; any plus or minus deviation from standard size is indicated on the scale.

Mechanical

Many types are available but essentially they comprise an indicator head adjustably mounted on a vertical (or in some cases, horizontal) column, with its measuring plunger over a small horizontal plate carrying the work-piece. Magnifications are from about 250 to 15,000 times, and various indicator systems (mechanical, optical electrical, pneumatic, etc.) are employed. The measurement is made by determining the change of reading when the work-piece is substituted for a standard consisting of slip gauges. Fig. EP10 shows an N.P.L. design for measuring gauges on which a tolerance of only 0·0001 in. is allowed. The magnification given by the indicator is about 1,000 to 1, and the dial is graduated in divisions of 0·0001 in., about 1/10 in. apart.

In this design, the surface of the table is truly flat and is lapped to a wringing finish. Fine adjustment is possible by means of the fine pitch adjusting screw. Both table and dial may be firmly locked in position.

B.S. 1054 covers Engineers' Comparators for external measurements specifying accuracy for magnifications up to 1,500. Larger values than this are obtainable, and Fig. EP13 shows an instrument with 3,000 magnification.

This comparator is manufactured by the Sigma Instrument Co., Ltd., and its mechanism is illustrated in Fig. EP14. The measuring plunger is supported by two flexible slotted plates and a small axial movement of the plunger is permitted by flexure of the plates. The vertical movement is applied to a sapphire contact on a pivoted lever by a knife edge attached to the plunger. The pivot of the lever is formed by two pairs of crossed steel strips of the type shown in Fig. EP15. The final stage of magnification is obtained by the two long arms of the lever which carry between them a flexible strip wrapped round the pointer spindle. In this instrument, a high accuracy of measurement is obtained by applying sound design principles which allow final adjustments for exact magnification.

Another much older mechanical comparator is illustrated in Fig. EP16. This is the Level Comparator, designed by A. J. C. Brookes at the N.P.L. in 1918. It is used chiefly

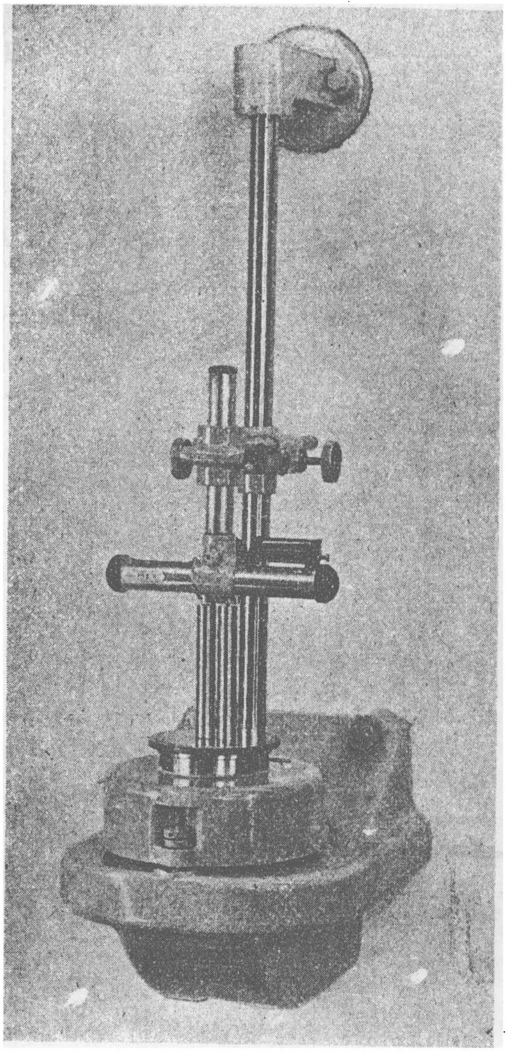

Fig. EP16

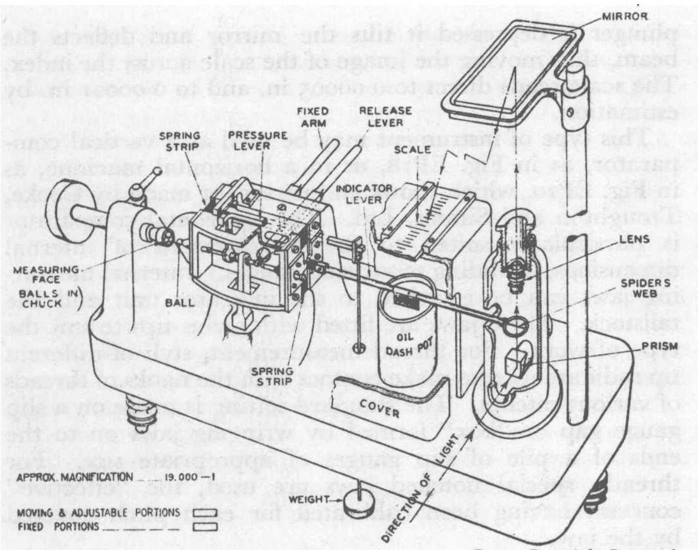

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Fig. EP17

for comparing end bars and has a magnification of about 17,000. In operation, the two gauges are wrung side by side on the horizontal lapped plate and the sensitive level, in a mounting fitted with ball feet spaced at 0·7 in., is lowered so that one foot rests on each gauge. A reading is taken on the graduations of the level and, after the level is raised, the plate is rotated so that the gauges change places. The plate is mounted so that it can rotate accurately in its own plane. Another reading is taken on the reversed gauges and, if their lengths are different, it is obvious that there will be a change in tilt corresponding to *twice* the difference between the lengths of the gauges. This instrument, although designed so long ago, is still made and is in constant use in standards rooms and laboratories all over the world. It is described in some detail by F. H. Rolt in *Gauges and Fine Measurements* (see Bibliography).

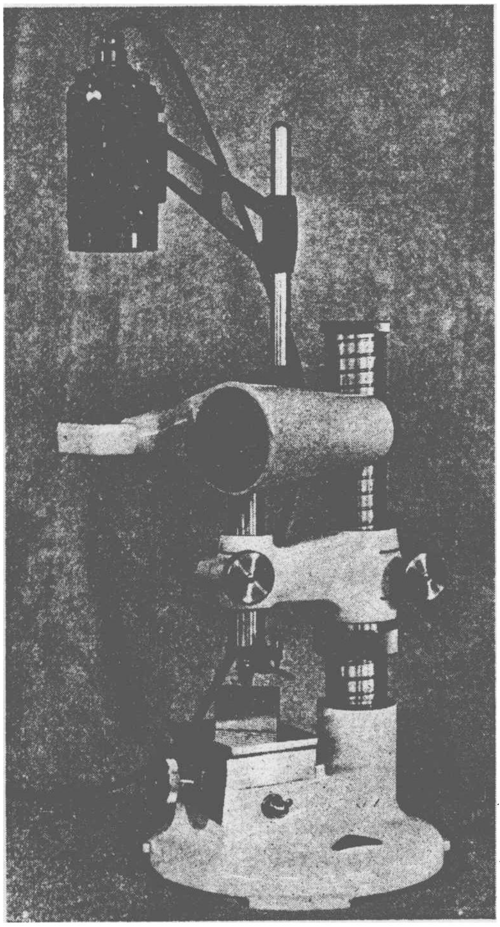

Fig. EP18

Optical

Many designs of comparator incorporate an optical system and, in most cases, the movement of the measuring plunger tilts a mirror which deflects a beam of light. The beam is arranged to focus the image of an index on a scale, or vice versa, and this is either projected on to a screen or is viewed through an eyepiece. There are several types of such instruments but only two will be considered here. They are considered to be quite distinct from measuring machines incorporating their own standards of length, but these will be dealt with later.

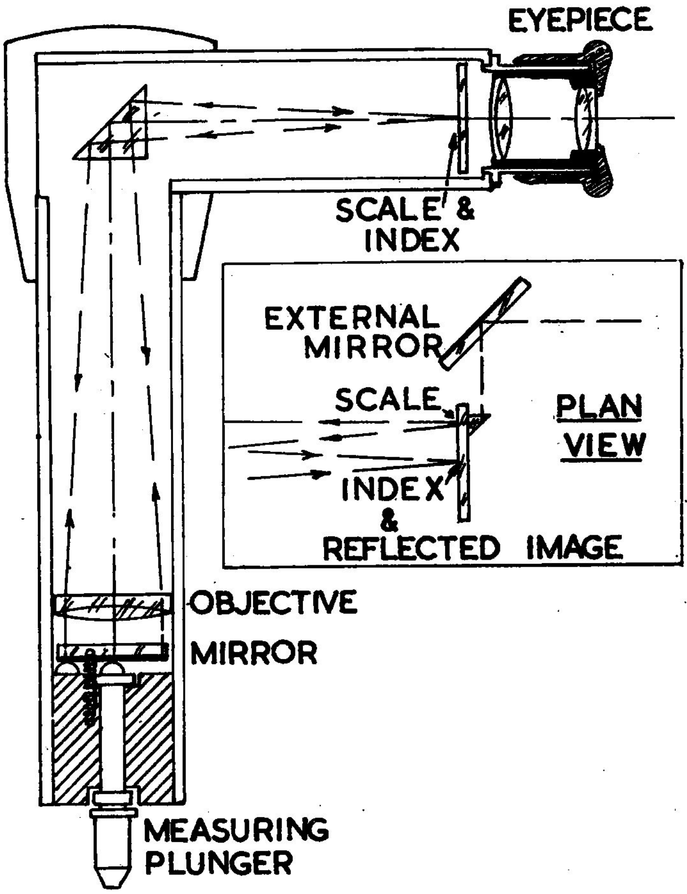

Fig. EP19

The first is another N.P.L. instrument of 1918 vintage, designed by E. M. Eden, and is still very popular for the calibration of slip gauges. Its principle of operation is shown in Fig. EP17. The measuring unit, which carries the ball contact, is attached to the main casting by two parallel steel strips and thus moves parallel to its length. Two strips at the end, one attached to the moving member