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NPL NOTES ON SCREW GAUGES

"Interchangeability and quality of fit of nuts, bolts, and other screwed fasteners e.g. threaded pipe joints, require precision in manufacture as monitored by screw gauges. Methods of measurement have been developed continuously at NPL over 70 years and are described in NPL Notes on Screw Gauges. Plugs and rings, parallel or taper, over a range from the BA series to 20 inch casing for oil wells are considered. This report deals with principles as well as methods, and includes data and references which are useful to designer and inspector as well as to operator and student."

NPL NOTES ON SCREW GAUGES

FOREWORD

As a result of experience gained in testing large numbers of screw gauges during the first World War, the Metrology Division of the National Physical Laboratory published a pamphlet "Notes on Screw Gauges", to assist firms who were unfamiliar with the accuracy required in the manufacture and testing of gauges. This pamphlet has been in continuous demand since it was first published, and was reprinted and revised several times. In 1951 the pamphlet was extensively rewritten and was renamed "Gauging and Measuring Screw Threads", forming the first of the series of handbooks prepared at the National Physical Laboratory under the general title of "Notes on Applied Science". Further editions followed, the latest in 1961.

This edition, which reverts to the original title, has been written in a time of flux. A balance has to be maintained between the commitment to the SI system of units and the need for the time being of the traditional imperial units since many measuring machines, tools and data sheets still perpetuate the traditional units. Simultaneously while there is reason and encouragement to prefer and to use the ISO metric screw thread, the traditional Whitworth, B.A., Unified, Acme and Pipe threads are still required. Also, considerable attention is focused nowadays on taper screw threaded gauges made with a precision which demands high quality measuring equipment in order to cover a wide range of size and applications.

Over the years since the pamphlet was first published the emphasis in the Notes has moved from manufacture of the product screw threads to gauges, and this edition concentrates on gauges. However, the methods used for verification of gauges may apply to product screw threads. As regards format, this edition follows much of the layout used previously. Definitions, principles, and the design of measuring machines endure, and due attention has been given to these features. New machines have been referred to since the older machines, often to be found still in good service, are no longer marketed.

In earlier editions much data relating to particular screw threads was supplied whereas now it is convenient to refer to British Standards for full information. Data which relates to measurement and which has been popular with inspectors and instructors has been added to and gathered in the Appendices.

Over post war years there has been some progress in formulating international standards for screw threads, e.g. ISO metric and Unified. However, unification of screw gauge limits and methods of inspection have not been agreed as yet. Meanwhile, these Notes continue to summarise past and contemporary practice at the National Physical Laboratory.

PART I: INTRODUCTION

1 SCOPE

Interchangeable screwed parts, e.g. bolts and nuts, are produced in quantity, one part by a process in a specialising workshop; the counterpart, by a different process, often in a different workshop. The parts are usually inspected independently before acceptance by using gauges made to appropriate limits which ensure that the accepted parts will assemble within the limits for quality of fit. The range of screw threads is remarkable from 12 BA and smaller to gauges like a 20 inch tapered casing ring gauge; thus indicating the diversity and range of size covered by this report.

An outline is given in Section 4 of the design of gauges and their use for testing acceptability of screwed parts.

Tolerances on gauges are kept small in order that the gauges may act closely to the limits on the parts themselves: consequently screw gauges call for fine measurement. These Notes describe the various methods of measurement which are applied to screw gauges and which are applicable when necessary to screwed parts.

There are several thread forms in use. Two common types are shown in Figs. 1a and 1b.

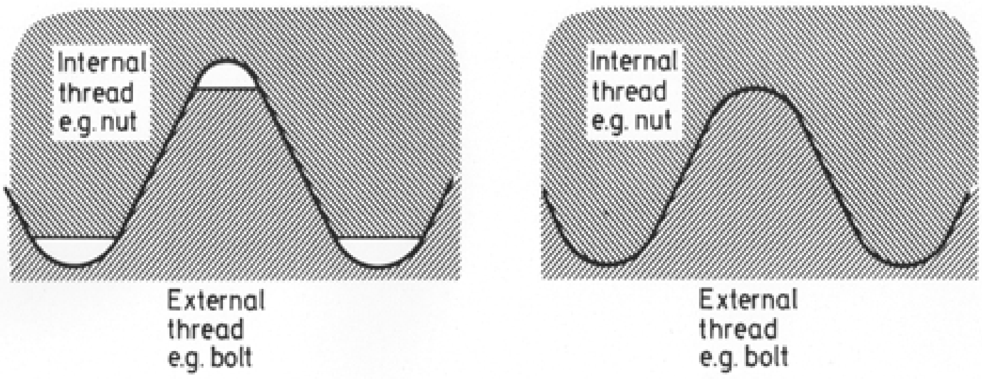

Fig.1a Fig.1b

Typical threadforms

The screw thread in Fig 1a is truncated at the crests and cleared at the roots whereas that in Fig. 1b shows crests and roots which are radiused, symmetrical and could engage at all points on the thread form. The latter is a traditional thread form; the former, where assembly concentrates on flank engagement, is gaining in preference. Examination and measurement applied to both types of thread form are described in some detail.

Part I of this report deals with definitions, the elements of screw threads and the effect of their errors. The design and use of gauges for parallel screw threads is explained.

A screw thread may be formed by a helical groove in a cylinder, known then as a parallel screw thread; or in a cone, known then as a taper screw thread. There are some consequential differences in measurements and these are described in Parts II and III respectively.

Finally, data about thread forms in common use in the United Kingdom, and other information which is required in connection with the measurement of screws are supplied in Part IV.

2 DEFINITIONS

Only those screw thread terms which are used in this report are defined; the definitions should be read in conjunction with Figs. 2 and 3.

Note: BS 6528: 1984, ISO 5408 – 1983 Glossary of terms for Cylindrical Screw Threads supply a complete set of definitions.

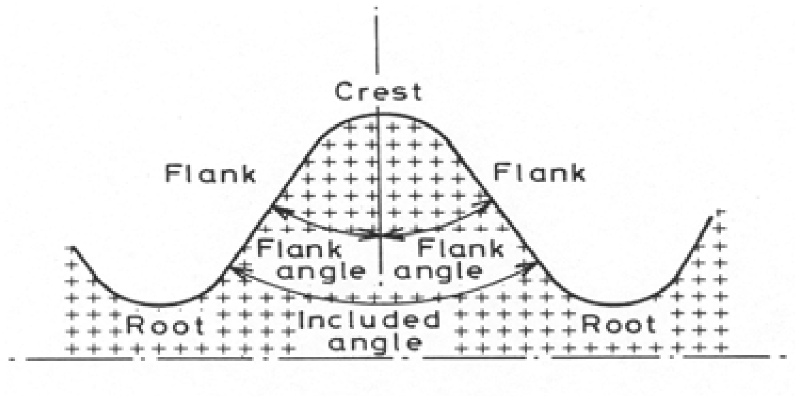

Fig 2 Nomenclature

2.1 General definitions for screws

Thread form is the shape of one complete profile of the thread, between corresponding points at the roots of adjacent grooves in an axial plane section.

Included angle is the angle between the flanks of the thread, measured in an axial plane section.

Flank angles are the angles between the individual flanks and the perpendicular to the axis of the thread, measured in an axial plane section.

A pitch (p) is the distance, measured parallel to the axis, between corresponding points on adjacent thread forms in the same axial plane and on the same side of the axis. Pitch is also used to describe advance of the helix parallel to the axis with full or partial rotation of the thread.

1) Progressive error of pitch is a gradual, but not necessarily uniform, deviation of the pitch of successive threads from the nominal pitch.

2) Periodic error of pitch is a cyclical pattern of departures from nominal pitch which is repeated regularly along the screw.

3) Drunkenness is a periodic variation of pitch where the cycle is of one pitch length.

Lead (p_n) is the axial movement of a point following its helix one turn around the thread axis. $p_n = n \times p$, where n=number of starts i.e. where there are n helices started at regular intervals round the same cylinder.

Rake angle (λ) is the acute angle formed by a thread helix on the pitch cylinder and a plane perpendicular to the cylinder axis.

$$\tan\lambda = \frac{p_n}{\pi E} \text{ (multi start thread)}$$

$$\tan\lambda = \frac{p}{\pi E} \text{ (single start thread)}$$

where E is the pitch diameter

2.2 Definitions for parallel screw threads

Major diameter is that of an imaginary cylinder (termed the major cylinder) which just embraces the crests of an external thread, or the roots of an internal thread.

Minor diameter is that of an imaginary cylinder (termed the minor cylinder) which just embraces the roots of an external thread, or the crests of an internal thread.

Simple pitch diameter is that of an imaginary cylinder (termed the pitch cylinder) which intersects the surface of the thread where the widths of the ridge and the groove are each equal to half a pitch.

Note: Pitch diameter and effective diameter were alternative terms: simple pitch diameter has now been more widely adopted and is used exclusively throughout these Notes; either in full, or without 'simple' when there is no risk of confusion.

Axis of a parallel thread is the axis of its pitch cylinder.

Virtual effective diameter of a parallel thread is the simple pitch diameter of an imaginary thread of perfect pitch and flank angles, cleared at the crests and roots but having the full depth of straight flanks, which would just assemble with the actual thread over the prescribed length of engagement.

Note: The virtual effective diameter exceeds the simple pitch diameter in the case of an external thread, and is less than the simple pitch diameter in the case of an internal thread, by an amount corresponding to the combined diametral effects due to any errors in the pitch and flank angles of the thread.

2.3 Definitions relating to taper screw threads

These are set out in Section 14 of Part III

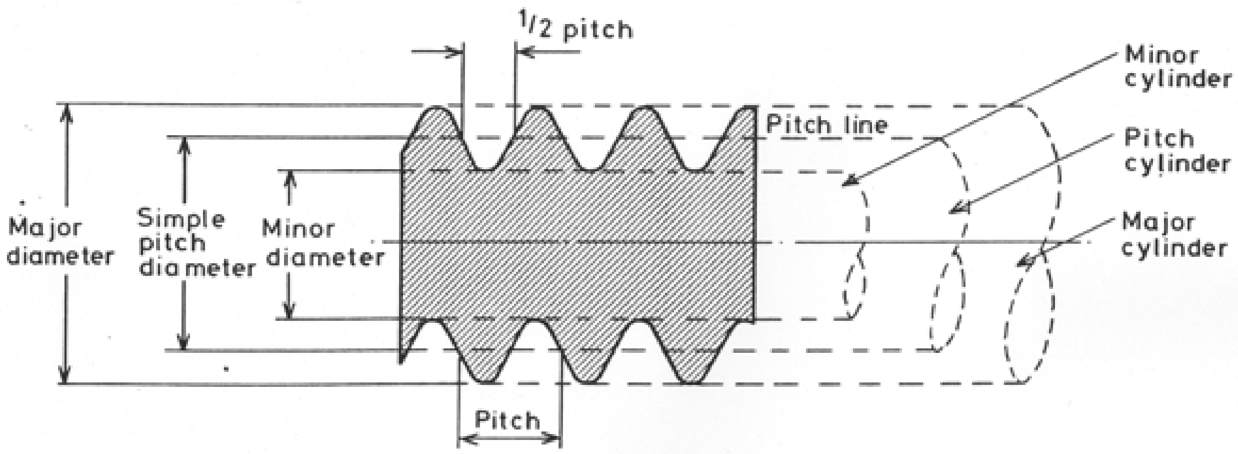

Fig 3 Elements of parallel screw threads

3 ELEMENTS OF A SCREW THREAD AND THEIR ERRORS

Figs. 1a, 1b, 2 and 3 indicate seven elements which require control in manufacture of screw threads. These elements are:

- major diameter
- pitch diameter
- minor diameter
- pitch
- flank angles
- radius at crest
- radius at root

The last two elements appear in the Whitworth and BA thread forms, see Fig. 1b, but the thread form in Fig. 1a makes no demand for a radius at its crests, and its roots are cleared, which is a requirement of sufficiency and not of precise contour.

Errors in any of the elements may affect the engagement of screwed parts or accuracy of screw gauges; pitch diameter, pitch and flank angles generally attract most attention as will be explained. The various elements and how errors may arise will now be discussed in some detail.

3.1 Pitch diameter

The importance of accuracy of the pitch diameter of a screw thread becomes evident when it is realized that errors in this diameter determine to a large extent the amount of "play" between assembled screw threads. Insofar as the pitch diameter of an external thread is less than its upper limit, so its threads will appear to be thin and increasingly slack in assembly with an internal thread on its own low diametral limit. Conversely, if the pitch diameter of the external screw is above its upper limit then the threads are said to be thick. The reverse of these conditions applies to internal screw threads.

3.2 Pitch

Section 2.1 defines nominal pitch or designated pitch as a length between consecutive turns of the thread. Additionally pitch is a function of the helix of the screw thread; for example, a screw thread should advance precisely a quarter of the pitch when the screw is rotated one quarter of a turn. Another way of looking at pitch is that if the outside of the pitch cylinder as in Fig. 3 were laid flat then the helix would appear as a straight line as illustrated in Fig. 4: pitch errors can be considered as departures from the inclined straight line depicted.

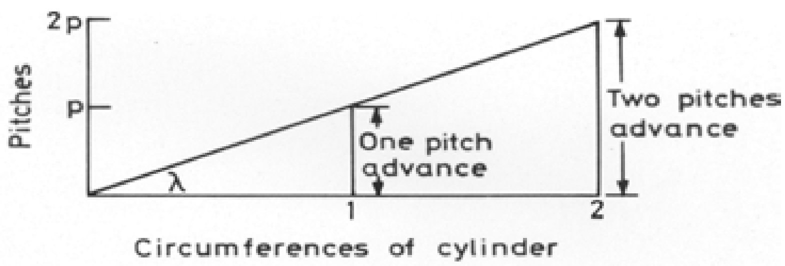

Fig. 4 Illustration of a perfect helix, advancing two turns, laid flat

Regarding pitch errors as positions where the flanks are situated incorrectly axially it is their mutual relative position, i.e. the cumulative pitch error, which affects the fitting together of screw threads. To illustrate this aspect consider Fig. 5a, which shows the errors in pitch, round and along, a screw. The errors are expressed with respect to a datum plane normal to the axis of the screw. Whereas there is a lengthening of pitch up to say 0.003 mm at region (a), at region (h) the pitch with respect to the datum is short by 0.002 mm. The cumulative error is a shortening of pitch between positions (a) and (h) of (0.003 + 0.002 mm), i.e. 0.005 mm. It will be seen also that the extremes of the plot are regions (i) and (f) between which there is a maximum cumulative pitch error of 0.0115 mm.

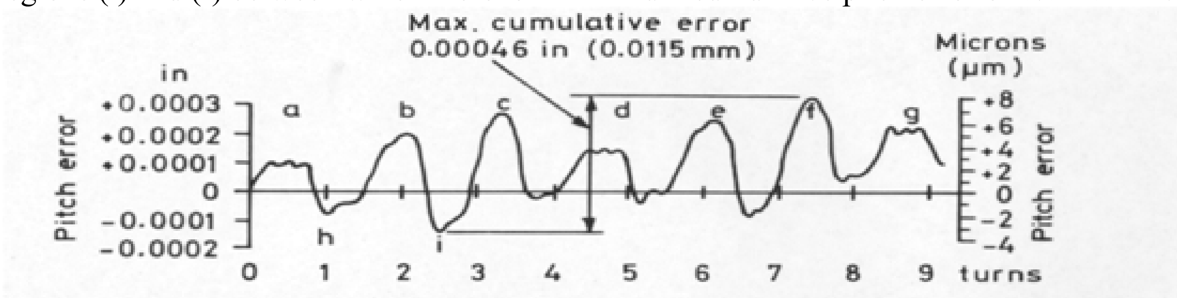

Fig. 5(a) Chart of cumulative pitch errors at intervals of less than one pitch

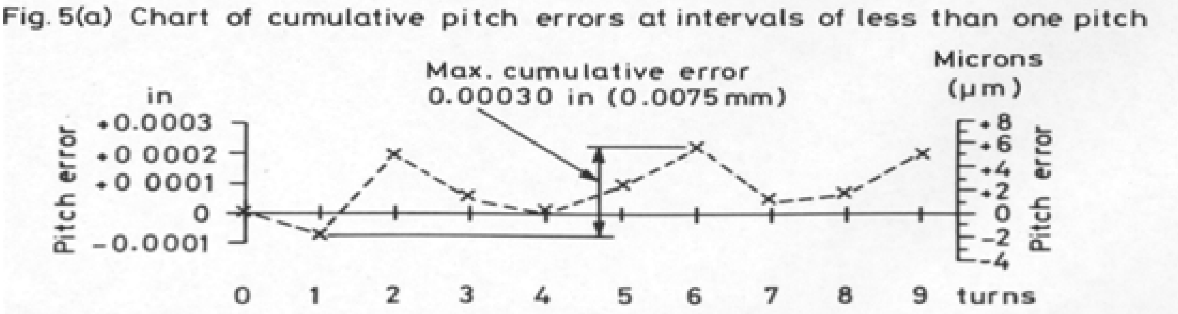

Fig. 5(b) Chart of cumulative pitch error measured at intervals of one pitch

The maximum cumulative error in pitch, i.e. the maximum error in the axial distance between any two positions along the helix, has to be accommodated when one screwed part is to assemble with another.

An examination of a detailed record of pitch error such as in Fig. 5a supplies clues as to the possible source of errors and thus to their reduction. For instance a general lengthening or shortening of pitch may be due to changes in the material in hardening, or a reproduction of an error in the leading screw of the lathe or thread grinding machine upon which the sample was made. Errors of a periodic nature, see particularly the record in Fig. 5a, may be due to a to-and-fro axial motion when the sample was made, caused by damaged centres, or an out-of-square abutment face on the leading screw of headstock spindle, or eccentrically mounted change gear wheels.

The quality of manufacture of modern thread grinding machines and screw correction lathes ensures that the pitch of screw gauges is well controlled and it is common practice to check accuracy of pitch only at consecutive pitches over the length of a screw gauge. However it is necessary not to lose sight of the possibility of local variations of thread from a true helix. To illustrate this need, if errors in pitch of a screw were suspected and they were checked only at one pitch intervals, Fig. 5b would be obtained; a more thorough examination as in Fig. 5a could be more revealing.

3.3 Error in pitch in relation to pitch diameter

It is important to realize that errors in pitch, namely incorrect relative position of the flanks, act obstructively: for example an otherwise perfect external screw which has pitch error will not screw into a perfect internal screw of the same nominal size. It can be made to do so by removing metal from its flanks and thus reducing its simple pitch diameter. An alternative way of appreciating the connection between errors in pitch and pitch diameter is that pitch errors virtually increase the pitch diameter of an external screw and virtually reduce the pitch diameter of an internal screw. The virtual difference in pitch diameter equivalent to a pitch error may be determined as follows.

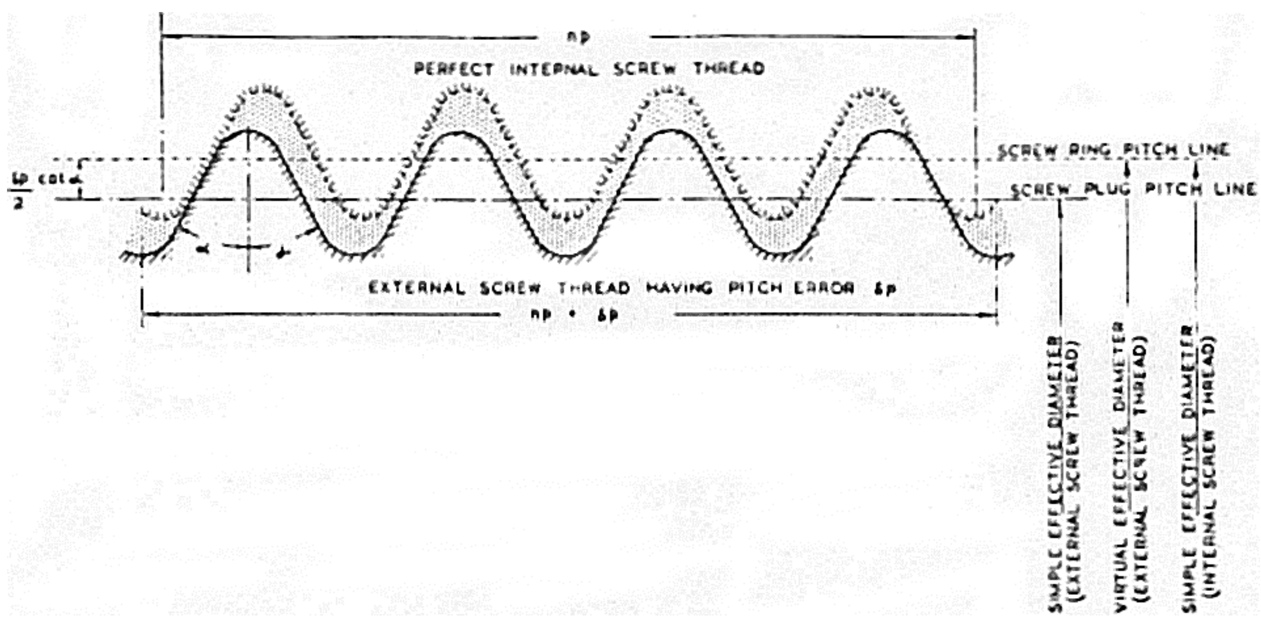

Fig. 6 Virtual Difference is pitch diameter for pitch error

Suppose the upper and lower outlines in Fig. 6 represent respectively a perfect internal screw and an otherwise perfect external screw but for having a pitch error of δp. The two screws just assemble over a length of n pitches, and are depicted in contact with each other on flanks at only the first and last threads. The maximum displacement between the two threads, the pitch error δp axially, can be seen as a symmetrical gap of $\delta p/2$ axially at each side at the centre thread, and can be expressed equivalently as $\frac{\delta p}{2}\cot\alpha$ radially. Thus the external screw which has a simple pitch diameter smaller than that of the internal screw engages by behaving virtually $\delta p \cot\alpha$ larger diametraly. The numerical values for cot α for threads in common use are as follows.

Table 1: Pitch error and virtual effect on pitch diameter

Thread form	2α	$\cot\alpha$
ISO metric	60°	1.732
Unified	60°	1.732
Whitworth	55°	1.921
British Association	47.5°	2.273
CME	29°	3.867

It will be seen that the virtual equivalent effect on pitch diameter is a multiple of pitch error, roughly two times for the commonest threads and roughly four times for Acme. For this reason of multiplied effect it is essential that pitch errors be kept as small as possible; measurements of pitch may be made to a resolution of 0.0002mm [0.00001 in] so that the threading process is checked closely.

Appendix 4 in PART IV gives for screws of various forms the virtual differences in pitch diameter corresponding to errors in pitch in steps of 0.001 mm up to 0.010 mm, and of 0.00005 in up to 0.0005 in.

3.4 Errors in flank angles in relation to pitch diameter

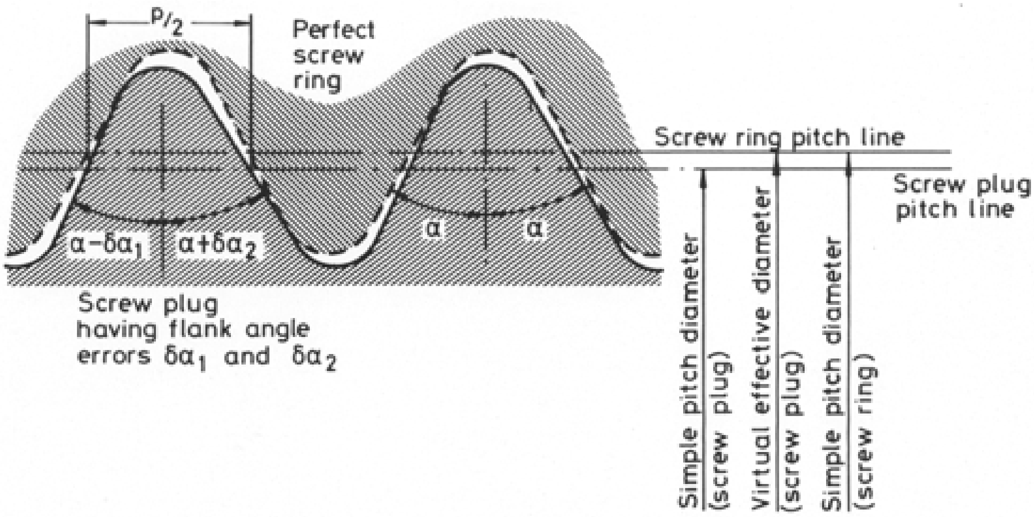

Fig. 7 Virtual difference in pitch diameter for errors of flank angles

Fig. 7 illustrates the obstructive effect caused by errors in flank angles. The corresponding flanks of the two screws are not parallel and cannot make full flank-to-flank contact. Instead, the flanks of the lower outline offer contact only at their extremities: although the plug has a smaller simple pitch diameter than the ring, it behaves as if increased. Notice that the error of each flank angle $\delta\alpha_1$, $\delta\alpha_2$

makes its contribution to the increase. Expressed in another way, the simple pitch diameter of a plug screw is virtually increased by the equivalent of the sum, irrespective of sign, of the errors of the flank angles.

If δa_1 and δa_2 represent the errors in the two flank angles of a screw thread, the virtual increase of pitch diameter of an external thread, (or virtual decrease, of an internal thread) is given by the following approximate expressions.

Table 2: Flank angle errors and virtual effect on pitch diameter

Thread form	Virtual change in pitch diameter
ISO metric Unified	* $0.0109 \times p \times (\delta a_1 + \delta a_2)$
Whitworth	$0.0105 \times p \times (\delta a_1 + \delta a_2)$
British Association	$0.0091 \times p \times (\delta a_1 + \delta a_2)$
Acme	$0.0180 \times p \times (\delta a_1 + \delta a_2)$
δa_1 and δa_2 are errors expressed in degrees and irrespectively of sign; the virtual change will have the same unit as is used for *p*, pitch.	

Tables in Appendix 5 of Part IV enable the virtual change in pitch diameter to be read for any particular case. It should be noted that the expressions tabulated above, and the Tables in Part IV are based on maximum flank engagement. Attention will be drawn later to cases in which one of the assembling screw gauges has designedly reduced length of flank.

* For ISO metric and unified threads the lengths of straight flank above and below the pitch line are unequal. For that reason positive errors in flank angles have slightly smaller virtual effects on pitch diameter of external screws and negative errors in flank angles (and *vice versa* for internal screws). The factors in the expressions above are the mean values corresponding to the two sets of conditions and are sufficiently accurate for practical purposes.

3.5 Radii at crest and root

Errors of size of the radiused form and of its positioning can present excess metal and hence offer obstruction to assembly, and in the case of gauges, incorrect performance. This is the situation in particular of nominally symmetrical thread forms such as Whitworth and British Association. In the cases of threads such as ISO metric and Unified where the crests are truncated and the roots cleared it is important that the form at the crests does not carry excess metal and that the root clearance is adequate, yet does not reduce the specified length of straight flanks.

3.6 Summary

The above account describes the elements of screws and shows that diameters, pitch, flank angles, and thread form have to be controlled. There can be interaction between the errors thus affecting the assembly and fit of screws. Although these notes are not intended to describe the manufacture of screws, it is important to stress attention to certain requirements. The thread cutting device, i.e. form grinding wheel, tap, die, or lathe tool, must provide an accurate form; a form tool must be presented square to the axis of the screw blank and with its form in a diametral section; the pitch must be under precise control.

4 GAUGING PARALLEL SCREW THREADS

Threaded components intended to assemble and to be interchangeable have to be tested to ensure assembly and, equally importantly, with no more slackness of fit than the designer permits. A system of limit gauges as follows is recommended and is common practice.

4.1 Gauges for external threads

a) A Go screw ring or calliper gauge made to the maximum permitted pitch diameter of the external thread. If the latter has a nominal thread form as in Fig. 1b the Go gauge should correspond with the maximum metal permitted outline of the product.

b) A Not Go pitch diameter calliper gauge or screw ring made to the minimum permitted pitch diameter of the external thread.

c) Go and Not Go plain calliper gauges made to the respective maximum and minimum permitted major diameters of the external thread.

4.2 Gauges for internal threads

a) A Go screw plug gauge made to the minimum permitted pitch diameter of the internal thread. If the latter has a nominal thread form as in Fig. 1b, the Go gauge should correspond with the maximum metal permitted outline of the product.

b) A Not Go pitch diameter screw plug gauge made to the maximum permitted pitch diameter of the internal thread.

c) Go and Not Go plain plug gauges made to the respective permitted minimum and maximum minor diameters of the internal thread.

4.3 Length of gauge

The Go screw gauges listed in sub-paragraphs (a) above should have a length of thread not less than the length of engagement of the components to be tested, thus ensuring that the effect of cumulative error in pitch in a component is taken into account.

The Not Go pitch diameter screw gauges listed in (b) above may be limited to not more than three turns of thread. In their cases cumulative error of pitch in a component can play little part over the short length of engagement of the Not Go gauge.

4.4 Thread form of gauge

Go screw gauges should be the counterpart of the maximum permitted metal outline of the thread to be gauged. Thus for Whitworth and B.A. threaded components the Go gauges will have radiused crests and roots to ensure that no part of the component outline exceeds its maximum permitted metal profile. However for American National, ISO metric and unified threads which have flat crests and clearance at the roots it is not practical to supply a flat at the roots of Go gauges. British Standards indicate the appropriate thread form for Go gauges and in each case it ensures that the full length of straight flank of the component thread is tested.

Not Go pitch diameter gauges concentrate on ensuring that the pitch diameter of the component is not outside the minimum metal limit. Accordingly the crests of the gauge are deliberately truncated and the roots cleared. Furthermore the Not Go gauge offers reduced flank contact with a component thread and thus is less affected by flank angle errors than it would be in full flank engagement.

In conclusion it should be understood that whereas the system of gauges works well it is not a complete inspection method. It depends upon satisfactory thread form; also on minimised errors of pitch and of flank angles of component and gauge.

5 PREPARATORY FEATURES OF GAUGES

It is necessary to give correct attention to certain features in making screw gauges where they affect the quality of the gauges and facilitate measurement.

5.1 Gauge blanks

It is a common practice to grind the threads of gauges in hardened and stabilized steel blanks. Recommended designs and dimensions of gauge blanks are specified in BS1044: Gauge Blanks. In the case of small ring gauges and when hardened blanks are not stocked, unhardened blanks must be threaded, hardened, stabilized and subsequently ground or lapped to form and size; in these circumstances BS1044 provides guidance.

In all cases the length of blank of GO gauges should be chosen to ensure that they operate over at least the length of engagement of the workpiece threads.

5.2 Hardness and stabilization

Finished gauges, and hence the hardened blanks, should be not so hard that the threads are brittle and likely to snap off, yet hard enough to avoid bruising. Hardness values between 650 and 750 DPN are in general satisfactory. It is difficult to make hardness measurements on the flanks of screw threads by diamond pyramid indentation methods but a fairly close estimate of their hardness can readily be obtained by the use of a special scriber, without causing them any damage. Such a scriber, as used at the NPL, consists of a small round Swiss file the end of which is ground to a smooth hemisphere of about 0.6 mm (0.025 in) radius. The tool is mounted in a wooden handle, and is used for comparing the flanks of the gauge with independent working standards of hardness, by drawing it across the face of each in turn, using as equal a pressure as possible, and by comparing the resulting marks. A reasonably heavy pressure, by the fingers bearing on the tool, should be used.

Gauge makers can readily provide such standards of hardness for themselves. They may consist of flat pieces of steel of convenient size, hardened and tempered down to different degrees. Five such pieces for example, one untempered and one each tempered at 200 °C, 300 °C, 400 °C and 500 °C, and checked in a hardness testing machine will probably be found to cover an adequate range.

The steel of gauges must be stabilized, before finishing the thread. Blanks to BS 1044 are supplied already stabilized. Otherwise a recommended treatment is to heat the hardened, roughed out gauges to 150 °C and maintain them at this temperature for five hours followed by slow cooling.

5.3 Centre of plugs; end faces of rings

The centres, internal or external, supplied in a plug define the axis for manufacture and measurement, and should be well-finished cones. Large, long centres should be avoided and the mouth should be protected by a small recess in $\frac{1}{32}$ or $\frac{1}{16}$ (0.8 or 1.5 mm) deep as shown in Fig. 8.

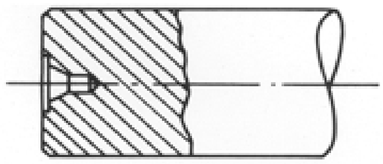

Fig. 8 Centre in plug screw gauge

The end faces of ring blanks should be surfaced before final threading and one of them should be finished flat and free from marking. This one should be used for a datum normal to the axis of the threading process, and for mounting for measurement.

5.4 End threading

Terminal threads decrease from a section of full thread form to nothing, but in the process of running out become a sharp fin of metal which is easily damaged in shape and position, and likely to falsify the performance of a gauge. Accordingly unless instructions to the contrary are given, the length of incomplete thread shall be removed or, in the case of small rings, bevelled down to avoid damage.

PART II: PARALLEL SCREW THREADS

6 CONDITIONS OF MEASUREMENT

6.1 Temperature

Measurements of diameter and pitch apply at the reference temperature of 20 °C (68°F). The machines described in this report use steel micrometer screws and hardened steel cylindrical standards for measurement by comparison. It is not essential that measurements in these circumstances be made at exactly 20 °C: it is vital however that steel gauge and steel standards are at the same temperature before and during comparison. This is usually affected by standing gauge and standard alongside, close to the measuring machine, in a situation at reasonably constant temperature near 20 °C, so that all items may reach the same temperature.

6.2 Units

The results of measurement are expressed in millimetres or in inches to compare with the units used for the prescribed limits of size of the gauges. National transition from inches to solely metric measure is incomplete and meanwhile some measurements required in metric measure are made on inch reading machines and *vice versa*. This presents no problem providing a conversion factor of 1 inch = 25.4 mm **exactly** is used either to convert limits or to convert results.

Throughout this report both units will be used as appropriate. The text background of this report justifies a fraction as small as 0.0001 inch and, in some cases, 0.00001 inch. Regarding metric measure, 0.00004 in is closely 0.001 mm which is denoted by µm, and errors will be expressed in this unit at times.

7 MECHANICAL MEASUREMENTS OF PARALLEL SCREW PLUG GAUGES

7.1 Major diameter

A bench micrometer of NPL design as illustrated in Plate II serves for measuring the major diameter of parallel plug screw gauges. It consists of a cast iron frame on which are mounted a micrometer head with an enlarged thimble opposite a fiducial indicator; the assembly makes a calliper by which measurements are reproducible within ±0.001 mm (±0.00005 in).

The micrometer is used as a comparator. Thus the bench micrometer reading R_B is taken on a standard cylindrical plug of known diameter B of about the same size as the major diameter to be measured. A reading R_G is then taken across the crests of the gauge. Its major diameter, D, is given by

$$D = B + R_G - R_B$$

Further readings should be taken along and round the gauge to explore the variations in major diameter. Finally the reading R_B on the standard should be checked to confirm that the original setting has not changed.

It is essential, if accurate results are to be obtained, that the above instructions should be followed.

It is not satisfactory to attempt to establish the "zero" setting of the machine by bringing the micrometer and indicator faces into direct contact, either with or without the interposition of gauge blocks.

The above procedure can be improved upon by carefully setting the bench micrometer so that $R_B = B$, as follows:

1) Set the micrometer to read B, the known diameter of the standard cylinder.

2) Adjust the indicator towards the micrometer until the standard cylinder is held between the measuring faces, and the indicator pointer is approximately opposite its fixed mark. Clamp the indicator.

3) Unscrew the micrometer a turn and then screw it forward until it grips the standard, and the indicator pointer is exactly in line with its fixed mark.

4) Rotate the micrometer barrel as necessary to adjust the reading to B exactly.

Subsequent readings R_G of the bench micrometer on the crests of the screw gauge with the indicator pointer at the fixed mark are major diameters, i.e. $R_G = D$.

It will be seen that the stated result depends on the accepted size B of the cylindrical standard. Sets of such standards may be purchased complete with a Report giving a calibrated size at 20 °C for each item.

If a bench micrometer is not available, then a hand micrometer in compliance with BS 870: Micrometers (External) may be used. It should be checked for reading R_B on a cylindrical standard of known size B close to the major diameter of the screw gauge and a correction to reading deduced. A light but positive measuring force should be used, and the same force applied when contacting the crests of the gauge.

Although measuring skill with the hand micrometer can be developed, nevertheless it is preferable and advantageous to use a bench micrometer as described earlier.

7.2 Pitch diameter

The pitch diameter is best measured by taking micrometer-machine readings over a pair of small cylinders seated between the flanks on opposite sides of the plug screw gauge (see Fig. 9). The cylinders should be chosen to make contact about half-way down the flanks, i.e. close to the pitch line. The small cylinders should be cylindrical to within 0.001 mm (0.00004 in) and their diameters should be known to well within the same figures. Suitable cylinders for metric and other threads may be purchased in compliance with BS 5590: Screw thread metric series measuring cylinders. See also Appendix 6 in Part IV.

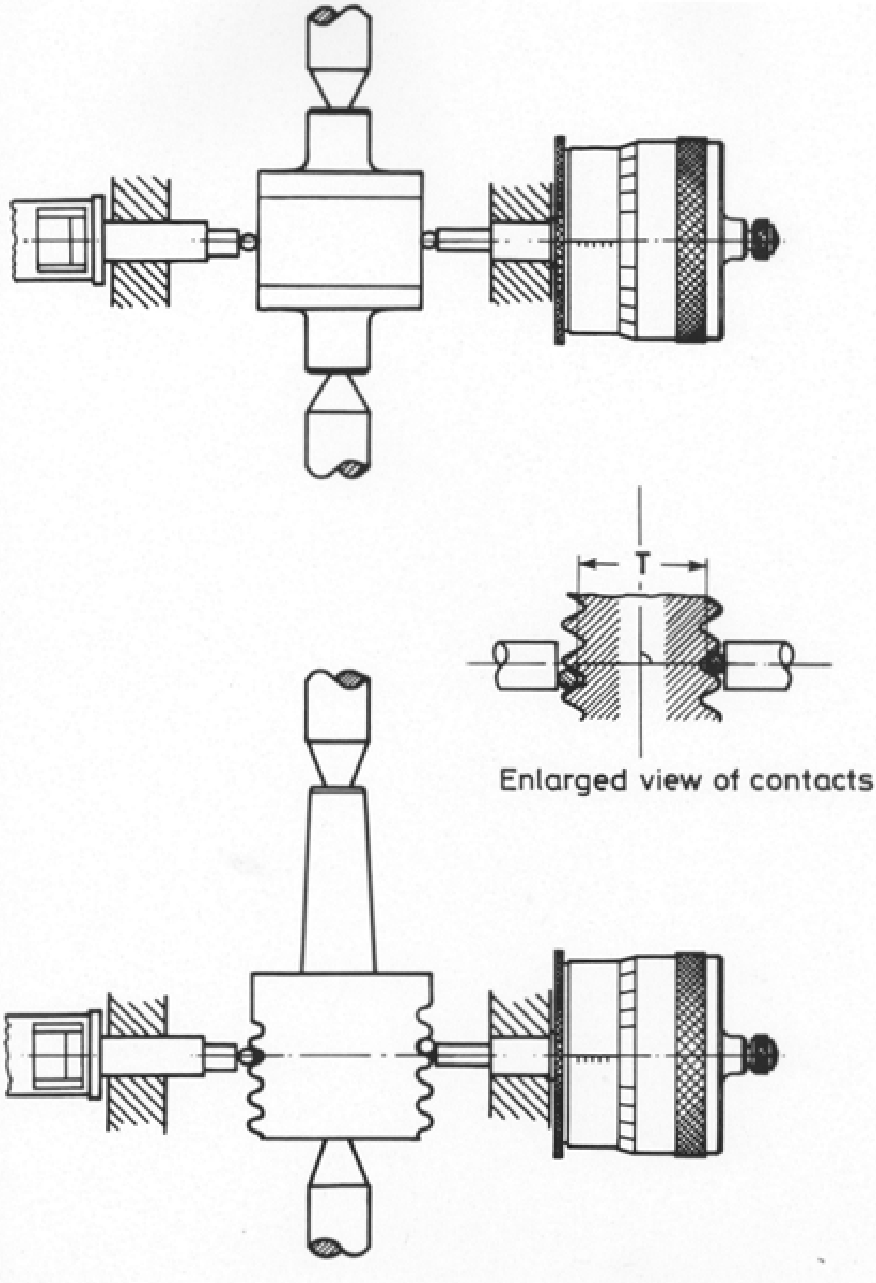

Fig. 9 Pitch diameter measurement on the machine shown in Fig.10

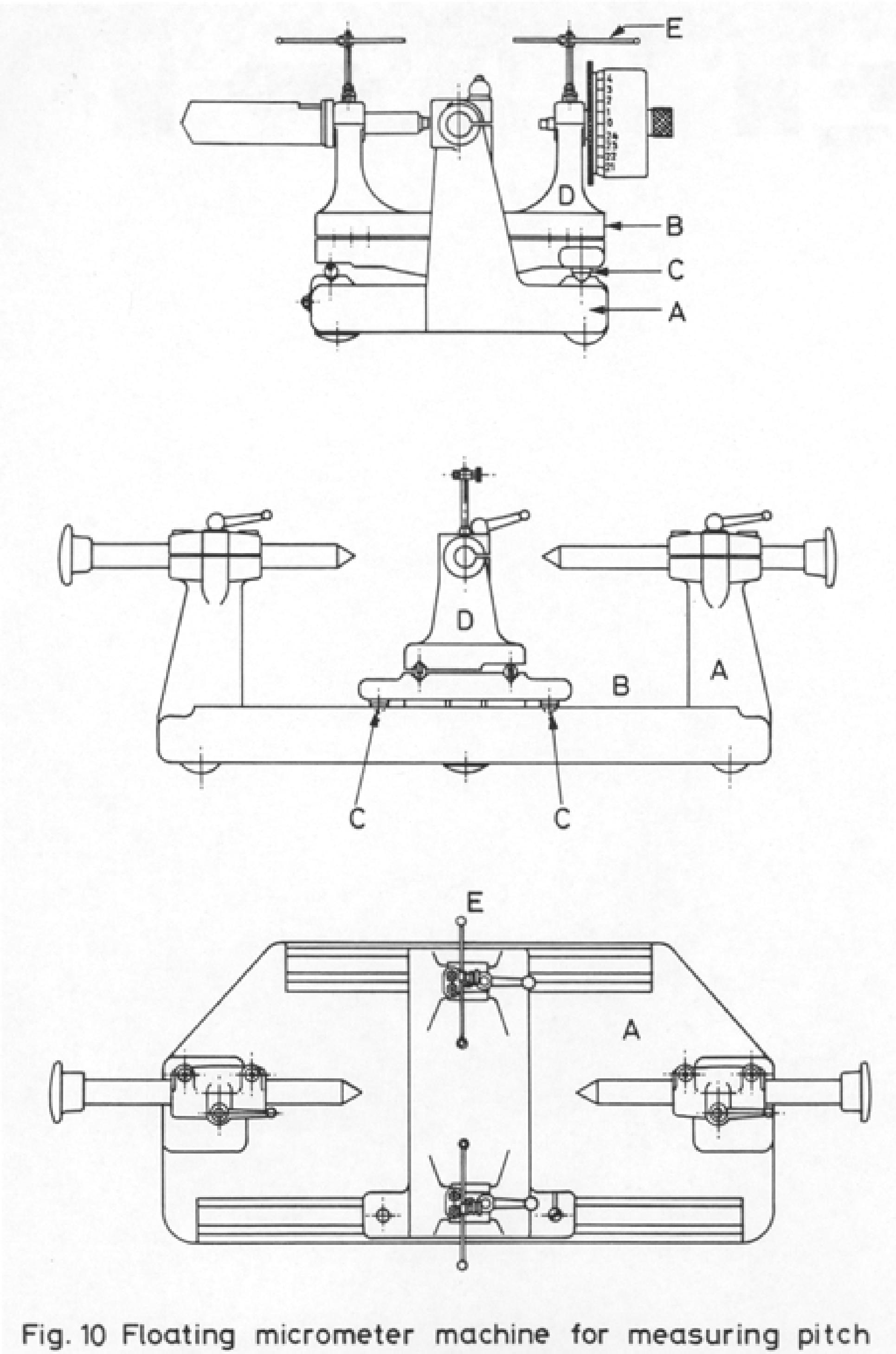

Fig. 10 Floating micrometer machine for measuring pitch diameter and minor diameters of screw plug gauges

With this method, it is essential that the micrometer should be held at right angles to the axis of the screw gauge being measured. This is best secured by using a "floating micrometer" diameter measuring machine of the type shown in Fig. 10. The gauge is mounted between a pair of centres carried on a base (A) which has two vee-grooves machined in its upper surface parallel to the line of the centres. These vee-grooves form runways for a saddle (B), having on one side two projecting conical pegs (C) which rest in one of the grooves. The other end of the saddle rests on a steel ball placed in the other vee-groove. A micrometer carriage (D), with a vee-groove and a flat on its underside, can move freely on steel balls resting in two vee-grooves cut in the upper surface of the saddle in a direction at right angles to the line of centres. This micrometer carriage is provided on one side with a micrometer head graduated to either 0.002 mm or 0.0001 in and capable of being read to 0.0005 mm or 0.00002 in, and on the other side with an adjustable anvil associated with a sensitive indicator. The common axis of the micrometer and anvil is at the same height as the line of centres. The shank of one of the conical pegs (C) is made eccentric; so that by turning it in its hole, it is possible to adjust the axis of the micrometer truly square with the line of centres. After making this setting, the position of the peg can be maintained by a clamping screw. Taken as a whole, the machine is a development of the bench micrometer already described, having a free motion at right angles to the line of centres, and capable also of being traversed along the bed of the machine so as to measure at any desired position along a screw gauge mounted between the centres. The cylinders used with the machine during the measurements of the pitch diameter are suspended by threads from light rods (E) fixed to the micrometer carriage. In order to eliminate entirely the personal element as regards the "feel" of the micrometer, and also to obtain a control of the measuring force, the adjustable anvil is fitted with a fiducial indicator (F) which operates under a force of about 250 grams wt (8 oz wt), or less if desired. The machine described, which was designed at NPL, is obtainable commercially in two or three sizes to accommodate gauges up to 250 mm (10 in) or so in diameter. Reference should now be made to Fig. 9 where the central diagram shows cylinders seated in the groove of the thread and the dimension *T* beneath them. The objective of the measurement in the floating micrometer machine is to determine *T*. The pitch diameter E is then obtained from the measured value of *T* by the formula:

$$E = T + P - c + e$$

Where *P* is a constant depending on the pitch and angle of the screw thread, and the mean diameter of the small cylinders used; c is a correction depending mainly upon the rake angle of the screw thread; e is a correction for the elastic compression of the cylinders. In practice the thread measuring cylinder are supplied with their measured diameter and with the *P* values appropriate to each combination of pitch and common thread form to which the cylinders may be applied. The values of *c* and *e* are in general relatively small for standard screw threads and the low measuring force used; however they must be taken into account as they are significant compared with tolerances for screw gauges. Formulae for calculating *P, c* and *e* are given in Section 8. Details of the measuring procedures are as follows. Select a cylindrical standard of known diameter of approximately the same size as the pitch diameter of the screw plug gauge to be measured, also a pair of thread measuring cylinders designated suitable for the pitch and thread form of the screw gauge; wipe clean the measuring faces of the machine, and its centres, and check that the transverse motion of the micrometer casting is free. Wipe clean the cylindrical standard and the pair of thread measuring cylinders. Clean the flanks of the screw plug gauge, its centres, and the centres of the standard with a toothbrush.

The cylindrical standard of known diameter *B* is mounted on the centres of the machine and the thread measuring cylinders are suspended one on each side between the standard and the adjacent measuring face, see Fig. 9. The micrometer is fed in to contact cylinders and standard giving a reading R_B. The standard is replaced by the gauge, the small cylinders put in the groove, and a reading R_G obtained. Note that in contacting standard or gauge the small cylinders should be gently and slightly rocked parallel to the line of centres to ensure that there is true contact.

Then

$$T = B + R_G - R_B$$

and pitch diameter *E* is given by

$$E = B + R_G - R_B + P - c + e$$

Note that the above procedure can be improved upon by pre-adjusting the machine as described in measurement of major diameter. In this case the initial reading R_B on the cylindrical standard and thread measuring cylinders is adjusted to be exactly $(B+P)$. Subsequent readings R_G across screw plug and cylinders give values of $(T+P)$. The pitch diameter is then given by the readings R_G at various positions when the rake correction c and compression correction e have been applied thereto. Measurements by the foregoing procedure are reproducible to within 0.0001 in (0.003 mm).

The above remarks are made in the context of gauges for standard threads. However there are multi start threads and threads where the pitch is coarse relative to the diameter, whereupon the rake correction c is relatively large. Correction to measurements of pitch diameter in such conditions is given detailed consideration in Section 8.

The procedure described is based upon the use of a floating micrometer machine. Only if a suitable measuring machine is not available and a hand micrometer has to be used, then a set of three thread measuring cylinders whose individual mean diameters fall within a range of 0.0001 in (0.003 mm) is used. Two cylinders in grooves on one side of the gauge align one micrometer face, and the third cylinder is situated in mid face on the other side of the gauge. The method described above of firstly reading over thread measuring cylinders engaging a cylindrical standard and then over the cylinders in the threads of a screw plug should be followed.

However, measurement of pitch diameter of gauges with a hand micrometer is cumbersome and cannot be recommended in comparison with the refined tolerances on screw gauges: the hand micrometer method is unsuitable for referee measurements.

7.3 Minor diameter

In those gauges, e.g. Whitworth or BA, where the thread form at the root has a precise radius and is not "cleared" to avoid contact, the minor diameter is best measured by taking measurements over the outsides of a pair of vee-pieces seating in the grooves on opposite sides of the screw plug gauge (see Fig. 11).

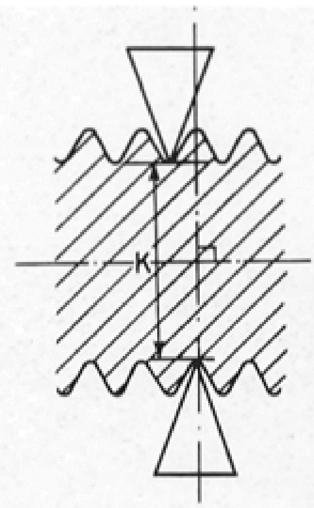

Fig. 11 Veepieces contacting minor diameter

The vee-pieces used consist of hardened steel prisms having an angle of about 45°, with the front edge finished to a radius somewhat smaller than that of the curvature at the roots of the finest thread which it is desired to measure. It is found useful to have such vees made in a series of different sizes, to cover the range of screws usually met. Details of suitable sizes of the vees will be found in Appendix 9 in Part IV.

The details of the procedure for measuring minor diameter are similar to those described already for measuring pitch diameter, *viz*

- carefully cleaning the items,
- taking reading R_B over the pair of prisms both contacting a cylindrical standard of known diameter B,
- taking readings R_G over the prisms seated in the roots of the plug screw gauge,
- finally checking that R_B still applies.

Then the minor diameter, $K = B + R_g - R_b$

As mentioned in measuring major and pitch diameters, an improved method is to pre-set the measuring machine to $R_B = B$ when it is in contact with vee-pieces on each side of the cylindrical standard. Subsequent readings R_G on the same prisms in contact with the roots of the screw gauge are then minor diameters at the particular positions.

Note that the actual sizes of the vee-pieces do not require to be known, nor do they need to be equal. It is essential, however, that each vee-piece should be uniform along its length, i.e. the front measuring edge must be parallel to the back face, and both must be straight. Measurements of minor diameter using the foregoing procedure are reproducible to 0.0001 in (0.003 mm).

7.4 Pitch

As a pitch error of say 0.003 mm between any two points on a plug screw gauge of uniform diameter virtually increases the pitch diameter by a multiple, i.e. to about 0.006 mm, see Table 1, there is always a need to monitor, and to restrict pitch error. To that end the measurement of errors in pitch is aimed at an accuracy well within 0.003 mm or 0.0001 in and thus to contend with the virtual multiplied effect on pitch diameter. If the error is periodic or variable, the greatest error can only be found with certainty by taking measurements from one point to every other point on the same spiral. For screw gauges of ordinary types having a fairly fine pitch it is usual, however, to measure the pitch along a line parallel to the axis by measuring from the first thread groove to every thread groove in turn in an axial section. The screw is then rotated 180° on the centres and another test made. Misalignment in elevation of the line of centres of the gauge with the measuring axis could introduce an error by gradually climbing up the helix in one position of measurement, and by gradually descending the helix in the other measuring position at 180°. The mean result eliminates the effect of misalignment. Unless the screw is "drunken", the maximum error which exists in the pitch can then be seen from the mean result and it is this maximum error which has to be used in estimating the virtual effective diameter (see Section 3.3). "Drunkenness" is a pitch error of a periodic nature and it will be referred to later, see Section 7.4.1. The significance of pitch error was recognised early and a pitch measuring machine was designed and made at NPL. Many 6" x 9" pitch machines, as they were known, were made to NPL design by specialising firms, and widely used. The same principles were used in the modernised and improved design of a pitch measuring machine which the Coventry Gauge and Tool Co Ltd made in the 1930s and which also is widely used. The main features of design are indicated in Plate III and in the following description. The three main portions of the machine are the bed (A) carrying a micrometer screw, the sliding bar (B) carrying the micrometer nut, and the indicator and saddle (K). Screw plug gauges are held between centres (C), and a thread groove may be located by using a hardened steel stylus (P) with a rounded tip. This is made to travel in a direction parallel to the axis of the screw, riding in and out of the threads in turn.

The stylus is fixed to the end of the first lever of an indicator (I). This lever is attached to the body of the indicator by crossed flexible steel strips which can both bend and twist under the action of the stylus in the thread. The indicator is clamped to the bar (B), which is supported on balls in vee grooves, and can be traversed over a range of 50 mm or 2 inches by the micrometer (M), which usually has a pitch of either 0.5 mm or 40 threads per inch. The thrust of the micrometer is taken by an anvil rod in the bed casting; rotating the micrometer screw propels its nut and the bar (B).

As the stylus is traversed along the screw being measured, the second lever of the indicator is deflected from side to side, and when its tip is brought repeatedly opposite a fixed fiducial mark ensures that the stylus is resting centrally in the successive threads, as in Fig. 12. Readings of the micrometer are taken at each point of fiducial setting, and from these the pitch errors of the screw can be obtained.

Screws of longer lengths than 50 mm or 2 in can be measured in successive lengths by moving the saddle (K) along the bar (B) and reclamping it in other positions.

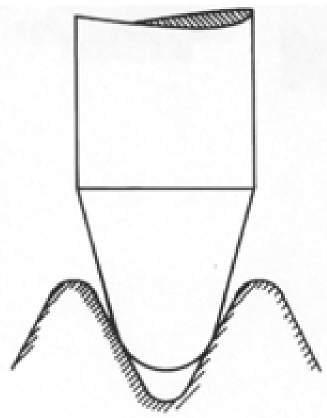

Fig. 12 Symmetrical contact of a radiused stylus near the pitch line.

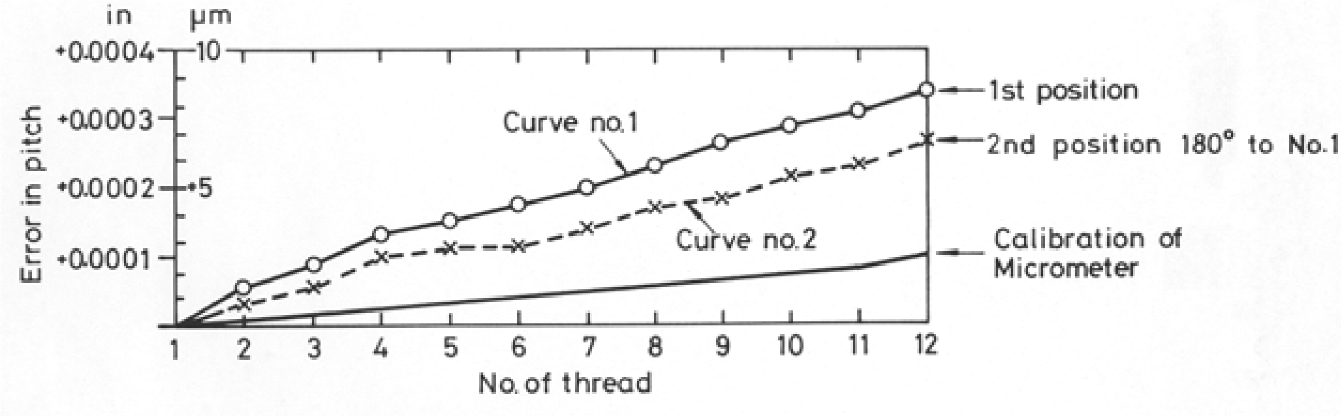

Fig.13 Plotted errors of pitch

Note: The above diagram is an illustration for explanation purposes: errors of pitch in gauges and of the measuring machine are usually smaller than those Fig. 13 depicts.

The errors of pitch are plotted as shown by curves No 1 and 2 of Fig. 13. From the mean of these curves the cumulative pitch error over the length of the screw appears to be +0.00030 in (+7.5 µm). Before the real pitch error of the screw can be stated, any error present in the micrometer screw of the machine has to be allowed for. The lowest curve in Fig 13 shows the calibration curve for that portion of the micrometer screw which has been used. This curve shows that the error in the machine is such as to cause a screw of perfect pitch to appear long in pitch by 0.00010 in (2.5 µm) over its length. Hence the real cumulative pitch error of the screw under test is +0.00020 in (+5µm).

To allow rapid measurements of the more common inch pitches to be made, a number of specially graduated dials (N in Plate III) are provided for attachment to the thimble of the 40 tpi micrometer. These dials are divided according to the whole number and fraction of a revolution of the micrometer screw necessary to move the stylus a distance equal to the nominal pitch of the screw under test. The actual errors of the successive threads are then readily obtained from a fixed dial (D) graduated to read direct to 0.0001 inch, and finer by estimation. In addition to these special dials, the machine is also provided with another which is fully divided in 250 parts. This is used for measuring the pitch of screws for which the special dials are unsuitable, as for example BA and ISO metric screws.

To assist in the measurement of the two last mentioned types, Tables given in Appendix 3 have been prepared, showing the nominal BA and ISO metric pitches, respectively, in inches. Of course the measurement of screws designed with metric pitches is facilitated by using a machine fitted with a metric micrometer and provided with appropriately specially graduated dials for fractional metric pitches.

Each machine is provided with a set of stylus points having a graded series of radii. The stylus is selected which touches about half-way down the flanks of the thread of the screw whose pitch is to be measured, as illustrated in Fig. 12.

7.4.1 "Drunkenness"

A machine designed at the Laboratory for measuring drunkenness of screw plug gauges is illustrated in Plate IV. The principle of the machine is based on the fact that if a screw thread has a true helix, then the thread grooves on one side of it are always exactly midway between those on the opposite side in the same axial plane. On a drunken screw, the threads on one side may vary from left to right of the true mid-way position. The machine shown in Plate IV will measure this variation as it is manifested at positions 180° apart; it resembles the floating micrometer diameter measuring machine, described earlier in this Section. It has the same type of base with a pair of centres for carrying the screw gauge and the same intermediate carriage (A) which is movable along the base, parallel to the line of centres. The upper carriage (B) can move freely at right angles to the line of centres and is fitted on each side with a stylus point (C). These stylus points make contact with the flanks of the thread along the pitch line. One of the points is fixed to the carriages but the opposite one is attached to an indicating mechanism, the front end of which is supported off the base of the carriage (B) on a vertical spring steel strip while the rear end rests on a vertical strut with pointed ends. Owing to the flexibility of the strip both in bending and twisting, this stylus point can move through a limited distance, not only at right-angles to the centres, but also parallel to them. Movements in the latter direction only are magnified two-fold by a simple lever system and are finally shown on an indicator.

To test a screw plug gauge for drunkenness, it is first mounted between the centres of the machine and the two stylus points are inserted in the thread groove, one on each side. Dovetail slides are provided on the upper carriage for altering the diametral distance between the two points to accommodate gauges of different diameter up to 50 mm and also for off-setting the points according to the half pitch of the gauge to be tested.

The gauge is then turned slowly on the centres and a to-and-fro movement of the indicator pointer during each turn of the gauge will reveal drunkenness. If the actual drunkenness error in the pitch of the helix is ±e over one turn of the helix, then the relative displacement of the moving stylus with respect to the fixed stylus will change by ±2e within a revolution. As the indicating unit has X2 magnification the total movement of the indicator pointer from its mean position will be ±4e as the gauge is revolved between centres. In carrying out any type of test for drunkenness, the axis about which the screw thread is revolved should coincide exactly with the true axis of its pitch diameter. For example, a screw gauge which had been accurately cut with a correct helix and whose centres had subsequently become damaged or in some way out of true, would appear to be drunken if tested on these false centres. Thus it is important that prior to attributing drunkenness of pitch to a screw gauge, the accuracy of its centres should be verified.

Very occasionally it is necessary to explore the accuracy of pitch of a screw gauge in detail. Then the gauge is mounted in a pitch measuring machine and measurements made as the gauge is turned through a series of precise angles.

7.5 Thread form and flank angles

The quality of the thread form is most conveniently examined by optical projection methods. Flank angles may be measured at the same time. Apparatus suitable for the purpose is described in Section 12.

Summarising, descriptions have been given above of the mechanical measurement of major, minor, and pitch diameters and of cumulative error of pitch.

8 FORMULAE AND CORRECTIONS FOR USE IN THE MEASUREMENT OF THE PITCH DIAMETER OF PARALLEL SCREW PLUG GAUGES BY MEANS OF SMALL CYLINDERS

8.1 Formula for calculating pitch diameter E of thread with symmetrical flank angles

A detailed description of the measurement is given in Section 7.2 and it is outlined in Figs. 14a and 14b below.

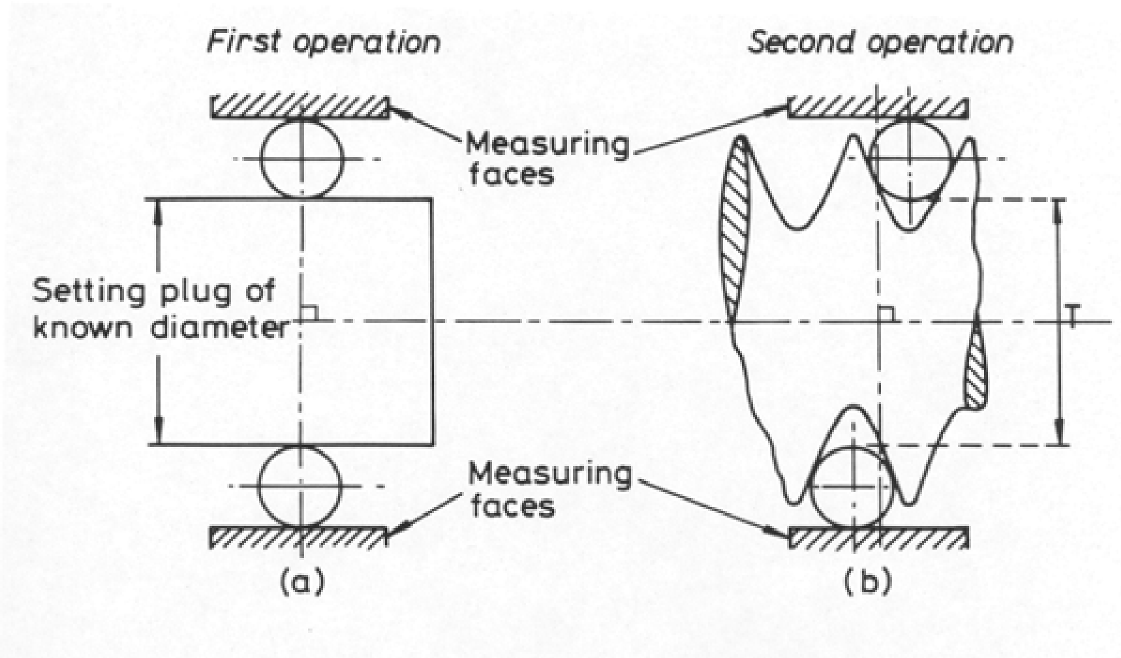

Fig. 14 Use of two cylinders to obtain dimension T

When E = pitch diameter, T = measured dimension under the cylinders p = nominal pitch of thread W = mean diameter of cylinders used, α = flank angle of thread, i.e. symmetrical, then $E = T + W - W \operatorname{cosec}\alpha + p / 2\cot\alpha - c + e$, where c = a correction due to the tilting of the cylinders on account of the rake angle and $e = a$ correction for the elastic compression of the cylinders.

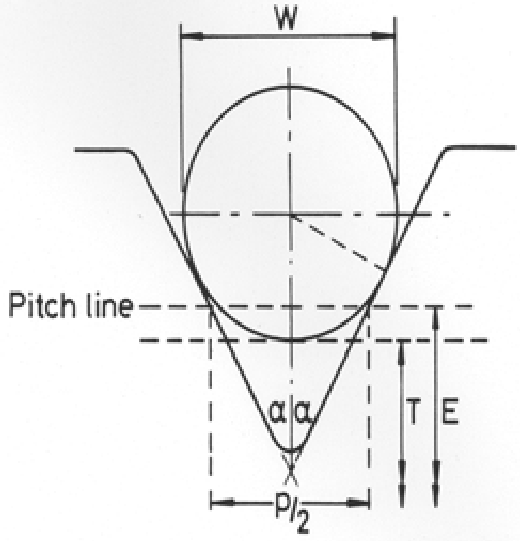

Fig.15 Cylinder contact and the relation of E to T

Given a screw plug gauge for measurement of pitch diameter, the nominal pitch and flank angle α are already designated and accordingly the above equation can be simplified to

$$E = T + Pvalue - c + e$$

where *P value is p* / 2cotα - (Cosecα - 1)*w*

[It is regretted that the traditional p for pitch and the composite formula expressed as "P value" are confusing on first acquaintance].

The formulae can be reduced further for application to particular thread forms as shown in Table 3:

Table 3: P value formulae

Thread form	P value
ISO metric Unified Whitworth B A	0.866025p - W 0.866025p - W 0.960491p - 1.165681 W 1.136336p - 1.482950 W
Note: The formulae given above for P value are for use with parallel threads and nominally symmetrical flank angles	

Certified pairs, or sets of three, thread measuring cylinders are accompanied by the measured diameter W, and the P value to be used for a particular pitch of a particular thread form for which they are suitable. In some cases cylinders may be used also on a pitch of another thread form in which case the appropriate P value is supplied also. See also Appendix 6 in Part IV.

Calculation of E for asymmetrical thread angles

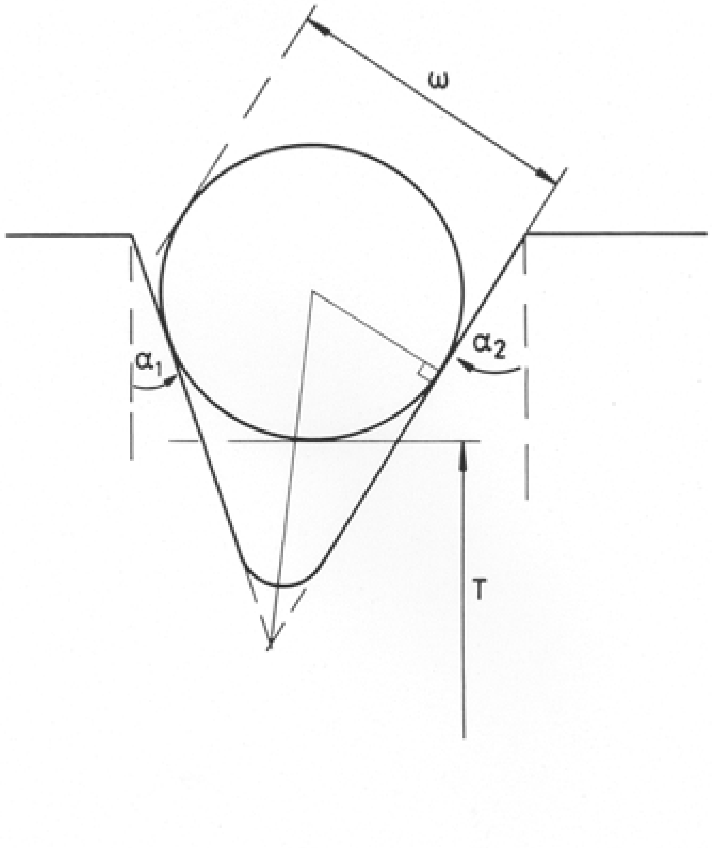

Fig. 16 Cylinder in contact with an asymmetrical thread

In the case of a parallel plug screw gauge having nominally unequal flank angle a_1 and a_2, the method of measurement given in Section 7.2 should be followed to determine T, the diameter separating the near most points of the thread measuring cylinders. Then

$$E = T + W - W\,\mathrm{cosec}\frac{\alpha_1 + \alpha_2}{2} + \frac{p}{\tan\alpha_1 + \tan\alpha_2} - c + e$$

This formula can be reduced, similarly to Table 3 above, given the nominal values of α_1 and α_2 for any particular thread form, and given the pitch of the screw concerned. For instance for a buttress thread of flank angles nominally 45° and 7°, $E = T - 1.15689W + 0.89064p - c + e$.

8.2 Determination of rake correction, c

When a thread measuring cylinder is used for measuring pitch diameter it aligns itself in the thread groove in the direction of the helix. In consequence the points of contact with the flanks will not be in the same axial section, and the cylinder will be lifted up the flanks away from the screw axis. As an example of the effect, although the diametral section of a cylinder can be depicted ideally contacting the flanks at the pitch line in axial section, and its diameter calculated, in practice such a cylinder will be prevented by the helix flank from reaching the pitch line. The correction, c, to be subtracted is affected by the coarseness of the helix, i.e. its rake angle, and the helix is a function of pitch and diameter. The correction is greater the larger the cylinder, i.e. the higher the contact on the flanks.

For single-start screws having a moderately coarse pitch in relation to the diameter, the value of *c* can be obtained with sufficient accuracy from one or other of the following formulae:

For ISO metric, Unified, and American National threads (60°) $c = 0.076 \dfrac{p^2 w}{(T+w)^2}$

For Whitworth threads (55°) $c = 0.086 \dfrac{p^2 w}{(T+w)^2}$

For BA threads (47.5°) $c = 0.105 \dfrac{p^2 w}{(T+w)^2}$

For single-start Acme threads (29°) $c = 0.190 \dfrac{p^2 w}{(T+w)^2}$

For ready use, Tables in Appendix 7 list c for standard screw threads when best size cylinders are used. Values of c for non-standard pitches and diameters of common thread forms of moderate rake angle may be read from Nomograms in the same Appendix.

The Tables concerned show that the values of c for the examples of ISO metric screws are less than 0.003 mm, and for BA sizes vary between 0.001 and 0.002 mm. Values of c for the British Standard Whitworth (BSW) series ranges between 0.0001 in and 0.00015 in with best size cylinders; the correction reaches 0.0002 to 0.00025 in if cylinders approaching maximum size are used.

While much of the consideration in these Notes relates to standard threads of moderate rake angle, nevertheless there are purposes for which a multi start thread, or coarse pitch associated with small diameter is used. In these cases the helix is coarse and the correction c is relatively large.

Thus in cases where the value of c as calculated from the above formulae exceeds 0.025 mm (0.001 n), and also for all multi-start screws, the value of c should be calculated again from the following more accurate formula:

$$c = \frac{\cos a \cot a}{2\pi^2} . \frac{\ell^2}{w} A^2 (1 + A \sin\alpha + A^2 \sin^2\alpha)$$

where ℓ = lead of thread (pitch in the case of a single start screw), and $A = \dfrac{w}{T+w}$

For the common types of threads this formula reduces to:

For ISO metric, unified, and American National threads:

$$c = 0.076 \frac{\ell^2}{w} A^2 (1 + \frac{A}{2} + \frac{A^2}{4})$$

For Whitworth threads:

$$c = 0.086\frac{\ell^2}{w}A^2(1 + 0.46A + 0.21A^2)$$

For Acme threads:

$$c = 0.190\frac{\ell^2}{w}A^2(1 + \frac{A}{4} + \frac{A^2}{16})$$

Units c is given in mm if p or, ℓ w and T are in millimetres
c is given in inches if p or ℓ, w and T are in inches.

In the case of screws with very large rake angles, even the above formulae may not be sufficiently accurate, and for such cases, and also for rake corrections for internal screw threads, reference should be made to a paper by R S Marriner and Mrs J G Wood entitled "Rake Correction in the Measurement of Parallel External and Internal Screw Threads". [1]

8.3 Correction *e* for the elastic compression of cylinders

In measuring the pitch diameter of screws by placing small cylinders in spaces between the threads, each cylinder makes two "point" contacts with the screw and, in addition, a wedging effect occurs between each cylinder and the flanks of the threads. Unless precautions are taken to apply only light forces, the measurement of pitch diameter is likely to be reduced on account of elastic deformation at various contacts. Experiment has shown that about half of the error due to this cause is eliminated if the comparative measurement is first made on a plain, cylindrical, steel plug of known size with the small cylinders included. By using a diameter machine with a sensitive indicator anvil as described in Section 7.2, the force of the measurement is known and due allowance can be made for the compression effect.

The amount of the correction depends upon the diameter, pitch, and the included angle of the screw, and one the force applied during the measurement. The problem of determining the correction to suit any given example has been investigated at the NPL both mathematically and experimentally. In the latter case, various screws were measured with reference to cylindrical plug standards under a series of known forces, and the results obtained confirmed a formula deduced from theoretical considerations.

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[1] **Pro.Instn. Mech. Engrs.,** London, 1958.

Values of the formula, applicable to various thread forms are given in Table 4 below

Table 4: Formulae for compression correction e

e in Metric measure	Thread form	e in Imperial measure
A is measuring force in grammes weight E is pitch diameter in mm e is correction in mm		A is measuring force in pounds weight E is pitch diameter in inches *e* is correction in inches
$e = 0.000\ 0379 \quad \frac{A^{2/3}}{E^{1/3}}$	ISO metric and Unified: 60° thread angle	$e = 0.000\ 03 \quad \frac{A^{2/3}}{E^{1/3}}$
$e = 0.000\ 0506 \quad \frac{A^{2/3}}{E^{1/3}}$	Whitworth 55° thread angle	$e = 0.000\ 04 \quad \frac{A^{2/3}}{E^{1/3}}$
$e = 0.000\ 0759 \quad \frac{A^{2/3}}{E^{1/3}}$	BA 47.5° thread angle	$e = 0.000\ 06 \quad \frac{A^{2/3}}{E^{1/3}}$
$e = 0.000\ 1644 \quad \frac{A^{2/3}}{E^{1/3}}$	Acme 29° thread angle	$e = 0.000\ 13 \quad \frac{A^{2/3}}{E^{1/3}}$

Appendix 8 provides graphs from which the compression correction may be read for various common steel screw threads under a range of measuring forces.

8.4 Consideration of rake and compression corrections

A comparison of the values of the corrections c and e shows that for common threads each correction is of an order within 0.004 mm [0.000 15 in]. Indeed there is a tendency to regard the rake and compression corrections as neutralising one another. However the attitude in practice towards these two corrections needs to be conditioned by circumstances, and different cases are cited as illustrations.

In cases where the tolerance on pitch diameter is as small as 0.005 mm [0.0002 in], the values of c and e should be applied in the measurement of pitch diameter. Such fine tolerances are encountered for setting plugs for calliper gauges and for check plugs for screw rings: the net correction may be significant compared with the tolerances. It is necessary also to apply the corrections in the circumstances of a referee measurement of pitch diameter and in the case of a comparison of results from different sources. In these instances 0.002 mm [0.0001 in] may well be the target accuracy and the appropriate net correction should be applied to each measurement.

Generally speaking the measuring force of the floating carriage machine used limits the compression correction. The limits for the NPL design machine are 8 to 16 oz [225 to 450 g]. In this regard the compression correction, e, can be minimised by choosing a machine with low limit measuring force, and this is good practice when a fine threaded screw gauge, eg a BA gauge, is under measurement.

The rake correction c, as described in Section 8.2, is of a different nature. Thus when Acme threads of coarse pitch, small diameter, and multistarts have to be measured, the rake correction can amount to 0.1 mm or more, [several thousandths of an inch]: but the compression correction e is likely to be small compared with the rake correction and is often ignored in these circumstances.

Note: American practice in regard to the rake and compression corrections is different from the method described in this report. Values of rake correction *c* which are less than 0.000 15 in [0.004 mm] are ignored in USA: when the rake correction exceeds 0.000 15 in it is calculated by an appropriate, expanded, formula and applied. A compression correction e is not considered; thread measuring cylinders are measured under specific loading in US practice whereas the measured sizes of thread measuring cylinders certified in UK are in the uncompressed condition. An investigation has been made into the "Effect of differences between US and British practices in measuring screw gauges for Unified threads" [2]. Reference to the article should be helpful to readers who have a need to reconcile the two practices.

8.5 Measurement of pitch diameter using cylinders other than best size

The measurement of pitch diameter described in Section 7.2 stipulates the selection of best size cylinders which verifies the pitch cylinder as defined, i.e. they contact the flanks at or very near the pitch line. If for any reason cylinders distinctly larger or smaller than best size are used, there are two possible situations in practice. Firstly if the thread angle is correct a true value will be obtained for the pitch diameter. Alternatively if the thread angle is incorrect (or the flanks are not straight), then the P value which depends on terms cot α and cosec α and is supplied assuming the nominal value of α, will itself be inaccurate in the circumstances. Either the actual value of mean half angle of thread must be used in the P value or a correction made to the assumed P value. The formulae for the corrections are as follows:

[2] Machinery (Lond.) 90, 723 (1957).

Table 5: Correction to P value for error in included thread angle

Form of thread	Correction to "P" value
Whitworth B A Unified, Metric, American National and BSC	$(0.036xw - 0.020 \times p) \times \delta(2\alpha)$ $(0.049xw - 0.027 \times p) \times \delta(2\alpha)$ $(0.030xw - 017 \times p) \times \delta(2\alpha)$
where: w = mean diameter of cylinders used, p = pitch of thread, $\delta(2\alpha)$ = error in total included angle of thread expressed in degrees.	

Example:

Screw plug gauge 2 in x 14 tpi Whitworth form.
Mean diameter of cylinders w = 0.051 17 in.
(Note: - Diameter of best size cylinders = 0.040 3 in.)
Case I -Angle error, $\delta(2\alpha) = +1°$
Case II -Angle error, $\delta(2\alpha) = -1°$

Case I

From the formula on in Section 8.1:

$$Pvalue = \frac{1}{2} p \cot\alpha - (cosec\,\alpha - 1)w$$

By substituting $a = 28°$, $p = \frac{1}{14}$ and $w = 0.051\ 17$ in, the value for P value, taking into account the error in angle, is found to be 0.009 35 in.

If, instead of 28°, we give to α the nominal value of 27½° we obtain a value for P, equal to 0.008 96 in. The correction to this value on account of angle error is:

$$\{(0.036 \times 0.051\ \ 17) - \frac{0.020}{14}\} \times (+1)$$

= + 0.000 41 in

Thus, the corrected value for P value = 0.008 96 + 0.000 41
= 0.009 37 in.

The small difference between the values of P value found by the two methods is due to the approximate nature of the factors 0.036 and 0.020 in the correction formula.

Case II

By the first method, substituting $\alpha = 27°$, $Pvalue = 0.008\ 55\,\text{in}$

Using the nominal angle, $Pvalue = 0.008$.

Correction to this $Pvalue = \left\{(036 \times 0.051\ \mathit{17}) - \dfrac{0.020}{14}\right\} \times (-1)$

$$= -\ 0.000\ 41\ \text{in.}$$

Hence the corrected $Pvalue = 0.008\ \ 96 - 0.000\ \ 41$

$$= 0.008\ 55\ \text{in.}$$

In this example the two methods agree exactly to the fifth decimal place of an inch.

Note: The example shows that errors in the half angles of thread can require significant correction of results. This point is another aspect of the reference in Section 3.6 and Appendix 5 namely that every attempt should be made to generate correct flank angles of thread in manufacture.

8.6 Measurement of thread angle using cylinders of different sizes

From what has been said above it is clear that, provided the flanks of the thread are straight, it is possible to determine accurately the error in the total thread angle by obtaining values for the pitch diameter with two different pairs of cylinders, preferably approaching the maximum and minimum sizes, respectively, for the particular thread concerned. In calculating the appropriate P values for the two sets of cylinders, the thread angle is assumed correct.

If E_2 = apparent pitch diameter as obtained with a larger pair of cylinders (mean diameter w_1),

E_2 = apparent pitch diameter as obtained with the smaller pair of cylinders (mean diameter w_2),

then the error in total thread angle in degrees is given by the following formulae:

$$\delta(2\alpha) = \frac{E_2 - E_1}{0.030(w_1 - w_2)}$$ for unified, Metric, American National and BSC (60°) threads

$$\delta(2\alpha) = \frac{E_2 - E_1}{0.036(w_1 - w_2)}$$ for Whitworth (55°) threads

$$\delta(2\alpha) = \frac{E_2 - E_1}{0.049(w_1 - w_2)}$$ for BA (47.5°) threads

It is to be noted that the total error in the included angle is obtained by this method; it provides no information as to the individual errors of the flank angles. These errors can best be measured by optical means in some such manner as is described in Section 12: nevertheless measurements with a series of cylinders of different diameters afford a means of confirming any lack of straightness of the flanks observed during the examination of the thread form on the projection apparatus.

9 MECHANICAL MEASUREMENTS OF PARALLEL SCREW RING GAUGES

Small screw ring gauges and screw calliper gauges are tested for size by check plugs: pitch and thread form are examined by methods described in Section 9.3 and 12. Larger ring gauges may be tested similarly when check plugs are to hand. Circumstances arise however when measurements of ring screw gauges are required on some, or all elements; various methods and equipment which may be used on screw rings larger than 6.5 mm (0.25 inch) are described below.

9.1 Minor diameter

The minor diameter can be sized by fitting into the ring a mandrel having a diametral taper of about 1 in 500 i.e. 0.000 2 in per in. The minor diameter is then taken as the diameter of the mandrel where it fits the screw thread. Unfortunately the tapered mandrel gives the minimum size of the minor diameter and does not check ovality. Alternatively, the minor diameter may be sized by a range of cylindrical plugs, differing in size by known small increments.

The minor diameters of screw threads above 20 mm (0.75 in) diameter may be obtained from the measurement by gauge blocks of the distance between two precise cylindrical rollers of known size placed diametrically opposite in the screw ring gauge. The minor diameter is then calculated by adding the diameters of the rollers to the size of the gauge block combination which just fits between the rollers. By using precision rollers, the minor diameters of ring gauges of nominal diameters up to 100 mm (4 in) may be estimated to an accuracy of ±0.001 mm (±0.00005 in). This method has the advantage that ovality of the minor cylinder may be determined by taking measurements around the circumference of the screw.

For screw rings of small diameter, a pair of accurately made sliding wedges, known as "taper parallels" may be used as in Fig. 17, the minor diameter being obtained by micrometer measurement over the projecting portions of the wedges.

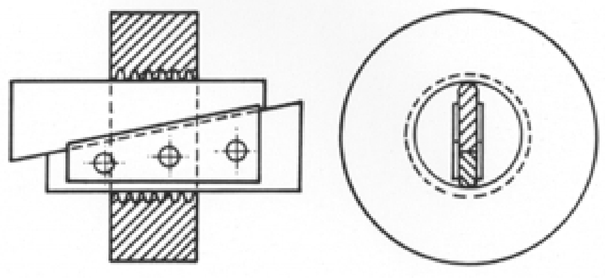


FIG. 17 Measurement of minor diameter by means of taper parallels

Minor diameters may also be measured on the Matrix Internal Diameter Measuring Machine (see Section 9.2.2).

9.2 Pitch diameter

The measurement of pitch diameter of individual ring screw gauges is undertaken only when necessary: the use of check plugs is quicker and preferred. Consequently although machines designed for measuring pitch diameter of ring screws are established and are to be found in some inspection rooms, their use may be occasional rather than routine.

The direct mechanical measurement of the pitch diameter of parallel screw ring gauges is practicable only by the use of measuring machines of special design. These internal diameter measuring machines can be grouped generally into the following three classes, each employing a different measuring technique:

i) Displacement method

ii) Radial method

iii) Horizontal diametral comparators

All three classes are comparators insofar as they compare the screw thread to be measured with a known standard, which may be of permanent, or built-up, form. A description of the principles of measurement and of the machines used is given below.

9.2.1 Displacement method

The basis is to measure the pitch diameter of a screw ring gauge by comparison with the "pitch diameter" of a precision annular groove in a solid cylindrical plug. The latter acts as a standard pitch diameter. In practice a number of annular grooves are finely ground in a cylindrical plug, the grooves corresponding in depth with a range of pitches and having closely nominal flank angles for various thread forms: each groove is standardised for pitch diameter (E_s) with thread measuring cylinders in a floating carriage machine as described in Sections 7.2 and 8.

Different designs of contact device have been used but in essence they are a double ended stylus carried in a bar. The stylus which has a radiused form at each end is selected to make contact at or near the pitch line to be measured; the stylus or the bar is so mounted as to be sensitive to contact pressure on either end of the stylus.

The four measuring stations are shown in Fig. 18

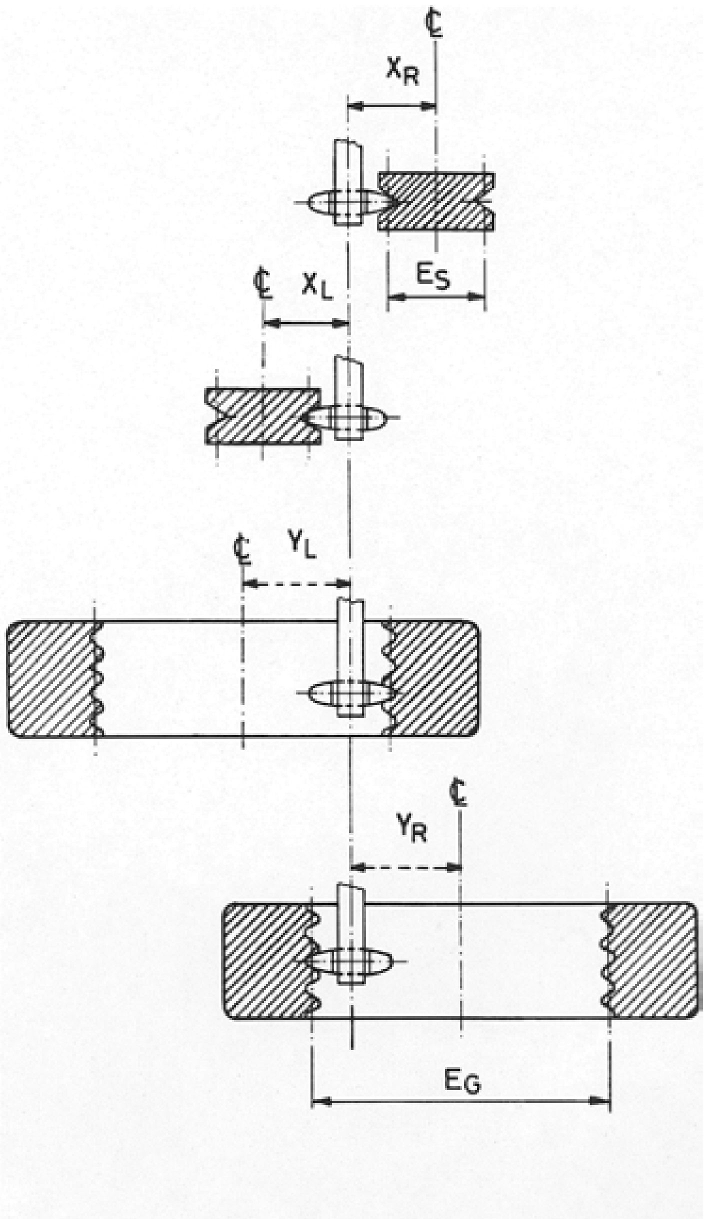


Fig.18 Displacement method contacts

Total displacement of standard of pitch diameter E_S in measurement is $X_R + X_L$

Total displacement of ring of pitch diameter E_G in measurement is $Y_L + Y_R$.

Notice that the two displacements located by each of the stylus contacts are in opposite directions

$$E_G = X_R + X_L + Y_L + Y_R - E_S$$

In the NPL machine the various displacements are imparted to a carriage upon which standard and/or ring may be mounted and which can be moved in a straight line parallel to the stylus. A micrometer on each side registers the position of the carriage. Two accurate straight line motions of the stylus are provided; one normal to the face of the carriage to move from thread to thread. The other, in a plane parallel to the face of the carriage to locate a diameter. Nowadays the displacement method is available in co-ordinate measuring machines (CMMs).

Major and minor diameter also may be measured using a suitable sharply radiused stylus and a precision plane-faced gap of known size as a standard.

9.2.2 Radial method

The basis is to mount the ring on a horizontal rotatable table and to measure the radii from the axis of rotation to the thread groove at positions precisely 180° apart. Transverse feed of the table along a straight line in order to locate diametrally, and a vertical straight line movement of the table in order to measure in different threads provide necessary adjustments.

Plate V shows the "Matrix" Internal Diameter Measuring Machine, which is a machine of the radial measurement type developed by the Coventry Gauge & Tool Co. Ltd, in collaboration with the National Physical Laboratory.

Fig. 19 is a diagrammatic arrangement of the machine. From this it will be seen that the machine consists essentially of a main casting (A) on which runs a sliding carriage (B), the position of which with reference to the main casting can be controlled by a micrometer (C) attached to the carriage, which bears against an abutment (D) on the main casting. The sliding carriage carries at its leading end an underslung cradle (E) on which is hinged a stylus rocking arm (F). The underslung cradle is suspended from the sliding carriage by spring steel strips (G), and the hinge of the stylus rocking arm is formed by crossed spring steel strips (H). A stylus mounted at the end of the rocking arm is therefore free to rock about the horizontal axis of the hinge and at the same time has a limited movement in a horizontal plane. The back end of the underslung cradle bears against a fiducial indicator (J) attached to the sliding carriage. The stylus rocking arm carries a sensitive spirit level.

The main casting (A) also supports a work table which can be elevated by handwheel (K), rotated through 180° by lever (L), and moved transversely in a horizontal plane across the measuring axis of the machine, by means of hand-wheel (M). The vertical movement of the work table can be controlled very accurately by means of the large diameter handwheel (K) and the machine is accordingly suitable for measuring pitch and rate of taper as well as diameter. A "throw over" device is also incorporated in the machine, and enables external diameters, as well as internal diameters to be measured.

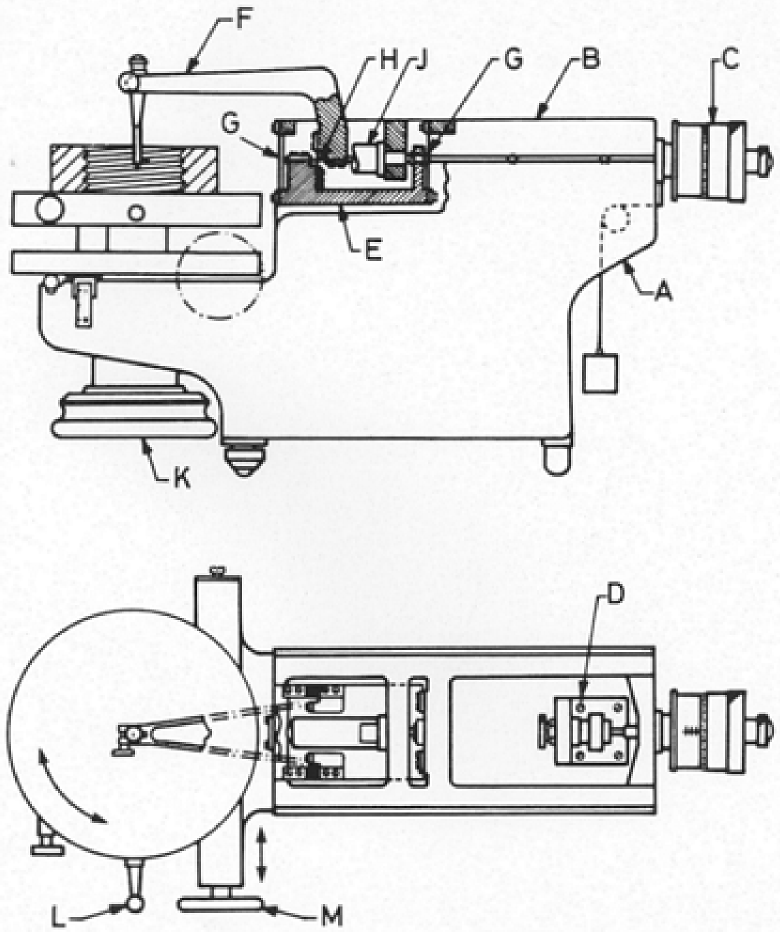


Fig. 19 Diagrammatic arrangement of "Matrix" internal diameter measuring machine

The pitch diameter of a screw ring is measured by comparison with that of a built up standard of box form, as shown in Fig. 20, comprising gauge blocks and grooved end pieces. The grooves in these end pieces are made to the nominal angle of the screw thread and their "E_0" value (see Fig. 20) is known for the pitch of the thread being measured. A standard of nominal pitch diameter can be set up by inserting between the grooved end pieces gauge blocks of a size equal to the required pitch diameter, less the E_0value.

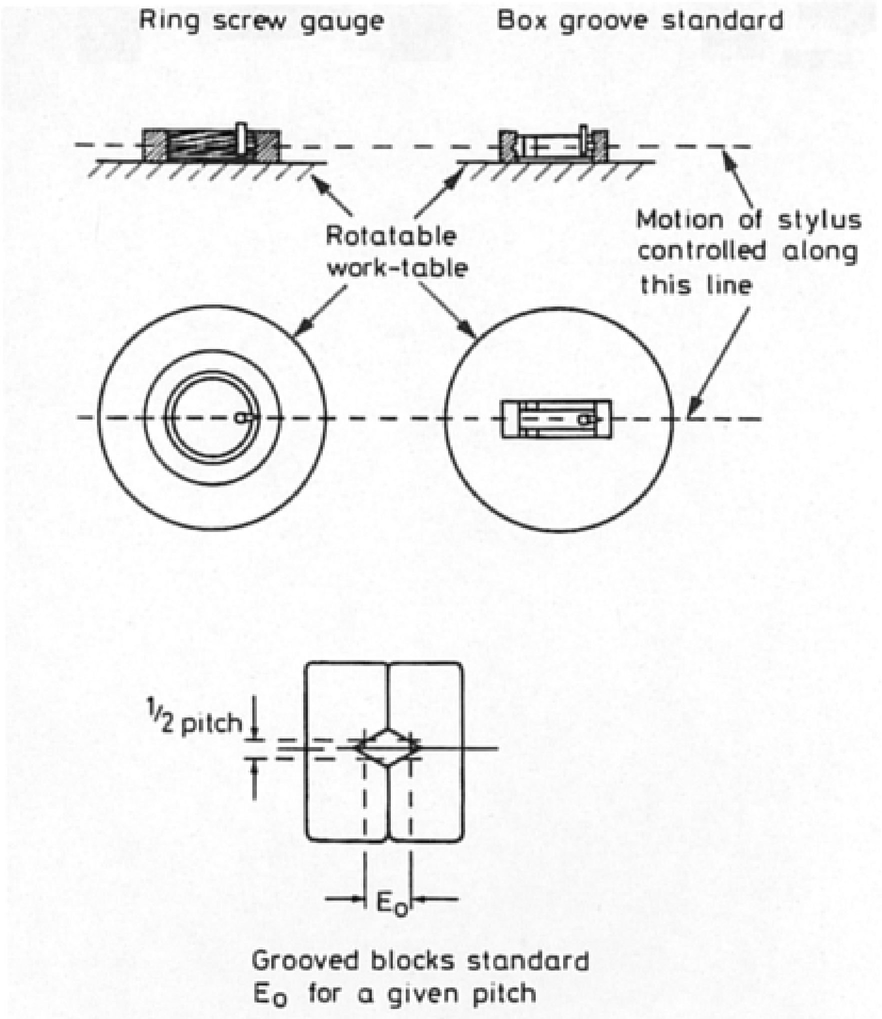


Fig. 20 Principle of measurement of 'Matrix' internal diameter measuring machine

The procedure adopted in measuring the pitch diameter of a screw ring gauge is as follows. A single ended stylus is mounted on the hinged rocking arm; this stylus has a radius such that the stylus when inserted in the screw thread under measurement contacts the flanks at the pitch line.

The box standard is placed on the rotatable worktable and aligned with the measuring axis of the machine by means of the adjustments provided. The micrometer records the position of the stylus, when it is in contact with the vee-groove of the box standard. The stylus is then retracted and the work table rotated through 180° to enable a corresponding setting to be made in the other end of the standard. Similar pairs of readings are then obtained on the screw ring gauge (Fig. 20) after it has been positioned so that the diameter under measurement lies on the measuring axis of the machine. It is necessary of course to elevate the work table by one half pitch when taking a reading on the opposite end of the diameter of the screw ring to that first measured.

The size of the screw ring is obtained from the following equation:

Size of screw ring - Size of standard plus sum of readings on standard minus sum of readings on screw ring.

Major and minor diameter measurements may also be made in a similar way on the machine. For these measurements the rocking arm is locked to the underslung cradle and the box form standard used has plane end faces. For the measurement of major diameters a stylus having a radius less than that of the roots of the thread should be used.

The measuring capacity of the machine is such that screw threads from 6 mm (0.25 in) to 150 mm (6 in) diameter can be measured.

An accuracy of 0.0003 mm (0.000 1 in) is claimed for diametral measurements on screws.

9.2.3 Horizontal diametral comparators

The procedure is to apply an internal calliper to compare the known "pitch diameter" of a built up standard with the pitch diameter at any position of a screw ring gauge. As the difference of standard from gauge can be arranged to be small, the measurement of the difference is made with a sensitive optical indicator of moderate range. Means to adjust from chordal to diametral position and to align the standard are provided.

Plate VI shows a horizontal comparator for internal thread measurement. This type of machine was first introduced by Carl Zeiss Ltd, and several similar machines of various measuring capacities, one of which is illustrated, have been made in Great Britain.

The machine is provided with a substantial base carrying a horizontal tube on which are mounted two arms which are adjustable along the length of tube to allow the measurement of work covering a wide range of size. The left hand arm carries a frame (A) pivoted at (B) (see Plate VI) one end of which contacts an anvil in the tailstock and the other end carries a stylus (C) which engages with the screw thread under measurement. The position of this stylus on the measuring axis of the machine is controlled by a fine adjustment operated by means of a set screw, but during measurement the frame and stylus are locked in position. The right hand arm also carries a frame (D) pivoted at (E) one end of which carried a stylus (F) which engages with the opposite side of the screw thread under measurement, and the other end contacts the optical indicating device, which registers its movement by means of an optically projected scale viewed through a microscope or on a projection screen. The work is mounted on a table which is universally adjustable.

The machine measures the pitch diameter of screw ring gauges by comparison with that of a built up standard, as shown in Plate VII, comprising gauge blocks and grooved jaw blades. These grooves are made to the nominal angle of the thread and their "E_0" value as in Fig. 20 is known for the pitch of the thread being measured. A standard of pitch diameter equal to the nominal pitch diameter of the screw ring being measured is made by inserting, between the grooved jaw blades, block gauges of a size equal to the required pitch diameter less the E value. The process is facilitated by mounting the slip gauges in an adjustable clamp (Plate VI) by means of which the vee-grooves can be staggered by an amount equal to half the pitch of the screw thread measured.

The following procedure is adopted to measure the pitch diameter of screw rings. On each of the frames (A) and (D) is mounted a stylus with a suitable radius so that, when inserted in the screw thread, the stylus contacts the flanks on the pitch line. The built up standard is then placed on the work table, with its vee-grooved jaw blades engaging with each stylus, and is lined up with respect to the measuring axis of the machine by means of the adjustments on the work table; meanwhile the fine adjustment operating on the left hand frame is adjusted until the scale of the machine reads zero and the left hand frame is locked in position. The standard is then replaced by the screw ring (see Plate VII) and the corresponding reading records the deviation of the size of the latter from the known size of the standard.

For major diameter measurements, two stylus points having radii less than that of the roots of the thread should be used and the machine is standardized by a built up plane faced gap of known size.

An accuracy of the order of 0.004 mm (0.000 15 in) is claimed for internal thread diametral measurements made on this type of horizontal comparator.

9.3 Pitch

The method of measuring the pitch of screw rings gauges is similar to that used for screw plug gauges and is described in Section 7.4.

In the case of a screw ring gauge tested by means of check plugs and found to be satisfactory, it is not necessary to measure its pitch independently, for if a ring gauge accepts completely a full form "go" screw check and refuses to allow the "not go" effective diameter check to enter, it cannot be in error on pitch by an amount which is outside acceptable limits. Nevertheless, as has been stressed earlier it is so important that pitch errors be controlled that measurement of pitch of screw ring gauges independently is common practice.

Drunkenness of pitch is uncommon in ring screw gauges because the threads are usually lapped. If suspected drunkenness has to be explored, then the gauge may be mounted in a pitch measuring machine and measurements made as the mounted gauge is turned through a series of precise angles.

9.4 Thread form and angle

The thread form and angle of internal threads are examined through the medium of a cast of the thread either in plaster or dental wax. The finest plaster of Paris is found to give the most satisfactory results for screw rings over about 12 mm (0.5 in) diameter; for small screw rings a dental wax which softens in hot water is most serviceable.

To obtain good results with plaster, the ring must be scrupulously clean, and the screwed ring surface coated with a very thin and uniform film of grease so as to prevent the cast adhering to the ring. A thin layer of mineral oil is found to be suitable for this purpose. The plaster is mixed with water to form a very thin, creamy liquid, and is poured into a segment of the ring, which is held with its plane vertical as in Fig. 21. To allow removal of the cast from the ring without unscrewing - an operation which would destroy the accuracy of the cast - the segment used should be considerably less than a semicircle. The cast should be removed before the plaster sets quite hard.

For very small rings, dental wax softened in hot water is pressed into a sector of the ring, which is slightly heated with hot water to prevent sudden chilling of the wax.

Some experience is usually necessary before satisfactory casts can be obtained but when properly carried out, the method of examining the form of thread by optical projection of casts has been found to be quite reliable. The type of apparatus on which the examination is made is described in Section 12.

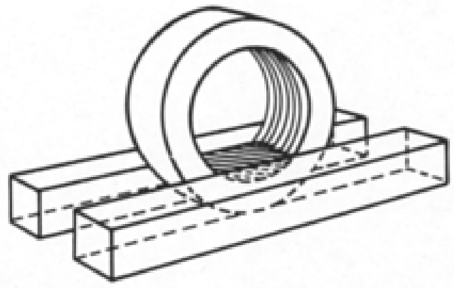


FIG. 21 Method of taking plaster cast

10 INSPECTION OF PARALLEL SCREW RING GAUGES WITH CHECK PLUGS

The diameters of screw rings gauges may be tested between limits by means of check plugs, the method being analogous to the checking of the internal threads on the workpiece by plug gauges, as outlined in Section 4.

Go check plugs are made to the minimum permitted diameters of the ring within a small negative tolerance; Not Go check plugs are made to the maximum permitted size of a particular element within a small positive tolerance. Thus the manufacturing tolerances for the check plugs do not encroach upon the zone of permitted variation of the ring screw gauge: also by reason of the close tolerances on the check plugs it is found that the use of check plugs is a successful method of test for ring screw gauges.

To test the diameters of a screw ring gauge completely the following check plugs are required:

1) A "go" full form screw check plug made nominally to the lower limit of size of the ring gauge on all diameters and correct in angle, pitch and form of thread. NOTE. For the Metric, Unified and other forms of screw thread having flat crested screw ring gauges, practical difficulties prevent the manufacture of screw check plugs having flat roots. The "go" screw check plugs for such rings are made nominally to the lower limit of size of the ring gauge on pitch and major diameters, and the roots of the thread are cleared below the minor diameter of the ring gauge.

2) A "not go" pitch diameter screw check plug, cleared on major and minor diameters, with correct angle and pitch, and with its pitch diameter made nominally to the upper limit of size of the ring.

3) A "not go" cylindrical check plug made nominally to the upper limit of minor diameter of the ring gauge.

4) For ring gauges with precise radiused roots at the major diameter, a "not go" major diameter screw check plug with thin threads and small angle, cleared on minor diameter and having its major diameter nominally on the upper limit of size of the ring gauge.

In addition one or more of the following are sometimes provided:

5) A "go" cylindrical check plug made nominally to the lower limit of minor diameter of the ring.

6) A "go" pitch diameter screw check plug, similar in form to No (2) but with pitch diameter made nominally to the lower limit size of the ring.

7) A "go" major diameter screw check plug similar to No (4) but with major diameter made nominally to the lower limit size of the ring.

Of the check gauges mentioned above, numbers (1), (2) and (3) represent the minimum equipment which must be provided for testing purposes. Number (4) may be dispensed with if the form of thread in the ring gauge is checked by projecting a cast. Number (5) is essential for checking Metric, Unified and other screw ring gauges having flat crests. It should also be provided for screw ring gauges having radiused crests, as it is an easy check plug to make, and it is advisable to have it if, as sometimes happens, the root of the thread on check plug (1) has been carried a little too deep. Numbers (6) and (7) are not required for inspection purposes, but may be found useful in manufacture, if the number of ring gauges being made justifies their provision. This is more particularly so if the gauges are being finished by lapping, since, together with check number (5), they enable a control to be maintained on each element separately during this operation.

Screw plugs numbers (2) and (4) need be only a few threads long, but numbers (1), (6) and (7) must be at least as long in the thread as the ring gauge.

The tolerances on the threaded check plugs should stipulate for diameter(s), and pitch, and flank angles: for plain plugs, for the permitted range of diameter of the envelope of the cylindrical gauge.

The method of testing screw ring gauges by means of check plugs is functional and very convenient, particularly when a large number of gauges of the same size have to be examined. When, however, only a limited number of gauges have to be tested, the expense and delay involved in the production of a set of check plugs can become prohibitive. In such cases, therefore, resort may have to be made to direct measurements of the screw ring gauges, the low limit of internal measuring machines being about 6.5 mm (0.25 inch) diameter.

11 TESTING OF SCREW CALLIPER GAUGES

Screw calliper gauges are used as an alterative to screw ring gauges for testing external screw threads. These calliper gauges usually have two pairs of anvils of which the outer pair acts as a "go" gauge for the thread as a whole and the inner pair as a "not go" gauge for the pitch diameter.

The actual design of the anvils varies with the make of gauge, but whatever the design, it is intended that, in effect, the "go" anvils shall constitute a gap which at every point will just permit a screw of the largest stipulated size to pass through it. Similarly, the "not go" anvils are intended to form a gap which will refuse passage to all the screws excepting those whose pitch diameters are below the specified minimum size of the product.

The most satisfactory way of testing these screw calliper gauges is by means of two sets of suitable check gauges, one set for the "go" and the other for the "not go" gap. The former set should comprise the following:

Note: The remarks made in Section 10 about the design tolerances of check plugs for rings apply here also.

1) A "go" full form screw check plug made nominally to the lower limit for the "go" gap on all diameters and correct in angle, pitch and form of thread. The length of its thread should be not less than that of the anvils.

2) A "not go" pitch diameter screw check plug, cleared on major and minor diameters, with correct angle and pitch, and with its pitch diameter nominally equal to the upper limit for the "go" gap.

3) A "not go" cylindrical check plug made nominally to the upper limit of minor diameter for the "go" calliper gauge.

To these may be added if considered desirable:

4) A "not go" major diameter screw check plug with thin threads and small angle, cleared on minor diameter and having its major diameter nominally equal to the major diameter upper limit for the "go" calliper gauge.

The checks for the "not go" gap should comprise:

1) A "go" screw check plug correct on pitch and angle, with its major and minor diameters nominally equal to the upper limit size for the work, and its pitch diameter nominally to the lower limit for the "not go" calliper gauge.

2) A "not go" screw check plug cleared on major and minor diameters, with correct angle and pitch, and with its pitch diameter nominally equal to the upper limit for the "not go" calliper gauge.

In addition to testing with check plugs mentioned, the thread-form of the anvils should be inspected.

In the actual manufacturing of these screw calliper gauges every care should be taken to see that the thread-forms of the anvils are satisfactory before the latter are assembled in the frame of the gauge. This can be ensured by careful inspection in an optical projection apparatus. With the knowledge that the anvils are of accurate thread-form, they can be set in the frame so that each gap just accepts the appropriate "go" screw check referred to above.

It should be mentioned that, in designing the "go" anvils of these gauges, careful consideration should be given to the possibility of interference taking place between their threads and these of the work, and if necessary the forms of the threads on the anvils should be modified to compensate for any such effect. Lack of attention to this point may well result in excessive errors in the "go" gap of a calliper gauge which has been adjusted merely to fit the "go" screw check plug.

12 OPTICAL PROJECTION APPARATUS

Methods of measuring major, minor, and pitch diameters of plug screw gauges have been described. However these may be very localised measurements with virtually point contact. In addition assurance is required about the thread form and the flank angles, and this examination is carried out most conveniently by optical projection apparatus. The main objective is to view the axial section when magnified so that one may compare it with the nominal outline, and measure the flank angles.

The descriptions which follow apply to the first optical projectors for screw gauges and illustrate the principles and main features of design. Mention is made in Section 12.3 of more compact modern projectors of different styles which have been developed over the last 50 years.

A simple and versatile apparatus for screw thread projection is the standard horizontal large-field type of projector designed at the Laboratory and examples of which are to be found in many workshops.

12.1 Horizontal projector

This machine is shown in Fig. 22 and is probably the most suitable type of apparatus for those establishments where a projector is required to do duty for a variety of purposes, such as the examination of the thread form of screw plugs and rings, the form of cutting tools and of profile gauges in general.

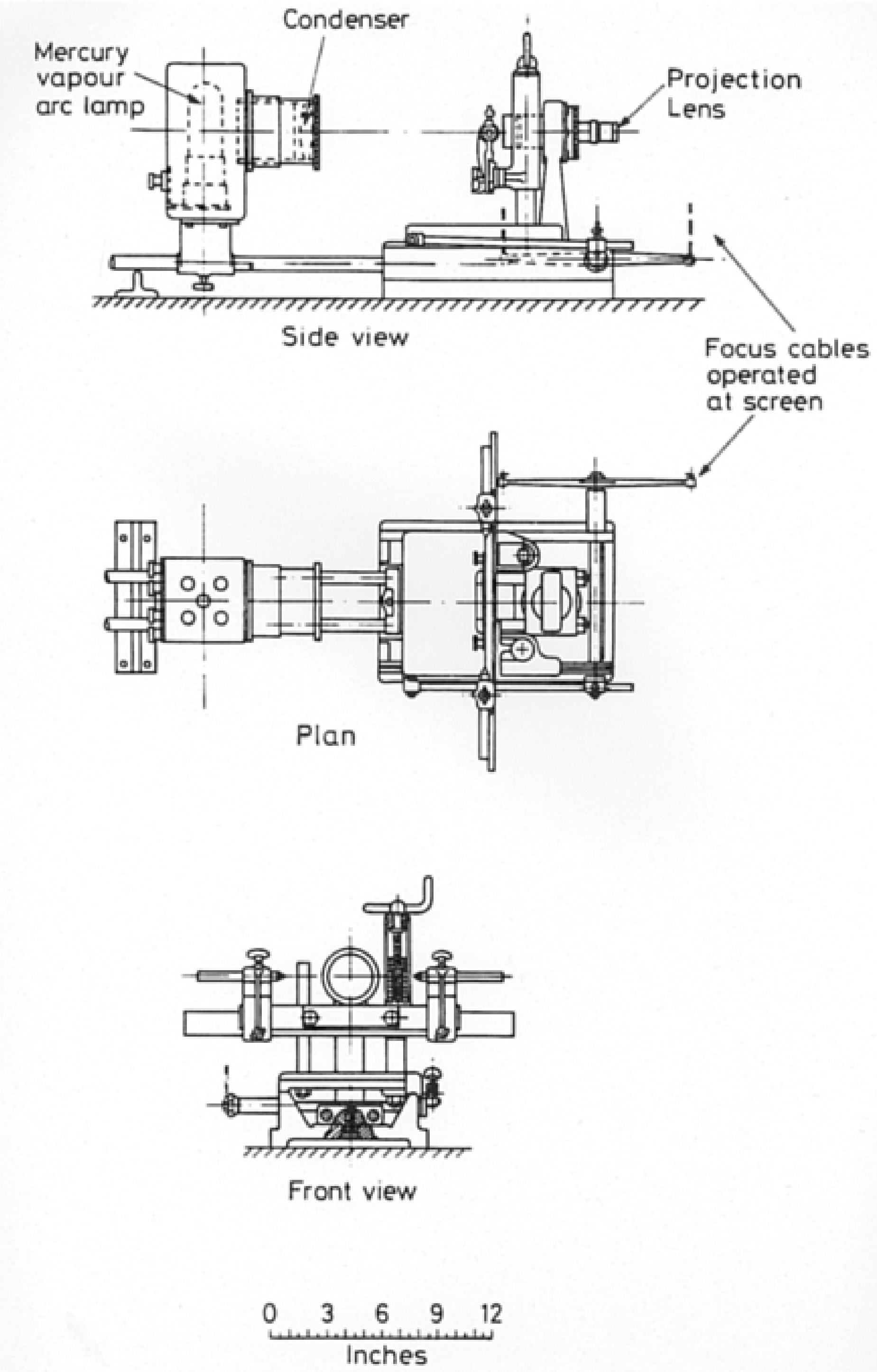


Fig.22 NPL simple horizontal optical projector

The optical system consists of a high intensity mercury vapour arc lamp used in conjunction with a condenser to give an illuminating beam of parallel light, and a projection lens. The object to be projected is mounted on a horizontal slide either between centres or in the clamp provided. Casts of screw ring gauges are mounted on a small horizontal turn-table attached to a shank which is interchangeable with one or other of the machine centres. In addition to its horizontal motion, the slide can be raised or lowered vertically, so that the position of the object can be readily adjusted in the field of the lens. The image, which is usually arranged to be enlarged exactly fifty times, is formed on a vertical screen situated about twenty feet away, and is focused by fine adjustment of the position of the object with respect to the projection lens by means of cords operated at the screen. The image is compared with a standard diagram carefully drawn to the correct scale. The type of diagram shown in Fig. 23 is used for screw threads.

The setting-up of the apparatus is a simple matter. With the screen set truly vertical and the bed of the machine carefully levelled, the next step is to set up the apparatus at the correct distance from the screen to obtain the desired magnification. This is done by adjusting the distance until the correct width is obtained for the image of, say, a 12 mm diameter cylinder, the diameter of which is know to 0.002 mm. Squareness of the optical axis of the apparatus to the screen in the horizontal plane is ensured if the apparatus is finally set so that the width of the image is the same on the left hand and right hand sides of the screen.

As the thread form is defined in the axial section, the line of centres is manufactured precisely square to the optical axis of the projection lens, thus presenting the axial section parallel to the lens.

However in projection practice there is some obscuring of that section by each flank. To minimise this disadvantage the direction of the illuminating beam is adjusted to coincide with the mean rake angle of the threads. This is done by rotating the rods supporting the lamp house about a vertical axis passing through the centre of the bracket which supports the projection lens. Inclinations up to 5° on each side of the centre line are possible. In practice, for a plug screw either the direction of illumination is set to the rake angle, or with the image slightly out of focus the direction of illumination is adjusted until the out of focus appearance is the same on both flanks. The image is then refocused. For a cast, the illumination is set to the nominal rake angle and the cast rotated to get the same quality of focus of opposite flanks.

12.2 Examination of thread form

The thread form of the screw is examined by meshing the image with a standard diagram, as shown in Fig. 23. The diagram consists of a profile of the thread form of the screw, 50 times true size, on a metal plate fitted with suitable handles. It is of a greyish or light-blue colour on a white background. Since, in a partially darkened room, the projected image is of a grey tint, the presence of excess metal at any point of the thread produces an overlapping of the grey image and the tinted diagram, which is indicated at once by the appearance of a black patch at the point concerned. Where metal is missing a corresponding contrasting white space is seen. The two effects are illustrated in Fig. 24, which shows the image (B) of a screw having an unsymmetrical thread angle, meshed with the standard outline (A). Standard thread-form diagrams to a magnification of x50 are used for all the usual pitches of ISO metric, Unified, Whitworth, and BA threads. The recommended thread form diagrams for Metric and Unified threads incorporate an outline of the maximum metal form of the nut, which has truncated crests, as well as the outline of the basic form of thread.

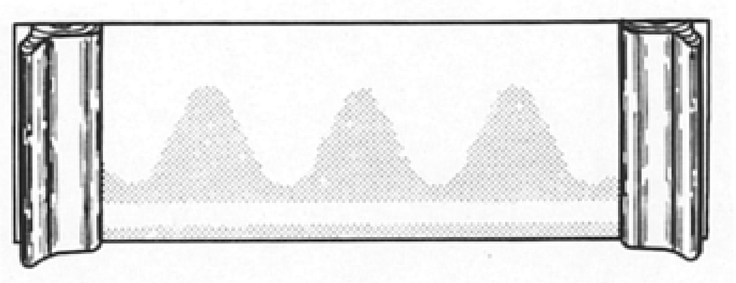


FIG. 23 Thread form diagram

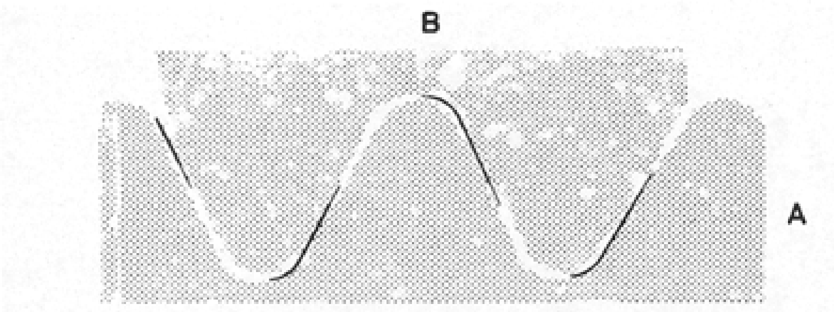


FIG. 24 Illustration of effect of thread form errors

The horizontal projector became popular for its value as an adaptable inspection apparatus. or instance for some purposes it is desirable to have facilities for altering the magnification of the projected image without disturbing in any way the squareness of the optical axis with the screen. To do this, the trestle supporting the apparatus is sometimes mounted on flanged wheels, running on a pair of straight rails extending from the screen to the back of the room. By means of a scale fixed along one of the rails, it then becomes a simple matter to set the apparatus to give any desired magnification within the compass of the room. Also a feature of the horizontal projector is the large area of field, 1.8 m [6 ft] in diameter, over which the distortion is negligible. This is attained by using a suitable projection lens such as a Ross Tessar gauge projection lens. With this lens, plate gauges up to about 35 mm (1.5 in) in size can be examined as a whole.

12.3 Modern projectors

The optical projector has been greatly developed over the last 50 years. A simple projector particularly for plugs or casts is shown in Fig 25. It uses vertical direction of projection and reflection to a screen alongside the thread. The whole apparatus is mounted on a cabinet on castors, and is compact. Another model of horizontal projector has been designed and made: it is very robust and is suitable for larger solid screw plugs used in the oil industry.

In addition, other designs of projectors are on the market having basic principles of operation which are essentially the same as those of the NPL projectors, although differences exist in detail. For example, certain models utilize a translucent screen on which the operator projects the image from the opposite side to that viewed. The thread form diagrams used with translucent screen projectors may have their thread forms made semi-opaque on a frosted glass background, or alternatively the nominal thread form is shown by a dotted line.

Thread forms may also be examined by the use of a Toolmakers' Microscope: in such case, the nominal thread forms are usually reproduced photographically on graticules which are fitted to the microscopes, and are shown as dotted lines on a transparent background.

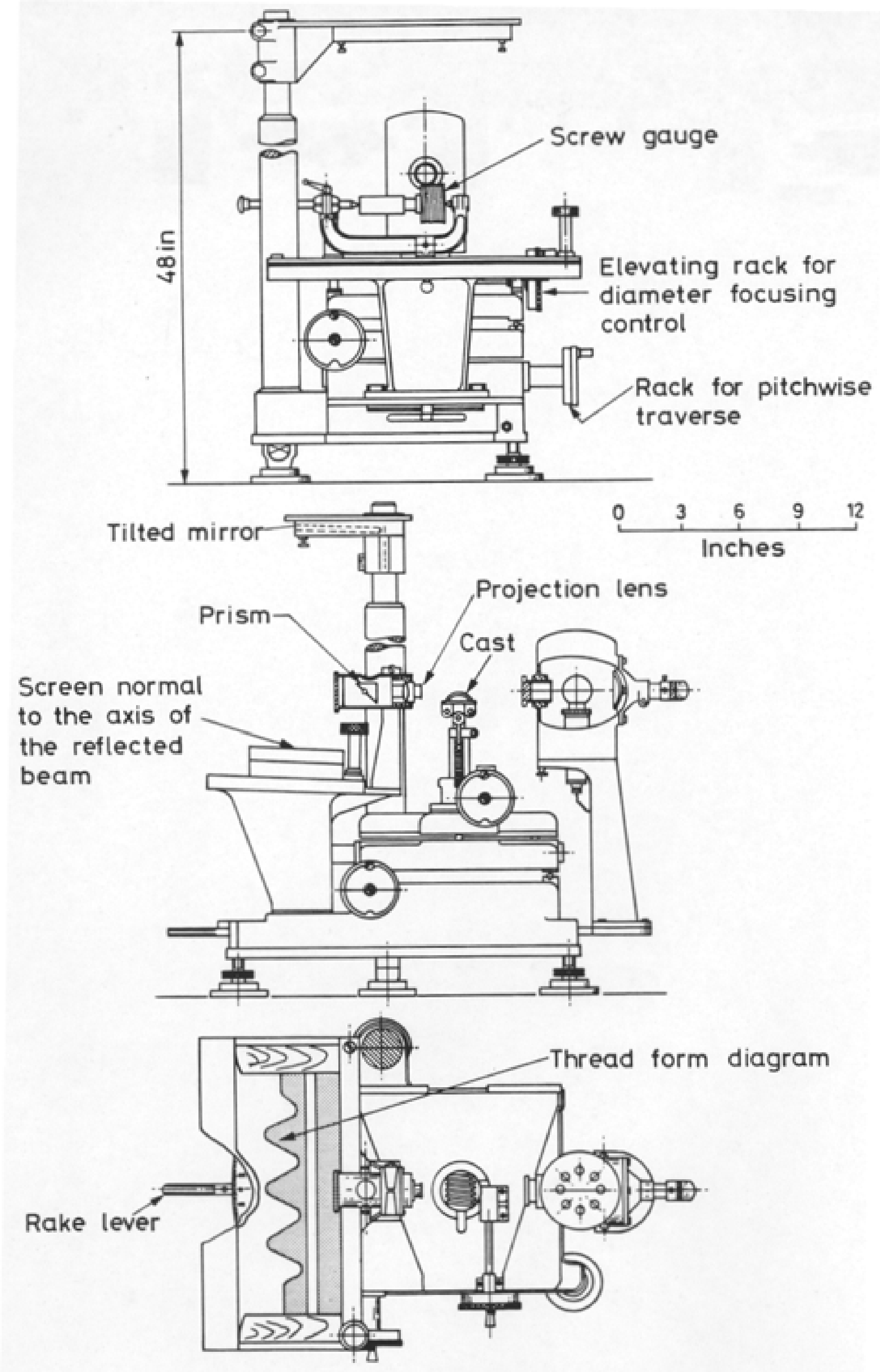


Fig. 25 Screw projector (NPL model 3)

12.4 Measurement of flank angles

The flank angles of a screw are measured by means of a shadow protractor such as that shown in Fig 26.

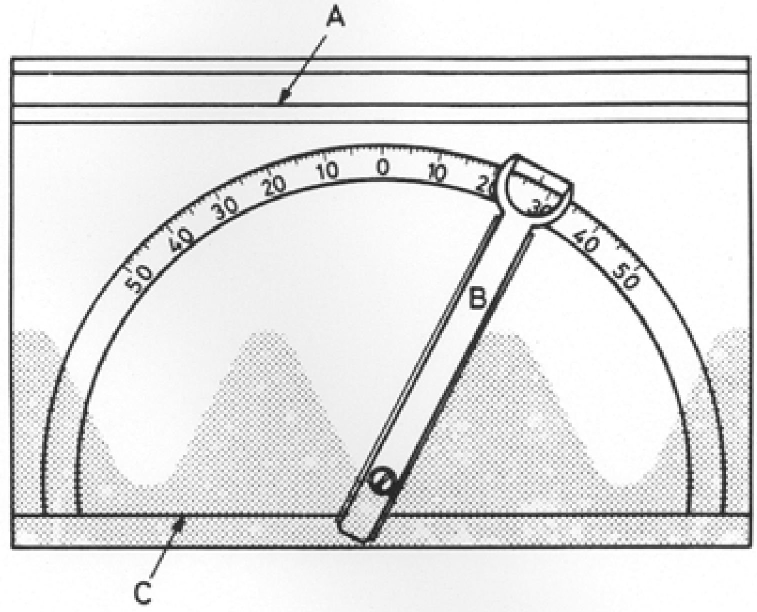


Fig. 26 Shadow protractor for use on horizontal projector

It is provided with mutually parallel straight edges at (A) and (C) and is supported on a straight ledge at the screen. A cam is used at one end of the ledge to set the image of straight edge (A) parallel to the crests of a plug screw gauge, or straight edge (C) parallel to the roots of a cast. The pivoted arm (B) of the protractor is rotated so as to bring the edge of its shadow on the white background parallel to the sloping flank of the thread under examination and the reading noted. The procedure is then applied to the opposite flank. This protractor has a scale which may read to 0.01°.

12.4.1 Improved protractor and throwover method of flank angle measurement

The shadow protractor in Fig. 25 serves for many routine purposes where 0.1° is sufficient precision compared with the tolerance on flank angles. A later development is shown in Fig. 26 where by means of tangent screws a fine means of adjustment is supplied as well as reading in terms of minutes.

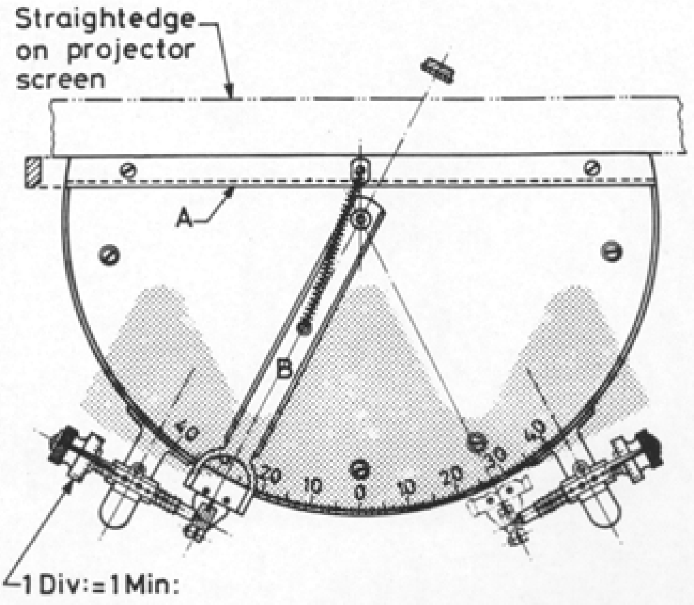


Fig. 27 Improved shadow protractor for measuring flank angles on horizontal screens

This development can be used to advantage on plug screw gauges mounted in a projector on which opposite ends of a diameter can be viewed in turn by an accurately straight transverse movement of the plug across the field of the lens. Thus first a measurement of each flank angle is taken from the combined readings of the circular scale and of the tangent screws. The screw plug is then moved across the field of the lens by means of the transverse adjustment, until the thread form of the other side appears on the white background of the protractor, the rake of the beam of light being reset to allow for the reversed direction of the helix. Without moving the alignment of the protractor on the table of the machine the pivoted arm (B) is swung across to measure the angle of the same flank as before. The mean of the two readings gives the inclination of the flank with respect to the normal to the axis of the screw. The method is described as the throwover method.

The accuracy attainable in flank angle measurement depends on the alignment of the axis of the screw with the protractor datum, the length of flank available for setting the protractor arm, and the fineness of reading offered by the design of the protractor. It is also affected by the crispness of the image. The throwover method eliminates small errors of alignment of the protractor with a plug screw axis but is available only for gauges with a diameter within the traverse of the projector.

The contribution made by the sum of errors of flank angles to virtually increasing the diameter of a plug screw gauge has been described in detail in Section 3.4. Consideration will remind us that equal and correct flank angles of the cutting tool must be sought in manufacture, and correction relation of the cutting tool must be sought in manufacture, and correct relation of tool axis of the cylindrical blank.

PART III: TAPER SCREW THREADS

13 SCOPE

This part describes various methods for measurement of screw threads formed on a cone. The threads may have precise radii at crests and roots, or may have truncated crests and cleared roots.

The information which follows relates primarily to taper screw threads having their thread forms normal to the axis of the cone on which the threads are formed. The bulk of taper threads manufactured are of this type, including British Standard Pipe Threads, American National Taper Pipe Threads and American Petroleum Institute Taper Threads.

Valve fittings for compressed gas cylinders however have their thread forms normal to the surface of the cone on which the threads are formed. The difference between these two types of taper screw threads justifies giving separate treatments, namely in detail to the first group reading from now on, and later referring to the special applications in the second group, Section 19 Taper screw threads normal to the cone.

14 DEFINITIONS FOR TAPER SCREW THREADS, SEE FIG. 28

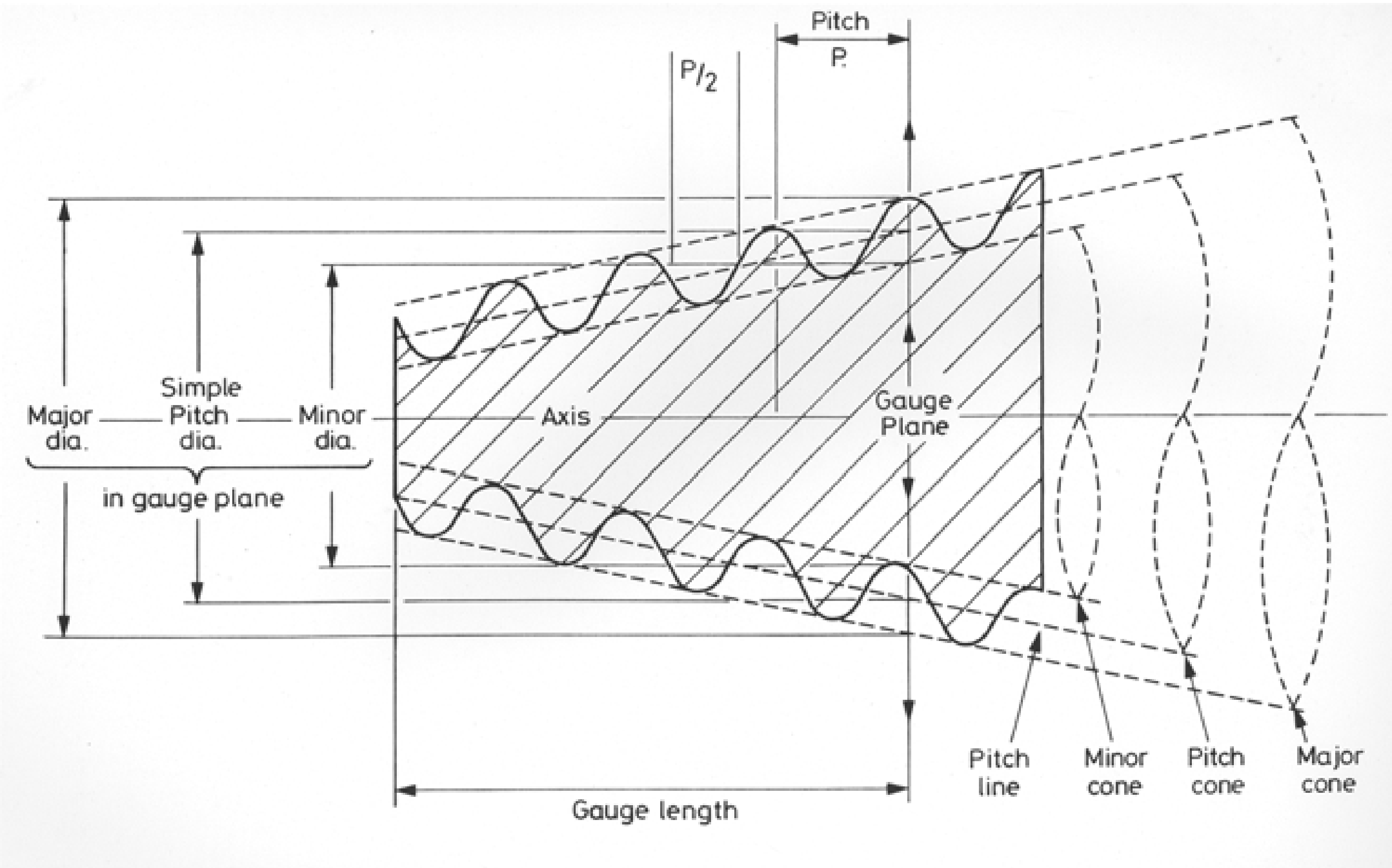


Fig.28 Elements of taper screw thread. (Thread form square to axis).

Definitions of thread form, included angle of thread, and pitch are as for parallel screw threads in Section 2.1.

Major diameter: the diameter in a specified plane normal to the axis of an imaginary cone (termed the major cone) which just embraces the crests of an external thread or the roots of an internal thread.

Minor diameter: the diameter in a specified plane normal to the axis of an imaginary cone (termed the minor cone) which just embraces the roots of an external thread or the crests of an internal thread.

Pitch diameter: the diameter in a specified plane normal to the axis of an imaginary cone (termed the pitch cone) which is coaxial with the thread and intersects the surface of the thread in such a manner that the axial distance between the points where a generator of the cone meets the opposite flanks of the thread-groove is equal to one half the nominal axial pitch of the thread.

Gauge diameter: the nominal major diameter of the thread, whether external or internal.

Gauge plane: the plane normal to the axis in which the major cone has the gauge diameter.

Gauge length: the axial distance on an external screw from the gauge plane to the small end of the screw.

15 GAUGING TAPER SCREW THREADS ON COMPONENTS

To ensure satisfactory mating and complete interchangeability of taper threads on components it is customary to use sets of limit gauges for inspecting both external and internal threads.

In theory each set of gauges should comprise:

a) A full form gauge made to the maximum metal size of the work.

b) A set of three gauges for checking the crest diameter at the large end, mid-length, and the small end of the taper thread.

c) A comparable set of three gauges for checking the pitch diameter.

d) A comparable set of three gauges for checking the root diameter.

The gauges outlined in sub-paragraph (b) above should have a short length of plain taper; the gauges in sub-paragraphs (c) and (d) should have a few turns only of taper thread. The crests and roots of the threads on the gauges in sub-paragraph (c) should be cleared so that the gauges operate on the mid part only of the flanks of the component thread. The gauges in sub-paragraph (d) should have thin threads of small included angle and should be cleared at the root so that the crests of the gauges operate on the roots only of the component thread. The acceptability of the tapered workpiece is usually decided by how far it engages with a tapered gauge; a step is provided on the gauge and a specified surface of the workpiece must fall within the axial limits set by the step.

In practice, however, gauging is often confined to the use of:

A taper threaded full form plug and ring gauges.

A plain taper plug and ring gauges.

Each of the four types of gauges is dimensioned and toleranced. It is found that this minimum of final gauging is sufficient provided an adequate control of the rate of taper is exercised during the manufacture of the product.

Another gauging system consists of a mating pair of taper threaded gauges; only the plug gauge is dimensioned, toleranced, and measured. The size of the ring is attributed by how far it assembles with the master plug, known as the stand off. American National Taper Pipe gauges and American Petroleum Institute Reference Master gauges are of this type. Details of these gauges are given in the US National Bureau of Standards Handbook No. H28 and the appropriate specifications of the American Petroleum Institute.

At this juncture it is well to consider that all the elements met in parallel screw threads are present in taper screw threads, plus the complication of taper. Taper can be used however in the following ways. If the direction of tolerances allows the taper of internal threads to be slightly slower than nominal, and of external threads to be slightly faster than nominal, then the likelihood is that engagement will be located at the large end of an assembling pair. If use is made of the direction of tolerances described in the previous sentence then there should be increasing clearance between the assembled taper threads towards the small end. This clearance can help to absorb the virtual effect of slight pitch errors on the pitch diameter. Finally using steps on gauges to assess size has the advantage that x units on diameter appear as mx units on length where the rate of taper diametrally is 1 in *m*.

16 MEASUREMENT OF TAPER SCREW PLUG GAUGES

16.1 Elements to be measured

The elements of a taper screw plug gauge requiring measurement are:

a) Major, minor, and pitch diameters in a specified plane normal to the axis, usually the gauge plane: note that measurement of diameter involves location of the position of the specified plane.

b) Taper

c) Pitch

d) Thread form

e) Flank angles

16.2 Measurement of pitch, major, and minor diameters

Since, by definition, diameter in a specified plane is required, the first operation is to locate the specified plane axially with respect to an end face of the gauge.

16.2.1 "Spotting off" to locate the specified plane

By this method it is possible to locate the particular position of the thread groove where the bisector of the groove lies in the plane in which the diametral measurements are required.

This position is located by means of a stylus in the form of a precision cylinder with a concentric cone which has an included angle equal to the nominal included angle of the thread of the taper screw. The cylindrical shank is mounted on gauge blocks on a Grade O surface plate (see Fig. 29 with its axis of the shank and cone is at the height of the specified plane. The cone is presented to the thread along a radius of the taper screw, which is also mounted with its end resting on the surface plate. Then cone/gauge block and the taper screw are rotated relatively on the surface plate until a position is found at which the flanks of the cone touch both flanks of the thread simultaneously. The process is facilitated by the use of a light box placed behind the cone and flanks. The position of cone/flanks contact is now finely marked in a small piece of wax fixed in the thread immediately above the point, or in etching ground. A carefully positioned straight edge is necessary to align the cone shank presentation along a radius when smaller diameters, coarser pitches, and faster tapers make location more critical.

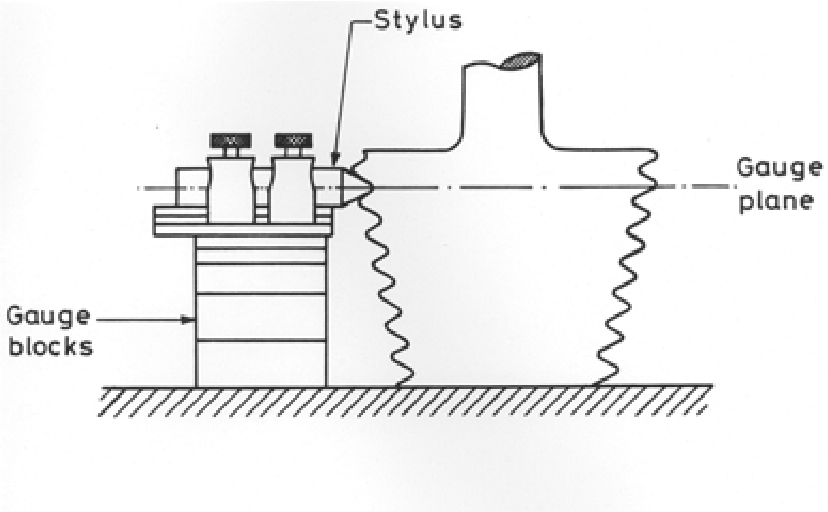


FIG. 29 "Spotting off"

16.2.2 Measurement of pitch diameter in a floating micrometer machine

Having "spotted off" the required position, the taper screw is transferred to a floating micrometer diameter measuring machine (see Section 7.2) previously standardized with a cylindrical standard and with appropriate thread measuring cylinders. Measurements are taken with one of these cylinders placed in the thread groove at the point located by the "spotting off" stylus, and with the second cylinder diametrically opposite but displaced half a pitch in advance. Next, the second cylinder is placed half a pitch behind the first one and a further reading taken. From the mean of these two readings, M_1 and M_2, see Fig. 30, the mean diameter T under the cylinders is calculated in the usual manner.

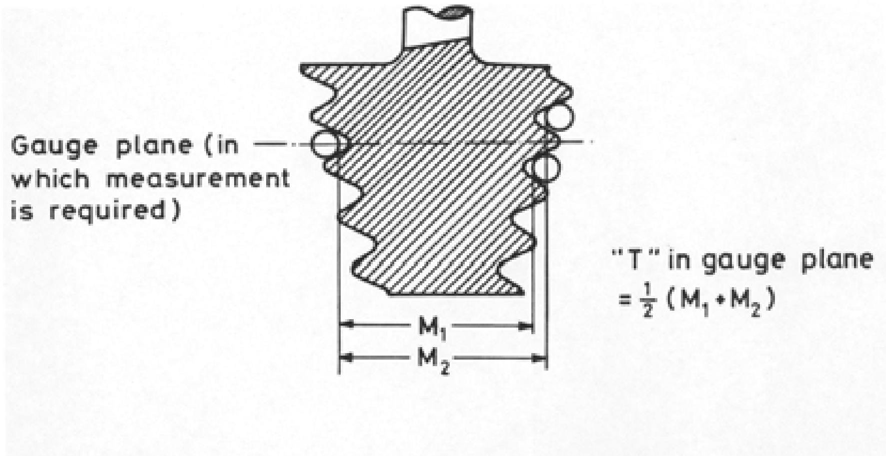


FIG. 30 Measurement of pitch diameter of a taper screw

The pitch diameter is obtained from the formula:

$$E = T + P_T - c + e \qquad (1)$$

where:

E	=	pitch diameter in specified plane
P_T	=	constant depending on the pitch, flank angle and rate of taper of the screw and the mean diameter of the cylinders used
c and e	=	small corrections depending on the rake of the screw and the elastic compression of the cylinders respectively

It should be noted that the value of P_T for taper thread measurement is slightly less than P for a parallel thread of the same pitch. The formula giving the value of P_T for the cylinders used in taper thread measurement (thread normal to the axis) is:

$$P_T = P\frac{\cot\alpha}{2} - (\operatorname{cosec}\alpha - 1)w - P\frac{\tan^2\beta\tan\alpha}{2} \qquad (2)$$

where

β	=	nominal semi-angle of taper
p	=	nominal pitch of thread
α	=	nominal flank angle of thread
w	=	mean diameter of cylinders

The above formula is identical with the formula for determining the value of P for parallel threads (see Section 8.1) except for the last term, which can amount to as much as 0.0009 inch in the case of some coarse pitch screws having a fast taper.

Values of c and e in the pitch diameter formula given above may be calculated as for parallel screws (see sections 8.2 and 8.3).

Value of the constant P_T for different standard thread forms

British Standard Taper Pipe Threads
Rate of taper is 1 in 16 on diameter: $\alpha = 27.5°$

$$P_T = 0.960\,24p - 1.16568w \quad (3)$$

American National Taper Threads
Rate of taper is 1 in 16 on diameter: $\alpha = 30°$

$$P_T = 0.865\,74p - w \quad (4)$$

American Petroleum Institute Taper Threads: $\alpha = 30°$

$Pr = 0.865\ 75p$ -w for rate of taper 1 in 16 on diameter (5)

$Pr = 0.864\ 02p$ -w for rate of taper 1 in 6 on diameter (6)

$Pr = 0.861\ 51p$ -w for rate of taper 1 in 4 on diameter (7)

Where the crests have a radiused form, the major diameter in the gauge plane may be obtained from the mean of two measurements, one from each of the two crests immediately adjacent to the marked thread groove to the crest diametrally opposite. The minor diameter in the gauge plane may be measured in a similar way to pitch diameter, using suitable vee-pieces inserted in the thread groove in place of the cylinders (see Section 7.3).

The accuracy of measurement of the diameters in the gauge plane depends largely on the accuracy of "spotting off" the position of the locating stylus, which is conditional upon the helix angle and nominal taper of the thread. For gauges up to, say, 4 in diameter it is possible to "spot off" to an accuracy of ± 0.02 in measured along the helix, and with the small helix angles and rates of taper of the majority of taper threads this accuracy is equivalent to a diametral error of ± 0.0001 in or less.

Some standard sizes of API (American Petroleum Institute) gauges range up to 20 in diameter. The plugs do not carry centres and are in the form of a robust shell. Spotting-off is used without difficulty for identifying the gauge plane. Then the plug is stood with its small end on a horizontal plane see Plate IX which can be raised or lowered on an axis which passes through a large slot in a floating micrometer casting. Because of the particular conditions the setting of the micrometer calliper is established by using an end bar and gauge block in combination (and the thread measuring cylinders) supported in vee supports with fine adjustments for alignment purposes.

16.2.3 NPL/Matrix radial measuring machine

The machine described in Section 9.2.2 is adaptable for measuring diameters in the spotted-off plane provided the gauge is within the capacity of 6 in diameter, 2 in length and can be mounted on the worktable.

16.2.4 NPL double sine bar machine

Although this machine is capable of measuring taper screw plug gauges of all diameters it is particularly useful for measuring those which are large or which have helix angles and rates of taper so large that the diametral effect of the errors of "spotting off" are excessive.

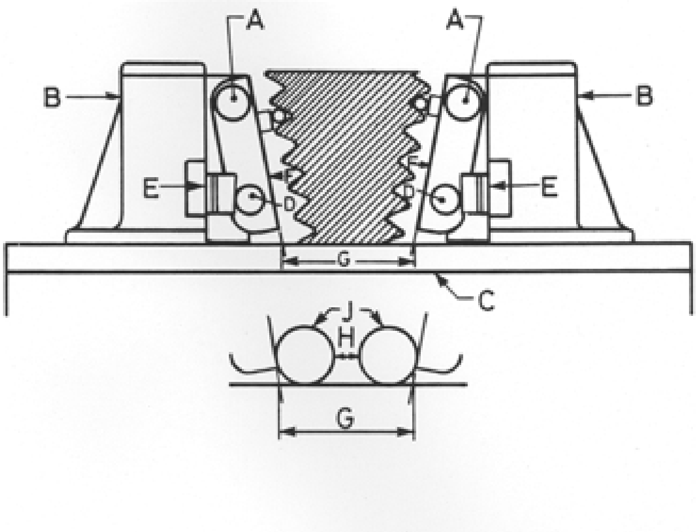


Fig. 31 NPL double sine bar machine

The machine consists of two equal vertical sine bars (F) pivoted at their upper ends at (A) on brackets (B) mounted on a base casting (C) having a flat upper face. The sine bars can be set to any required angle from the vertical by inserting slip gauges between their lower pins (D) and vertical abutments (E) on the brackets. The brackets (B) are aligned on the base casting so that when the sine bars are in a vertical position their gauging faces (F) are in parallel planes. The distance between the brackets on the base may be altered to allow for different sizes of gauges to be mounted on the base casting.

In use each sine bar is set to the nominal half included angle of taper of the gauge and the brackets are spaced so that there is a small clearance between the sine bars and the crests of the gauge when the gauge is stood on the base between the sine bars. The gauge is then removed and the separation G of the gauging faces of the sine bars in the plane of the base is calculated from the measured dimension H between equal size rollers (J) contacting the base and the sine bars.

$$G = H + w(1 = \sec\beta) - w\tan\beta$$

where w= mean diameter of the rollers (J) and β is the nominal half included angle of taper.

The gauge is then replaced on the plane between the sine bars.

To measure the pitch diameter in any plane, gauge blocks are inserted between the sine bars and the taper screw gauge, and are adjusted in size until the appropriate thread measuring cylinders can just be inserted between the gauge blocks and the thread groove. The measurement should be made near the gauge plane to avoid errors due to departure of the taper from nominal. The formula for calculating the pitch diameter in the gauge plane is:

Pitch diameter $E = G - (V + w)\sec\beta - w + P_T + 2L_1 \tan\beta$ where:

G	=	previously determined constant of the machine
V	=	sum of the gauge blocks
w	=	mean diameter of cylinders
β	=	nominal half included angle of taper
P_T	=	constant depending upon the mean diameter of the thread measuring cylinders (see section 16.2.1)
L_1	=	height to gauge plane

The machine is used similarly for measuring the major and minor diameters. For the major diameter, the gauge blocks are fitted directly between the sine bars and the crests of the threads on the gauge. We then have:

$$\text{Major diameter } D = G - V\sec\beta + 2L_1 \tan\beta$$

The minor diameter, vee-pieces of known width are used in addition to gauge blocks to obtain contact at the roots of the threads. If the combined width of the vee-pieces is U, we then have:

$$\text{Major diameter } K = G - (V + U)\sec\beta + 2L_1 \tan\beta$$

The double sine bar method is advantageous in not being over dependent upon identifying the gauge plane on the thread. This feature is important for fine pitches where spotting off has to be made against short flanks, and for fast tapers. The principle of the double sine bar method can be extended to measuring numbers of taper screw plug gauges of the same nominal size by using fixed taper blocks, as illustrated in Fig. 32. For example four such blocks in graded sizes and with a nominal taper of 1 in 16 on diameter are sufficient for the full range up to 6 in nominal diameter of B.S. Pipe taper screws. Details of the blocks are given in Appendix 10. These fixed taper blocks advance the double sine bar machine in that the taper is set permanently to the required angle, and the value for G, once determined, is a constant for the block.

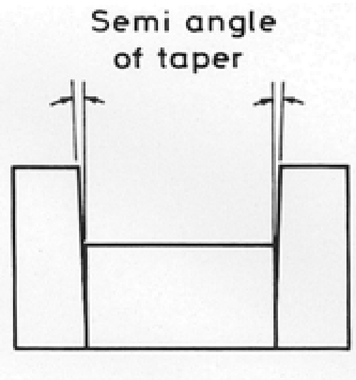


Fig. 32 Fixed taper blocks for measurement of taper screw plug gauges

16.3 Measurement of taper

The objective is to check the rate of change of diameter with known advance along the axis and for this purpose the pitch of successive threads taken axially supplies regular known intervals of sufficient accuracy.

16.3.1 Floating micrometer machine

The screw gauge is mounted in the machine and restrained so that it cannot rotate. Then a series of diametral readings is taken across thread measuring cylinders as they are engaged in successive thread grooves. If R_0 is the micrometer reading at the large end and R_n is the reading n pitches towards the small end, 1 in X the nominal rate of taper, p the nominal axial pitch, then the measured taper of pitch diameter is R_0 - R_n which can be compared with $\frac{np}{x}:or(R_o - R_n) - \frac{np}{X}$ is the measured deviation of taper.

16.3.2 Double sine bar machine

Since the faces of the sine bars are set at the nominal half angles of taper, the gauge blocks inserted at various positions trace deviation of taper of the gauge from nominal. Thus if a total V_0 gauge block combination is required at the large end, a total V_y at another position, then there is a deviation in taper of $(V_y - V_o)$ sec diametrally.

16.3.3 Minor diameter: major diameter

When the crests and roots are finished precisely, the taper of the minor diameter can be explored as described above but substituting core prisms for thread measuring cylinders. For major diameter, direct contact may be made on the radiused or truncated crests by the floating micrometer or double sine bar. Alternatively the parallelism of crests with pitch line may be checked during examination of the magnified thread form.

16.4 Measurement of pitch

In order to measure the pitch of taper screw gauges up to 8 inches in diameter, a suitable machine such as a "Matrix" pitch measuring machine is recommended; this machine is described in Section 7.4, and has an attachment for measuring taper screws. For gauges which cannot be accommodated in such a machine a pitch indicator of the type designed at the National Physical Laboratory and illustrated in Plate VIII may be used. The stylus point, mounted on a crossed strip hinge and sensitive to movement in the vertical plane, operates a 0.000 1 in indicator. The gauge under measurement is clamped to a surface plate with its axis vertical, and the pitch indicator is presented to the threads in a radial direction by locating the back of the instrument against a fixed vertical surface. The indicator is supported on gauge blocks and adjusted to give a zero reading in the bottom thread groove of the taper screw. The instrument is then moved step by step up a generator of the cone, increasing the supporting block pile by an amount equal to one nominal axial pitch on each occasion, and the errors of pitch for each successive thread are read off directly from the indicator. The gauge is turned through 180° and the readings repeated; the mean is taken of the two series.

16.5 Thread form

The thread form of small taper screw plug gauges is examined by optical projection at a magnification of 50 times (see Section 12), the projected form being compared with a nominal outline at the same magnification. Should the dimensions of the taper screw under examination be outside the capacity of the available projector, a cast must be made in plaster of Paris of the thread form and the cast projected (see Section 9.4). It is important to pare the cast down to present a thin axial section to the beam of the projector so that a well defined image can be produced.

16.6 Flank angles

After the thread form has been examined as described in the preceding paragraph, the flank angles may be measured with a protractor at the screen. If the taper screws are of such a size that the "throw over" method cannot be used the protractor is lined up to the crests of the threads and the flank angles are measured in the usual manner, making an allowance for the tilt of the protractor base line according to the semi-angle of taper of the plug.

17 INSPECTION OF TAPER SCREW RING GAUGES WITH CHECK PLUGS

Taper screw ring gauges are readily inspected by the use of the following sets of check plugs:

a) A full form taper screw check plug having a thread sufficiently long to mate with the full length of thread of the maximum and minimum sizes of ring gauges.

b) Two pitch diameter taper screw check plugs. Each of these check plugs has a few threads only, located at the large diameter end of one plug and at the small diameter end of the other plug. The crests of the threads are truncated and the roots are cleared, so that the check plugs bear on the middle part of the flanks of the gauge.

c) Two minor diameter taper plain check plugs, having only short lengths of taper, located at the large diameter end of one plug and at the small diameter end of the other plug.

If the taper of each plug and the diameter at one end is known, the sizes of the various elements of the ring gauges with which they are mated can be determined by measuring the axial stand-off of each check plug when assembled with the ring gauge. In addition to examination with these check plugs, pitch errors should be measured, and a cast of the threads of the gauge examined by optical projection. It is not considered necessary to have separate check plugs for inspecting the major diameter of the ring gauge. The use of the full form screw check plug number (a) verifies that the major diameter is nowhere less than the minimum limit, and it is then sufficient to check that the depth of thread in the ring gauge is satisfactory by optical projection of the cast of the threads.

18 MECHANICAL MEASUREMENTS OF TAPER SCREW RING GAUGES

18.1 Measurement of diameter

The diametral sizes of taper screw ring gauges may be controlled between limits by the use of the system of check plugs already described, the sizes at the two ends of the gauge being determined from the “stand off” from one end face of the gauge of the appropriate check plug when inserted in the gauge. For example, when measuring the pitch diameter of the small end of a taper screw ring gauge, the check plug used would be one of the two pitch diameter checks plugs [(b) in Section 17] having only a few threads at the small end of the taper.

Alternatively, when no check plugs are available, the major, pitch and minor diameters of taper screw ring gauges may be measured on the Internal Diameter measuring machine already described in Section 9.2.2, providing the thread diameters lie between ¼ in and 6 in and the axial length of thread is not greater than 2 in.

With thread forms rounded precisely at crest and root it is sometimes required to measure the major, pitch and minor diameters in a specified plane and also the rate of taper as well as to make the usual measurements of pitch, flank angles and thread form. Large taper screw ring gauges are invariably associated with mating plug gauges of known sizes, and it is sufficient to size the ring gauge by assembling with the plug gauge and measuring the "stand off" of one from the other provided supplementary measurements are made of taper, pitch, flank angles and thread form.

18.2 Measurement of taper

18.2.1 NPL/Matrix radial measuring machine

The taper may be measured on the measuring machine, see Section 9.2.2, providing the size of the gauge falls within the capacity of the machine.

18.2.2 Taper measurements with a modified internal micrometer

For gauges exceeding the capacity of the "Matrix" internal diameter measuring machine a ready means of obtaining the rate of taper is by the use of a modified internal micrometer. The modification consists of replacing the usual anvils by ball pointed anvils, the balls being of such a size that they will contact the flanks near their intersection with the pitch diameter cone. The method used (see Fig. 33) is to take "diametral" measurements of the pitch diameter, thread by thread; then to compare the change in actual diameter derived from the above measurements with the nominal change in diameter for axial increments of one pitch at a time.

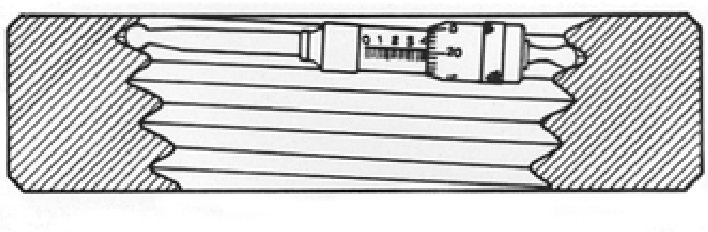


Fig. 33 Measurement of taper by means of internal micrometer

Two considerations arise with this method of measurement:

i) Ensuring that the measurements are made in an axial plane.

ii) Determination of the correction to be applied to the micrometer measurements to compensate for the error caused by the axis of the micrometer not being normal to the axis of the thread, owing to one anvil, in the measuring position, being one half pitch in advance of the other anvil.

Location of the axial plane

An axial plane of the gauge to be measured is determined by marking a generator of the minor diameter cone. To do this the parallel blade of a bevel protractor is set at 90° to its stock, and is placed in the taper thread with the flat of the blade held firmly against the threads and the stock seating on the end face of the gauge. A finely sharpened pencil is then drawn down on edge of the blade, leaving marks on the crests of the threads. The protractor is now moved round the thread until the other edge of the blade intersects the pencil line and another pencil line is drawn down this edge of the blade. It will be found that the two pencil lines thus marked on the crests of the threads diverge; this is particularly noticeable with fast taper threads. A mean line is then drawn, preferably with Indian ink, on the crests of the threads midway between the two pencil lines; this line is a generator of the minor diameter cone and distinguishes an axial plane. "Diametral" measurements in an axial plane can now be made. The fixed ball anvil of the internal micrometer is located in the first thread space near the large end of the thread and held lightly so that it contacts the flanks in the plane containing the axis of the thread, and the marked generator. Sufficient accuracy will be obtained if the ball of the anvil appears, to the eye, to be in line with the Indian ink line. The micrometer is then unscrewed until the other ball anvil locates in a thread space diametrically opposite the marked generator and half a pitch in advance of the first anvil. The micrometer is then swung gently from side to side about the fixed anvil as a pivot and adjusted until a maximum reading is obtained, i.e. a reading in an axial plane. This process is repeated thread by thread thus giving a series of "diametral" readings in an axial plane for advances along the axis of one pitch at a time.

Correction for inclination of the micrometer

The measurements obtained are not made normal to the axis but are inclined due to the half pitch stagger of the thread grooves. As this inclination increases towards the small end of the thread, it is necessary to make a correction to the measured differences in order to obtain the actual taper.

Referring to Fig. 34, it is required to know the differences $(d_1 - d_2)$, $(d_1 - d_3)$ etc, whereas the measurements made give the differences $(M_1 - M_2)$, $(M_1 - M_3)$ etc.

It will be found that:

$$(d_1 - d_n) = (M_1 - M_n) + \frac{np^3 \tan\beta}{4d_1 d_n}$$

where: n = number of pitches between the measurements M_1 and M_n.
p = pitch
β = semi-angle of taper

As an illustration of the magnitude of the correction

$$\frac{np^3 \tan\beta}{4d_1 d_n}$$

this amounts to approximately 0.0003 in for a taper thread 3 ½ inches in diameter at the large end, 2 ¾ inches long, and having five threads per inch and a taper of 1 in 4 on diameter.

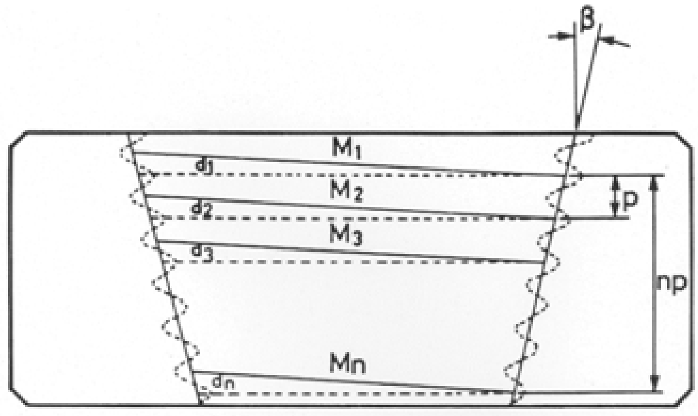


Fig. 34 Diagram illustrating principle of measurement of taper

18.2.3 NPL taper comparator

An alternative method of measuring the taper is by means of the machine of NPL design which is shown diagrammatically in Fig. 35. The principle of the machine is to set the traverse of a stylus moving along a straight line corresponding to the nominal slope of the wall of the ring, and then to measure how much the ring thread differs from that slope. The machine is mounted on a surface plate and consists essentially of a main casting (A) on which a robust "L" shaped

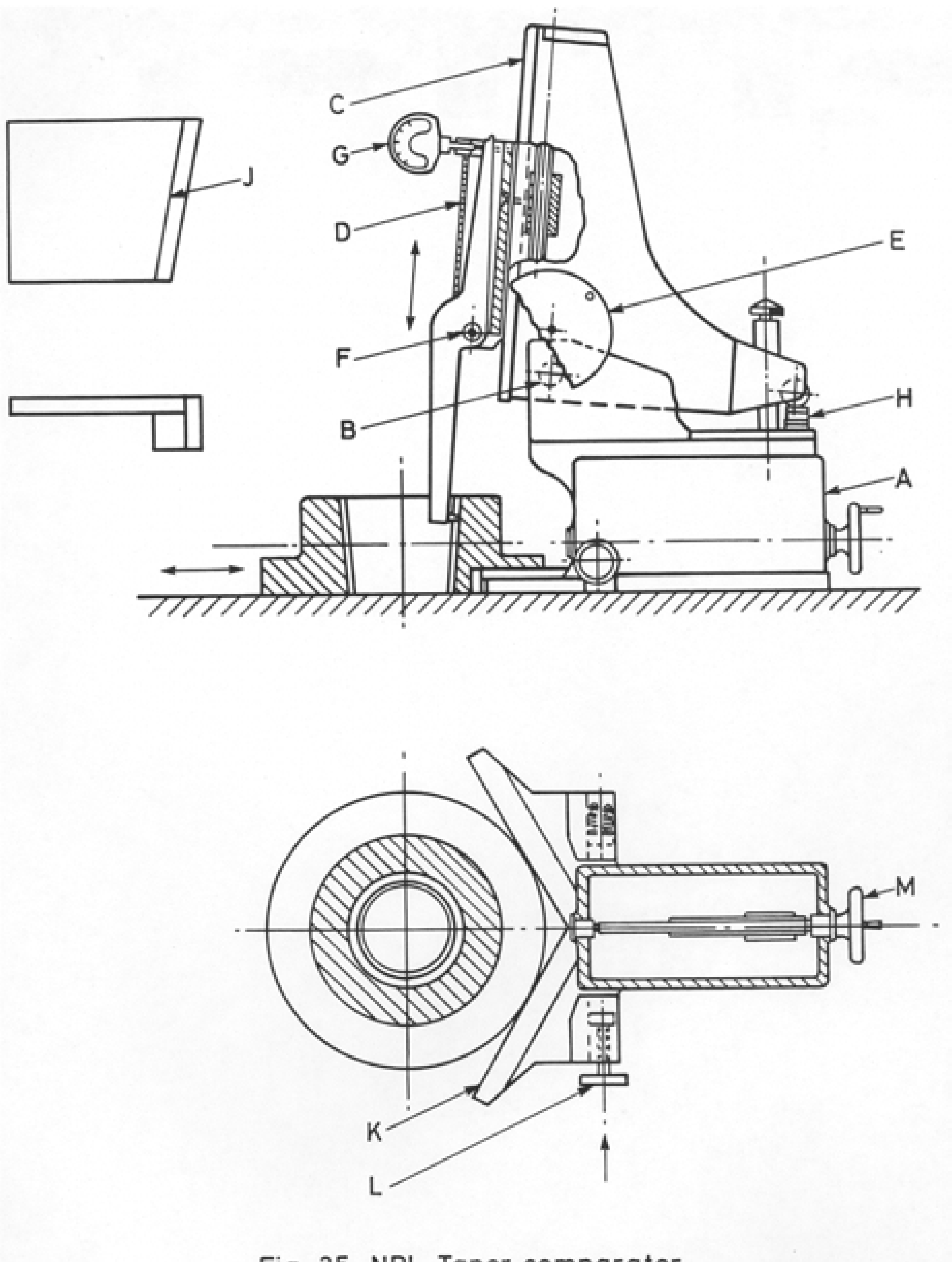


Fig. 35 NPL Taper comparator

casting is pivoted at (B). The left-hand face (C) of this "L" shaped casting is machined accurately flat and carries a carriage (D) which is moved up or down the face by means of handwheel (E). At the lower end of the carriage a lever is pivoted at its mid-point (F) and has stylus mounted at its lower end; the upper end of the lever bears on the anvil of a sensitive measuring head (G). The face (C) is set to the nominal half-angle of taper by inserting gauge blocks at (H) between a horizontal surface on the main casting (A) and a radiused contact face on the right-hand end of the "L" shaped casting. The setting is facilitated by the use of a block (J) having a face machined at the correct half-angle of taper with respect to the base. This block (J) is placed in position on the surface plate with the stylus in contact with the tapered face, and the gauge blocks at (H) are altered until the reading on the measuring head (G) remains unchanged when the stylus is traversed over the length of the tapered face by means of the handwheel (E). The setting block (J) is then replaced by the taper ring gauge, as shown in the diagram. The ring gauge is located on the surface plate by a vee-plate (K) which has a lateral adjustment operated by knob (L) and a longitudinal adjustment operated by handwheel (M); these two adjustments are used to locate the ring gauge in the position in which the stylus traverses a generator of the cone. The stylus is then located in successive thread grooves by turning handwheel (E) and readings are taken on the measuring head. The differences between these readings and the reading in the groove of the end thread are a measure of the error on radius of the taper from its nominal value. The ring is turned through 180° and another set of readings taken. The sum of the two sets corresponds with the error in taper on diameter.

18.3 Measurement of pitch

18.3.1 Matrix pitch machine

The most convenient method of measuring the pitch errors of taper screw ring gauges is by means of the "Matrix" pitch machine, which is capable of measuring gauges having external diameters up to 6 in.

18.3.2 NPL/Matrix radial measuring machine

Alternatively pitch measurements of taper screw rings may be made on the machine described in Section 9.2.2.

18.3.3 NPL tilted gauge machine

For taper threads of sizes beyond the capacity of the "Matrix" machines another larger machine of NPL design may be used (see Plate X). It is provided with an inclinable face plate (A) upon which the taper ring gauge to be measured is mounted. By adjusting the plate (A) the ring gauge (B) is tilted sufficiently to bring the lowest generator of the pitch cone parallel to the line of movement of a carriage (C) operated by a micrometer (D) and fitted with a suitable stylus (E) and a fiducial indicator. The stylus is located in successive threads and the micrometer operated until the indicator reads fiducially for each thread. The readings thus obtained are each subtracted from the first reading, and the resulting values give the cumulative pitch along the generator of the pitch cone. These values must be multiplied by the cosine of the semi-angle of taper and compared with nominal axial pitches in order to obtain the cumulative error in pitch along the axis of the thread.

18.3.4 NPL laser pitch machine

Large size API gauges are heavy so that handling for measurement is a problem. At NPL a laser pitch machine is now in use, see Fig. 36.

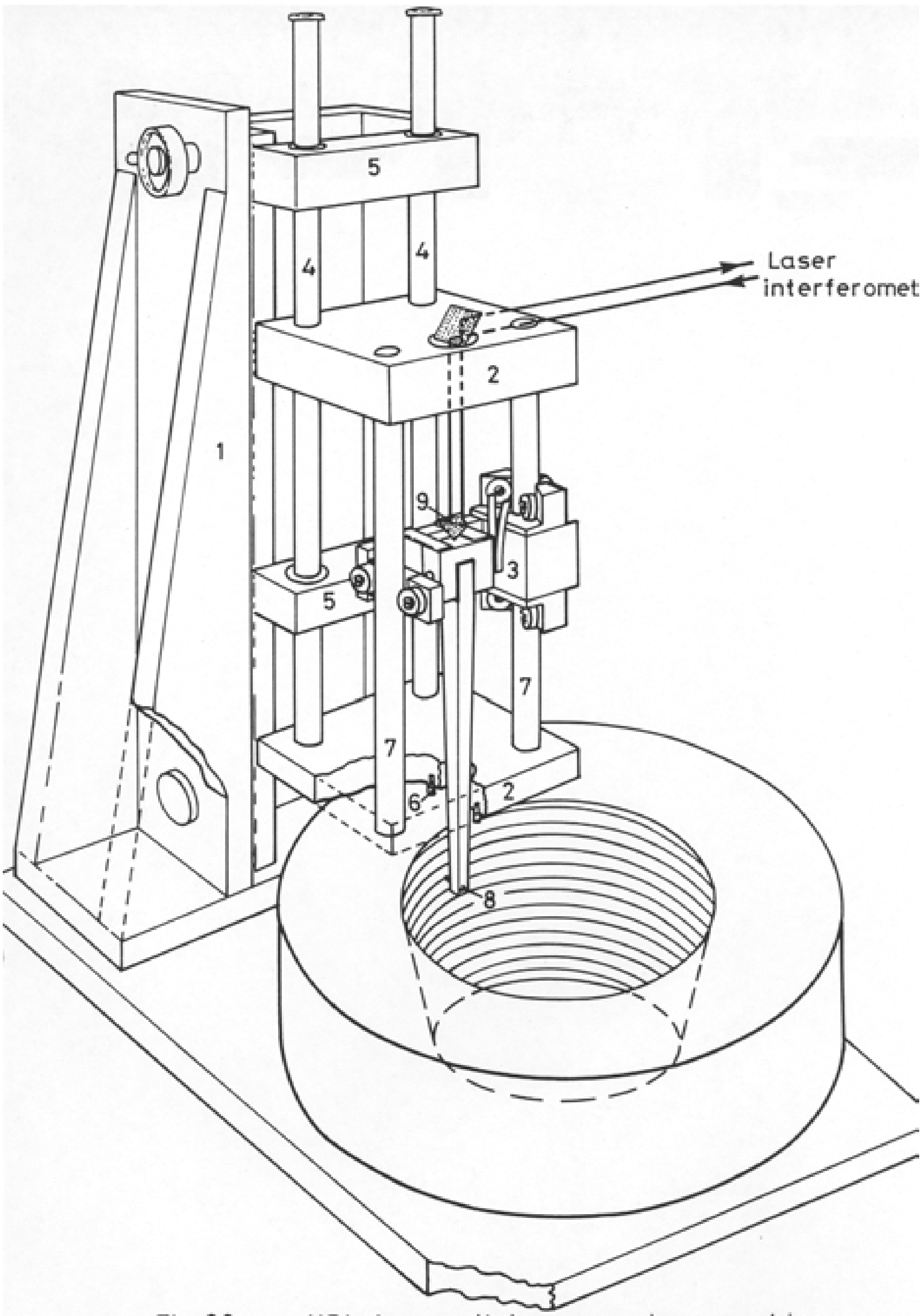


Fig. 36 NPL laser pitch measuring machine

The basic elements of the instrument comprise the support column (1), the measuring head frame (2) and the stylus arm assembly (3). One pair of guide rods (4) of the measuring head frame slides through two pairs of guide bushes (5) attached to the support column and permits the frame to be raised and then lowered until it is supported by the radiused foot (6) resting on the upper surface of the gauge. The other pair of guide rods (7) of the measuring head frame provides the guide ways for the displacement of the stylus arm assembly. The pitch is determined by locating a ball-ended stylus (8) in each thread groove in turn and measuring the resultant displacement of the cube corner reflector (9) mounted on the stylus arm assembly. Adjustment has been provided to allow the measuring head frame to be tilted in the support column in order to permit the stylus arm assembly to move parallel to the surface of the pitch diameter cone of the gauge.

18.4 Thread form and flank angles

A cast of the threads is made in plaster of Paris or other suitable material and optically projected at a magnification of 50 times. The projected form is compared with a nominal outline also at X50 magnification, and the flank angles are measured as described for taper plug gauges (see Section 16.6).

When the cast has been made it must be prepared for projection by paring it to a thin axial section. This is facilitated by marking a generator of the gauge with Indian ink as described for the measurement of taper (see Section 18.2.2). The cast is made over the marked generator so that the ink spots are transferred to the plaster thus indicating an axial section.

19 TAPER SCREW THREADS NORMAL TO THE CONE

This section relates solely to taper screw threads normal to the cone and the text will focus on the threads of gas cylinder valves as defined in BS 341.

The prescribed thread form is Whitworth outline i.e. symmetrically radiused at crest and root and with 27.5° flank angles; the form is normal to the cone; the pitches are various and specified along the cone; the tapers on diameter are various.

Comparing these requirements with those in the definitions in Section 14, it will be seen that the flanks are at asymmetrical angles with respect to a normal to the axis, that the pitch cone intersects the flanks symmetrically, the intercepts being one half the nominal pitch which is already specified along the cone.

Regarding methods of measurement described in Sections 14 to 18, the method of spotting off a specified axial plane is inapplicable because the flank angles are unequal about a normal to the axis. The double sine bar method, especially in the taper block form, see section 16.2.3, is used for diametral measurement. The formula for pitch diameter E becomes

$$E = G - (V + 2w - P)\sec\beta + 2L_1\tan\beta$$

and in this application P is unaltered from the value for parallel threads.

Plug gauges of this type of thread can be measured for major and minor diameters, pitch, taper, thread form and flank angles as already described. Ring gauges are very well assessed with check plugs, see Section 15.

PART IV: APPENDICES

APPENDIX I

SCREW THREAD SYMBOLS

Table 6: General Screw thread symbols (See Fig. 37)

Dimension	Symbol	Remarks
Major diameter.	D	Exception: symbol "B" is used for basic major diameter when this differs from the designated major diameter. Suffixes s or n indicating screw or nut may be used if necessary.
Pitch diameter	E	Suffixes s or n indicating screw or nut may be used if necessary
Minor diameter	K	
Pitch	P	
Lead	ℓ	
Number of threads per inch	n	
Number of turns per inch	N	
Depth of fundamental triangle . . .	H	
Basic depth of thread	h	h_s for external thread h_n for internal thread
Half-angle of symmetrical thread . .	α (alpha)	
Angle between leading flank of thread and normal to axis of screw	α_1	
Angle between following flank of thread and normal to axis of screw	α_2	

Table 6: General Screw thread symbols (continued)

Dimension	Symbol	Remarks
Lead angle at pitch diameter	λ (lambda)	$\text{Tan } \lambda = \dfrac{\ell}{\pi E}$
Radius of rounding at crest Radius of rounding at root	r	Suffixes c or r indicating crest or root, and s or n indicating screw or nut may be used if necessary
Depth from apex of fundamental triangle to adjacent root or crest of basic thread: 1). If rounded . . . . 2). If flat	 s f	
Depth from apex of fundamental triangle to: 1). Basic flat at crest of screw 2). Basic flat at root of screw 3). Basic flat at crest of nut 4). Basic flat at root of nut	 f_{cs} f_{rs} f_{cn} f_{rn}	
Width of: 1). Basic flat (general) 2). Basic flat at crest of screw 3). Basic flat at root of screw 4). Basic flat at crest of nut 5). Basic flat at root of nut	 F F_{cs} F_{rs} F_{cn} F_{rn}	
Length of bolt or screw	L	
Length of engagement	L_e	
Diameter of thread measuring cylinders	w	
Measured diameter over thread measuring cylinders	M_w	
Measured diameter under thread measuring cylinders	T	
Correction to measured diameter over cylinders to give pitch diameter	C	$E = M_w - C - c + e$ $C = w(1 + \text{cosec}\,\alpha) - p/2 \cot \alpha$

Table 6: General Screw thread symbols (continued)

Dimension	Symbol	Remarks
Correction to measured diameter under cylinders to give pitch diameter	P	$E = T + P - c + e$ $P = \frac{1}{2} p \cot a - (coseca - 1)w$
Rake correction	c	See Section 8.2
Correction for elastic compression of thread measuring cylinders	e	See Section 8.3
Error in any dimension	Prefix symbol with δ	Examples: Error in pitch, δp Error in half-angle, δa_1, or δa_2
Pitch diameter equivalent of errors in flank angles	ΔE_{α}	
Pitch diameter equivalent of error in pitch	ΔE_{p}	
Basic truncation of crest from full Whitworth form	U	1). U= height of segment of B.S. Whitworth crest 2). These symbols apply only to truncated Whitworth threads
Height of truncated thread	k	
Allowance at pitch diameter	G	

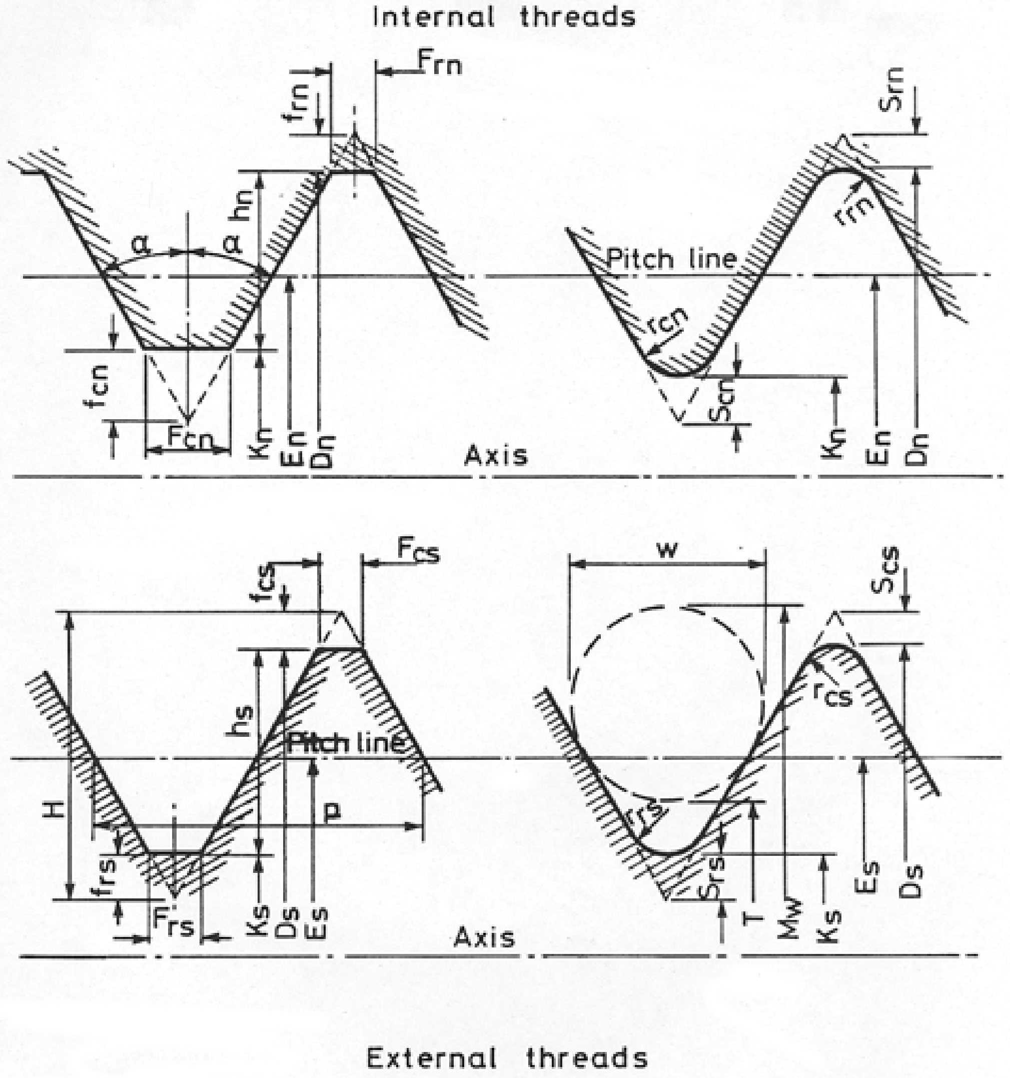


Fig. 37 General screw thread symbols

Table 7: Pipe thread symbols (See Fig. 38 to 40)

Dimension	Symbol	Remarks
Outside diameter of pipe	D	Suffex 4 is used for dimensions in plane of vanish point when these differ form D, d, or t, respectively
Inside diameter of pipe	d	
Wall thickness of pipe	t	
Major diameter	D_x	Suffix x denotes plane containing the diameter. For axial positions of planes see foot of Table. Suffixes s or n designating screw or nut may also be used if necessary.
Pitch diameter	E_x	
Minor diameter	K_x	
Length of thread from plane of pipe end to plane containing basic diameter D_x, E_x or K_x	L_x	For axial position of planes containing basic diameter see foot of Table
Length of washout (vanish cone) threads	V	
Half apex angle of pitch cone of taper thread	β (beta)	
Angle of chamfer at end of pipe measured form a plane normal to the axis	γ (gamma)	
Hand tight standoff of face of coupling form plane containing vanish point on pipe	A	
Length from plane of hand tight engagement to the face of coupling or internally threaded member	M	
Distance of gauging step of plug gauge from face of coupling for hand tight engagement	S	
Length from centre line of coupling, face of flange, or bottom of internal thread chamber to face of fitting	L_n	

Table 7: Pipe thread symbols (See Fig. 38 to 40) (continued)

Dimension	Symbol	Remarks
Length from centre line of coupling, face of flange, or bottom of internal thread chamber to end of pipe wrenched engagement.	J	
1) Length of external parallel thread 2) Length from plane of hand-tight engagement to small end of internal taper thread.	L_t	
Diameter of recess or counter-bore in fitting	Q	
Depth of recess or counter-bore in fitting	q	
Outside diameter of coupling or hub of fitting	W	

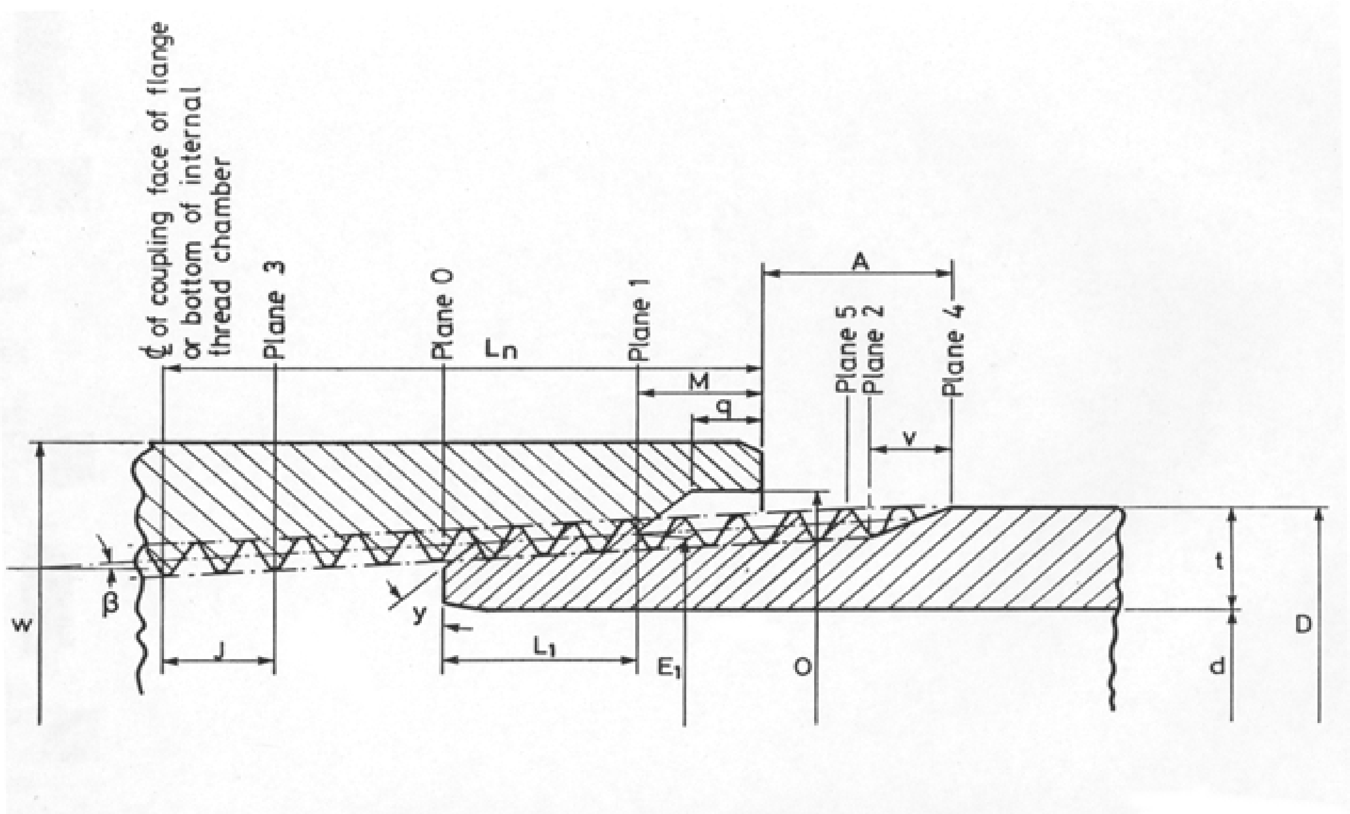


Fig. 38 Pipe thread symbols – General

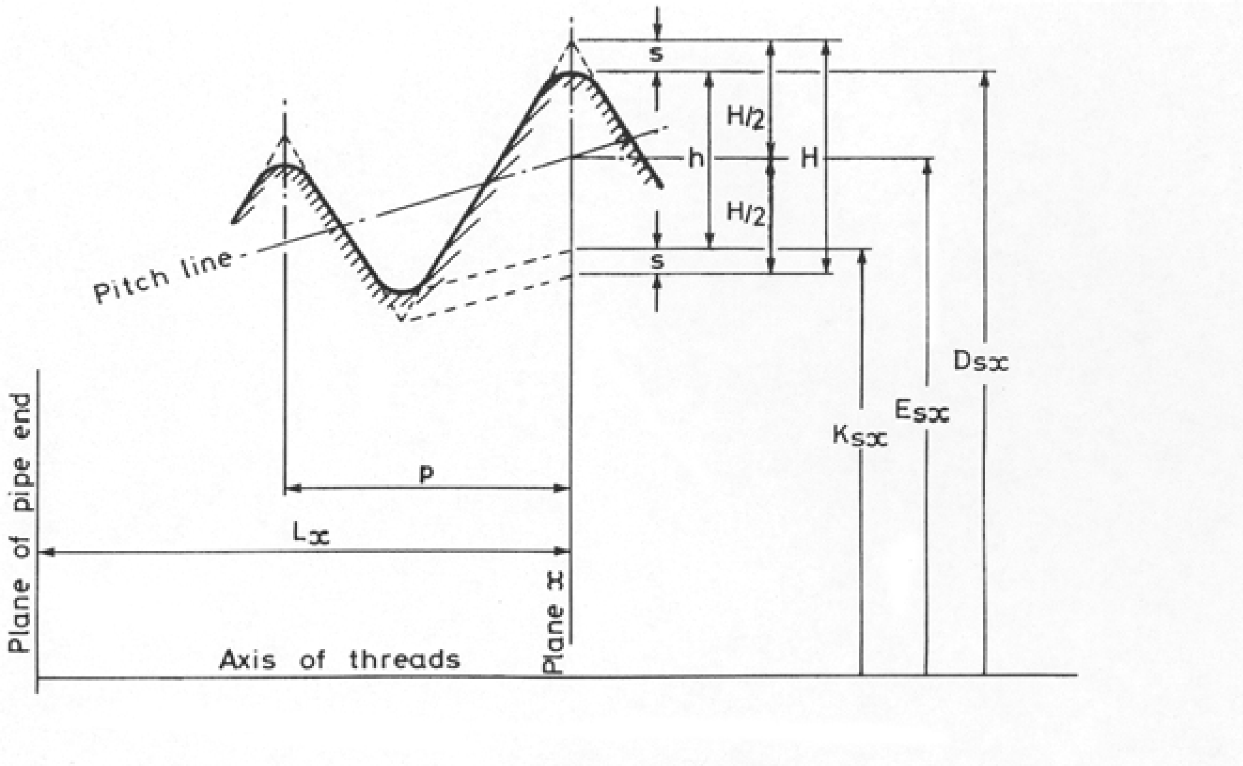


Fig. 39 Pipe thread symbols - radiused thread form square to axis

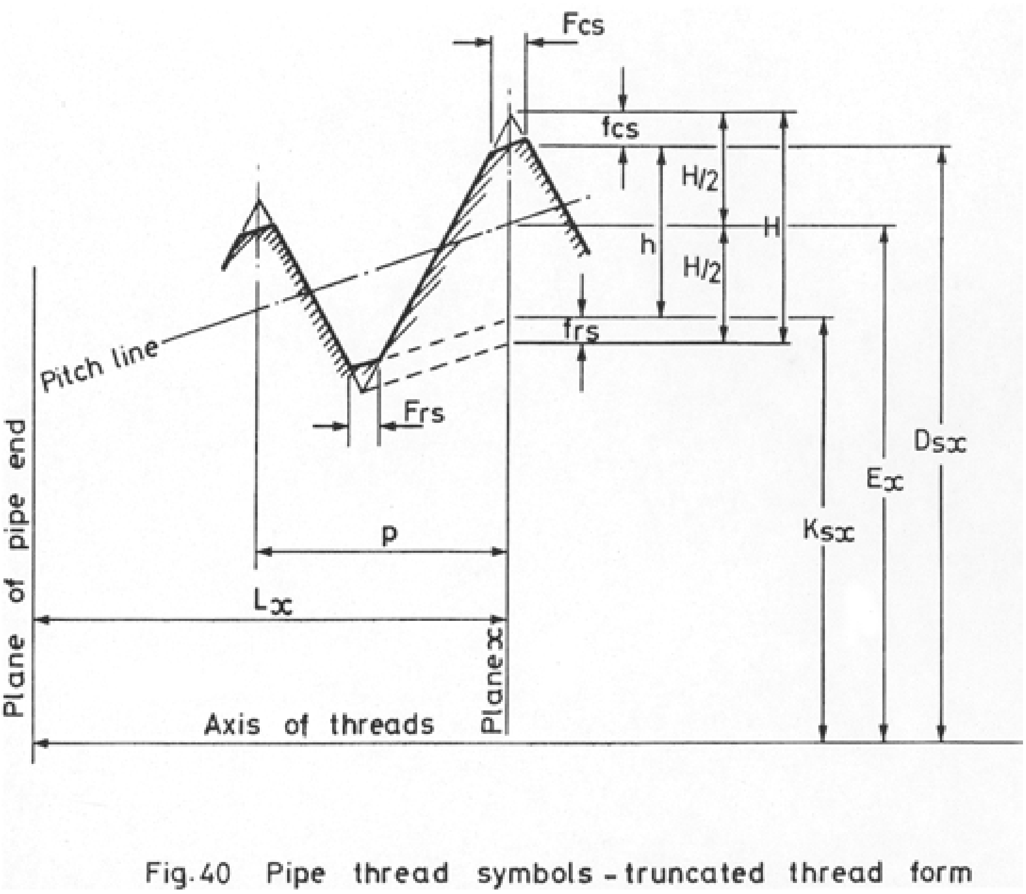


Fig. 40 Pipe thread symbols - truncated thread form

Table 4: Definition and designation of planes denoted by suffix x in table 3

Dimension	Symbol	Remarks
Plane of pipe end	x = 0	
Gauge plane, or plane at mouth of coupling (excluding recess if present)	x = 1	
Plane at which washout threads on pipe commence	x = 2	
Plane in coupling reached by end of pipe in wrenched condition. Note : L3 is measured from plane containing pipe end in position of hand tight engagement	x = 3	
Plane containing vanish point of thread on pipe	x = 4	
Plane at which major diameter cone of thread intersects outside diameter of pipe	x = 5	

APPENDIX 2

PARTICULARS OF STANDARD SCREW THREADS

Various thread forms have been developed to serve general and particular purposes, and have been standardized by the British Standards Institution. The reader is advised to refer to British Standards for full details of the thread forms, limits and tolerances, and gauging procedure.

The tables which follow give typical thread forms and a selection of information.

Tolerances for gauges are specified in BS919: Specification for screw gauge limits and tolerances. Gauges for screw threads of unified form.

Meanwhile discussions in the International Standards Organization (ISO) are aiming to co-ordinate national standards: ISO Metric and Unified screw threads are examples of progress.

American National Threads

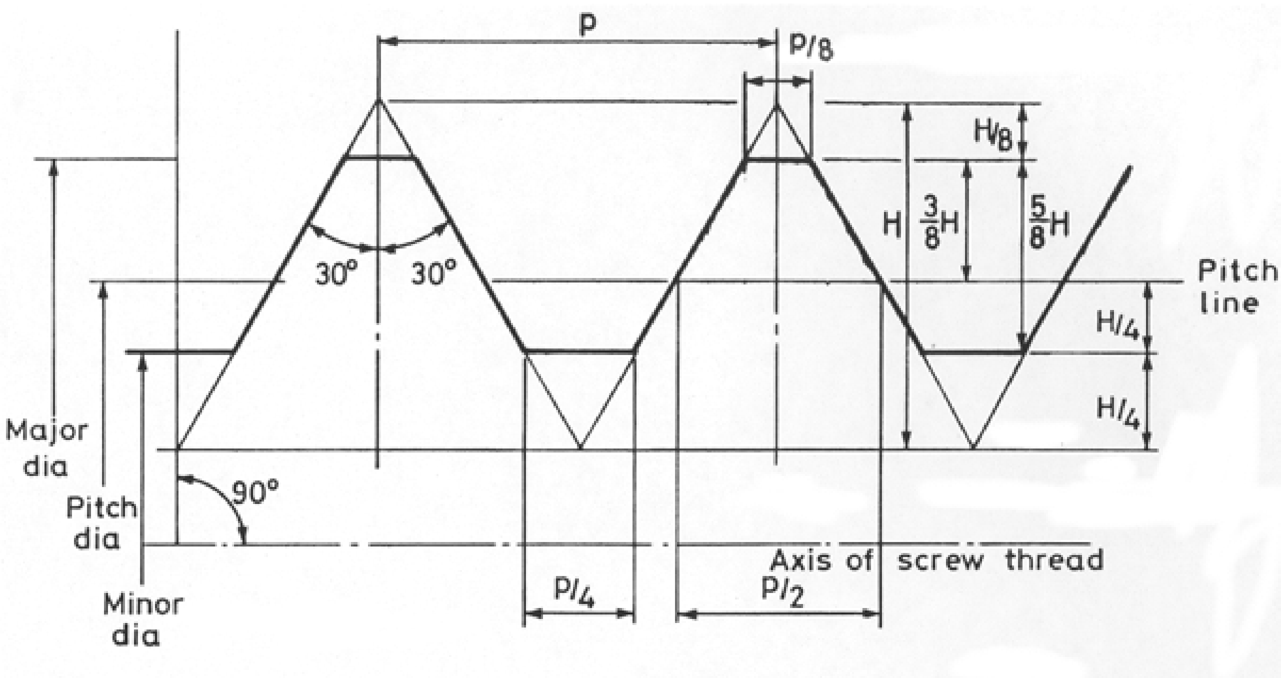
Details of these threads are given in the National Bureau of Standards Handbook, H28, entitled "Screw Thread Standards for Federal Services", issued from the Government Printing Office, Washington, U.S.A. Copies of this Handbook may be purchased from the British Standards Institutions, 3i8 Chiswick High Road, London, W4 4AL.

The American Petroleum Institute issues specifications for ranges of both parallel and tapered screw threads for oilfield equipment and for the gauges to be used.

Particulars are given for the following threads:

ISO metric	BS 3643
Unified screw thread	BS 1580
Whitworth thread form (obsolescent)	BS 84
British Association (BA) form (obsolescent)	BS 93
Acme thread form (obsolescent)	BS 1104
British Standard Cycle (BSC) thread	BS 811
Buttress thread	BS 1657
British Standard Insulator thread	BS 16
British Standard Pipe Thread (Taper)	BS 21
British Standard Gas Cylinder Thread (Taper)	BS 341
Round Threads for fire hose couplings	BS 336
Round Threads for underground fire hydrants	BS 750

ISO metric screw thread form



$$H = \frac{\sqrt{3}}{2} \cdot p = 0.866025p$$

Fig. 41 Basic ISO metric thread form

Table 8: Numerical data for ISO metric screw threads

Pitch p	H	5/8H	3/8H	H/4	H/8
mm	mm	mm	mm	mm	mm
0.2	0.17	0.1083	0.0650	0.0433	0.0217
0.25	32	0.1353	0.0812	0.0541	0.0271
0.3	0.21	0.1624	0.0974	0.0650	0.0325
	65				
0.35	0.25	0.1894	0.1137	0.0758	0.0379
0.4	98	0.2165	0.1299	0.0866	0.0433
0.45		0.2436	0.1461	0.0974	0.0487
	0.30				
0.5	31	0.2706	0.1624	0.1083	0.0541
0.6	0.34	0.3248	0.1949	0.1299	0.0650
0.7	64	0.3789	0.2273	0.1516	0.0758
	0.38				
0.75	97	0.4059	0.2436	0.1624	0.0812
0.8		0.4330	0.2598	0.1732	0.0866
1	0.43	0.5413	0.3248	0.2165	0.1083
	30				
1.25	0.51	0.6766	0.4059	0.2706	0.1353
1.5	96	0.8119	0.4871	0.3248	0.1624

Pitch p	H	5/8H	3/8H	H/4	H/8
1.75	0.6062	0.9472	0.5683	0.3789	0.1894
2	0.6495	1.0825	0.6495	0.4330	0.2165
2.5	0.6928	1.3532	0.8119	0.5413	0.2706
3	0.8660	1.6238	0.9743	0.6495	0.3248
3.5	1.0825	1.8944	1.1367	0.7578	0.3789
4	1.2990	2.1651	1.2990	0.8660	0.4330
4.5	1.5155	2.4357	1.4614	0.9743	0.4871
5	1.7321	2.7063	1.6238	1.0825	0.5413
5.5	2.1651	2.9770	1.7862	1.1908	0.5954
6	2.5981	3.2476	1.9486	1.2990	0.6495
8	3.0311	4.3301	2.5981	1.7321	0.8660
	3.4641				
	3.8971				
	4.3301				
	4.7631				
	5.1962				
	6.9282				

Note: For full information, see BS3643: ISO metric screw threads

UNIFIED Screw Thread Form

The basic thread form for the Unified screw thread is the same as for ISO metric screw threads, see Fig. 41. The two systems, Unified and ISO metric, use inch and metric units respectively.

Details of recommended thread forms and tolerances on product threads are given in BS 1580 Unified screw threads. Data for the basic form is tabulated below.

Table 9: Numerical data for Unified screw threads

Threads per inch n	Pitch p	H	5/8H	3/8H	H/4	H/8
	in	in	in	in	in	in
40	0.02500	0.02165	0.01353	0.00812	0.00541	0.00271
36	0.02778	0.02406	0.01504	0.00902	0.00601	0.00301
32	0.03125	0.02706	0.01691	0.01015	0.00677	0.00338
28	0.03571	0.03093	0.01933	0.01160	0.00773	0.00387
24	0.04167	0.03608	0.02255	0.01353	0.00902	0.00451
20	0.05000	0.04330	0.02706	0.01624	0.01083	0.00541
18	0.05556	0.04811	0.03007	0.01804	0.01203	0.00601
16	0.06250	0.05413	0.03383	0.02030	0.01353	0.00677
14	0.07143	0.06186	0.03866	0.02320	0.01546	0.00773
13	0.07692	0.06662	0.04164	0.02498	0.01665	0.00833
12	0.08333	0.07217	0.04511	0.02706	0.01804	0.00902
11	0.09091	0.07873	0.04921	0.02952	0.01968	0.00948
10	0.10000	0.08660	0.05413	0.03248	0.02165	0.01083
9	0.11111	0.09623	0.00614	0.03608	0.02406	0.01203
8	0.12500	0.10825	0.06766	0.04059	0.02706	0.01353
7	0.14286	0.12372	0.07732	0.04639	0.03093	0.01546
6	0.16667	0.14434	0.09021	0.05413	0.03608	0.01804
5	0.20000	0.17321	0.10825	0.06495	0.04330	0.02165
4.5	0.22222	0.19245	0.12028	0.07217	0.04811	0.02406
4	0.25000	0.21651	0.13532	0.08119	0.05413	0.02706
3.5	0.28571	0.24744	0.15465	0.09279	0.06186	0.03093
3	0.33333	0.28868	0.18042	0.10825	0.07217	0.03608
2.5	0.40000	0.34641	0.21651	0.12990	0.08660	0.04330
2	0.50000	0.43301	0.27063	0.16238	0.10825	0.05413
1.5	0.66667	0.57735	0.36084	0.21651	0.14434	0.07217
1	1.00000	0.86603	0.54127	0.32476	0.21651	0.10825

Whitworth Thread Form

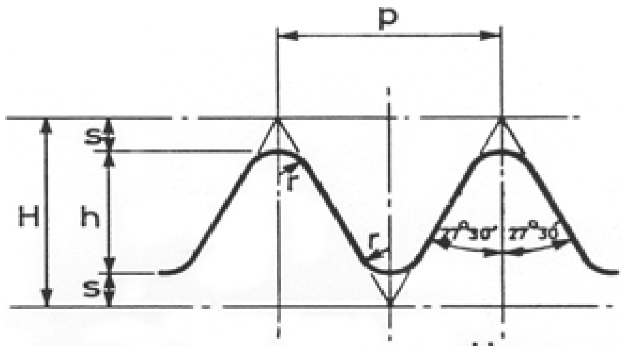
The depths of thread calculated from the data in Fig. 42 are rounded to the nearest 0.0001 in., and are given, together with the corresponding values for s, r and H in Table 10.

Table 10: Numerical data for Whitworth screw threads

Threads per inch	Pitch p	Depth of thread	Double depth of thread	Shortenting	Radius	H
n	p	h	2h	s	r	
	in	in	in	in	in	in
40	0.02500	0.0160	0.0320	0.0040	0.0034	0.0240
36	0.02778	0.0178	0.0356	0.0044	0.0038	0.0267
32	0.03125	0.0200	0.0400	0.0050	0.0043	0.0300
28	0.03571	0.0229	0.0458	0.0057	0.0049	0.0343
26	0.03846	0.0246	0.0492	0.0062	0.0053	0.0369
24	0.04167	0.0267	0.0534	0.0067	0.0057	0.0400
22	0.04545	0.0291	0.0582	0.0073	0.0062	0.0437
20	0.05000	0.0320	0.0640	0.0080	0.0069	0.0480
19	0.05263	0.0337	0.0674	0.0084	0.0072	0.0506
18	0.05556	0.0356	0.0712	0.0089	0.0076	0.0534
16	0.06250	0.0400	0.0800	0.0100	0.0086	0.0600
14	0.07143	0.0457	0.0914	0.0114	0.0098	0.0686
12	0.08333	0.0534	0.1068	0.0133	0.0114	0.0800
11	0.09091	0.0582	0.1164	0.0146	0.0125	0.0873
10	0.01000	0.0640	0.1280	0.0160	0.0137	0.0960
9	0.11111	0.0711	0.1422	0.0178	0.0153	0.1067
8	0.12500	0.0800	0.1600	0.0200	0.0172	0.1201
7	0.14286	0.0915	0.1830	0.0229	0.0196	0.1372
6	0.16667	0.1067	0.2134	0.0267	0.0229	0.6101
5	0.20000	0.1281	0.2562	0.0320	0.0275	0.1921
4.5	0.22222	0.1423	0.2846	0.0356	0.0305	0.2134
4	0.25000	0.1601	0.3202	0.0400	0.0343	0.2401
3.5	0.28571	0.1830	0.3660	0.0457	0.0392	0.2744
3.25	0.30769	0.1970	0.3940	0.0493	0.0423	0.2955
3	0.33333	0.2134	0.4268	0.0534	0.0458	0.3202

Note: 1) Details of tolerances on product threads are to be found in BS84: Parallel screw threads of Whitworth form

2) Special Whitworth threads with truncated crests are described in BS84.



$H = 0.960\ 491p$ $\qquad s = \frac{H}{6} = 0.160\ 082p$

$h = \frac{2}{3}H = 0.640\ 327p$ $\qquad r = 0.137\ 329p$

Fig.42 Whitworth thread form

British Association (B.A) Thread Form

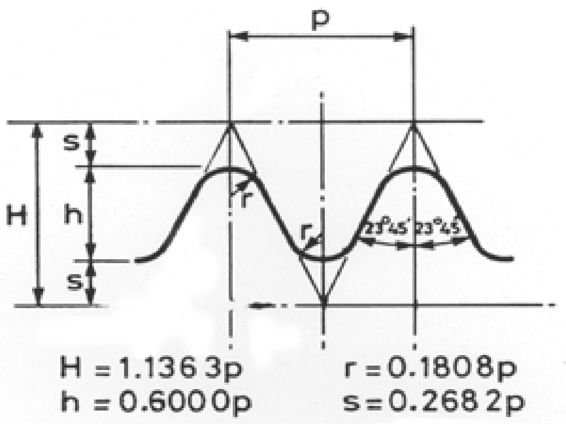


Fig. 43 B.A. thread form

Note: Details of tolerances on product threads are to be found in BS93: British Association (B.A) screw threads. (Current Obsolescent)

The following are the basic sizes and pitches, expressed in millimetres, for the sizes of B.A. threads down to 0.79 mm diameter.

Table 11: Basic sizes of B.A. thread

Designating number	Pitch	Major diameter	Pitch diameter	Minor diameter
	mm	mm	mm	mm
0	1.00	6.0	5.40	4.80
1	0.90	5.3	4.76	4.22
2	0.81	4.7	4.215	3.73
3	0.73	4.1	3.66	3.22
4	0.66	3.6	3.205	2.81
5	0.59	3.2	2.845	2.49
6	0.53	2.8	2.48	2.16
7	0.48	2.5	2.21	1.92
8	0.43	2.2	1.94	1.68
9	0.39	1.9	1.665	1.43
10	0.35	1.7	1.49	1.28
11	0.31	1.5	1.315	1.13
12	0.28	1.3	1.13	0.96
13	0.25	1.2	1.05	0.90
14	0.23	1.0	0.86	0.72
15	0.21	0.9	0.775	0.65
16	0.19	0.79	0.675	0.56

The inch equivalents of the millimetre sizes, rounded off to the nearest 0.0001 in, are given in Table 12.

Table 12: Basic sizes of a B.A. thread
Approximate inch equivalents of Table 11

Designating number	Threads per inch (approx)	Major diameter	Pitch diameter	Minor diameter
		in	**in**	**in**
0	25.4	0.2362	0.2126	0.1890
1	28.2	0.2087	0.1874	0.1661
2	31.4	0.1850	0.1659	0.1469
3	34.8	0.1614	0.1441	0.1268
4	38.5	0.1417	0.1262	0.1106
5	43.1	0.1260	0.1120	0.0980
6	47.9	0.1102	0.0976	0.0850
7	52.9	0.0984	0.0870	0.0756
8	59.1	0.0866	0.0764	0.0661
9	65.1	0.0748	0.0656	0.0563
10	72.6	0.0669	0.0587	0.0504
11	81.9	0.0591	0.0518	0.0445
12	90.7	0.0512	0.0445	0.0378
13	101.6	0.0472	0.0413	0.0354
14	110.4	0.0394	0.0339	0.0283
15	121.0	0.0354	0.0305	0.0256
16	133.7	0.0311	0.0266	0.0220

Acme Thread Form

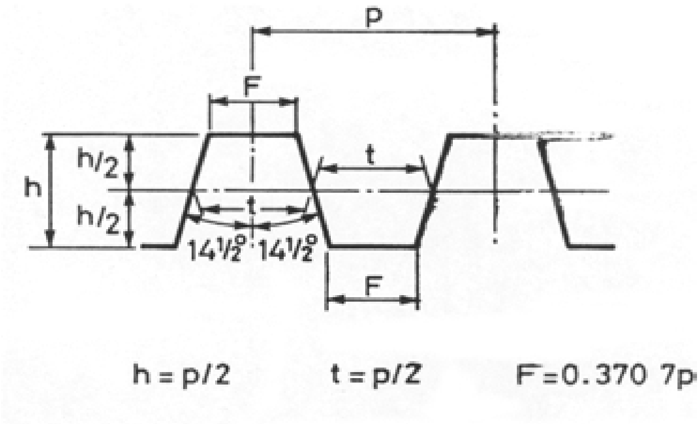


Fig. 44 Basic Acme thread form

Details of tolerances on product threads are to be found in BS1104: Acme screw threads.

Data for the basic form is tabulated below.

Table 13: Numerical data for acme threads

Threads per inch n	Pitch p	Depth of thread h	equals	Thickness of thread t	F
	in		in		in
16	0.06250		0.0312		0.0232
14	0.07143		0.0357		0.0265
12	0.08333		0.0417		0.0309
10	0.10000		0.0500		0.0371
8	0.12500		0.0625		0.0463
6	0.16667		0.0833		0.0618
5	0.20000		0.1000		0.0741
4	0.25000		0.1250		0.0927
3	0.33333		0.1667		0.1236
2	0.50000		0.2500		0.1853

British Standard Cycle (BSC) Threads

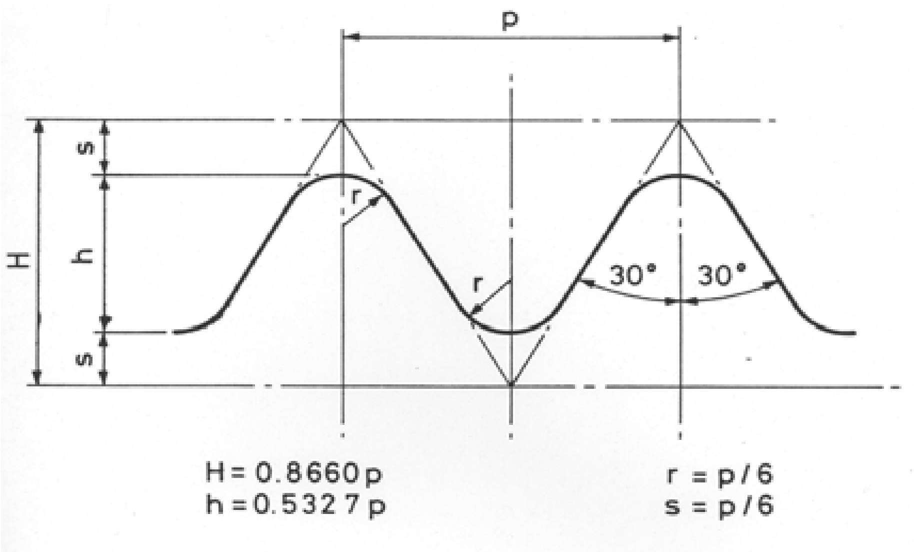


Fig. 45 Basic form of B.S.C. thread

(Formerly known as cycle Engineers' Institute (CEI) Thread).

Table 14 gives numerical data for the standard pitches of BSC threads.

Table 14: Numerical data for BSC thread

Threads per inch n	Pitch p	Depth of thread h	Double depth of thread 2h	Basic truncation s	Radius r	H
	in	in	in	in	in	in
56	0.017 86	0.009 5	0.019 0	0.003 0	0.003 0	0.015 5
44	0.022 73	0.012 1	0.024 2	0.003 8	0.003 8	0.019 7
40	0.025 00	0.013 3	0.026 6	0.004 2	0.004 2	0.021 6
32	0.031 25	0.016 6	0.033 2	0.005 2	0.005 2	0.027 1
30	0.033 33	0.017 8	0.035 6	0.005 6	0.005 6	0.028 9
26	0.038 46	0.020 5	0.041 0	0.006 4	0.006 4	0.033 3
24	0.041 67	0.022 2	0.044 4	0.006 9	0.006 9	0.036 1

See BS 811: Cycle threads for further information

Buttress Thread

BS1657; 1950 gives details of the British Standard Buttress thread in two forms, one (standard) with flank angles of 7° and 45°, the other (special) with flank angles of 0° and 52°: both forms aim at 0.4*p* depth of flank engagement. The American National Buttress thread is specified in detail in FED-STD-H28/14: it refers to flank angles of 7° and 45°, and to a depth of flank engagement of 0.6*p*. However, as the Buttress thread is applied under special circumstances it is considered that the choice amongst the three above mentioned is justified.

British Standard Buttress Thread

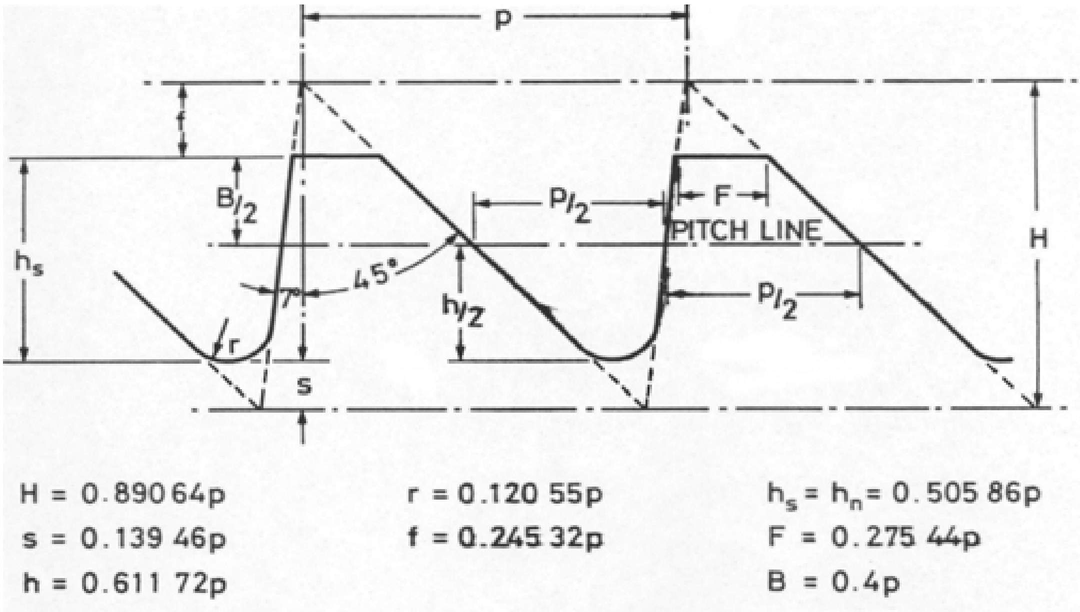


Fig.46 British Standard form of buttress thread.

Table 15 gives numerical data for the standard pitches of buttress threads.

Table 15: Numerical Data for BS Buttress Thread

Threads per inch	Pitch p	Basic depth of engagement B	H	f	$h_s = h_n$	h	s	r	F
	in	in	in	in	in	in	in	in	in
20	0.050 00	0.020 0	0.044 5	0.012 3	0.025 3	0.030 6	0.007 0	0.006 0	0.013 8
16	0.062 50	0.025 0	0.055 7	0.015 3	0.031 6	0.038 2	0.008 7	0.007 5	0.017 2
12	0.083 33	0.033 3	0.074 2	0.020 4	0.042 2	0.051 0	0.011 6	0.010 0	0.023 0
10	0.100 00	0.040 0	0.089 1	0.024 5	0.050 6	0.061 2	0.013 9	0.012 1	0.027 5
8	0.125 00	0.050 0	0.111 3	0.030 7	0.063 2	0.076 5	0.017 4	0.015 1	0.034 4
6	0.166 67	0.066 7	0.148 4	0.040 9	0.084 3	0.102 0	0.023 2	0.020 1	0.045 9
5	0.200 00	0.080 0	0.178 1	0.049 1	0.101 2	0.122 3	0.027 9	0.024 1	0.055 1
4	0.250 00	0.100 0	0.222 7	0.061 3	0.126 5	0.152 9	0.034 9	0.030 1	0.068 9
3	0.333 33	0.133 3	0.296 9	0.081 8	0.168 6	0.203 9	0.046 5	0.040 2	0.091 8
2 ½	0.400 00	0.160 0	0.356 3	0.098 1	0.202 3	0.244 7	0.055 8	0.048 2	0.110 2
2	0.500 00	0.200 0	0.445 3	0.122 7	0.252 9	0.305 9	0.069 7	0.060 3	0.137 7
1 ½	0.666 67	0.266 7	0.593 8	0.163 5	0.337 2	0.407 8	0.093 0	0.080 4	0.183 6
1 ¼	0.800 00	0.320 0	0.712 5	0.196 3	0.404 7	0.489 4	0.111 6	0.096 4	0.220 4
1	1.000 00	0.400 0	0.890 6	0.245 3	0.505 9	0.611 7	0.139 5	0.120 6	0.275 4

B S Insulator Thread

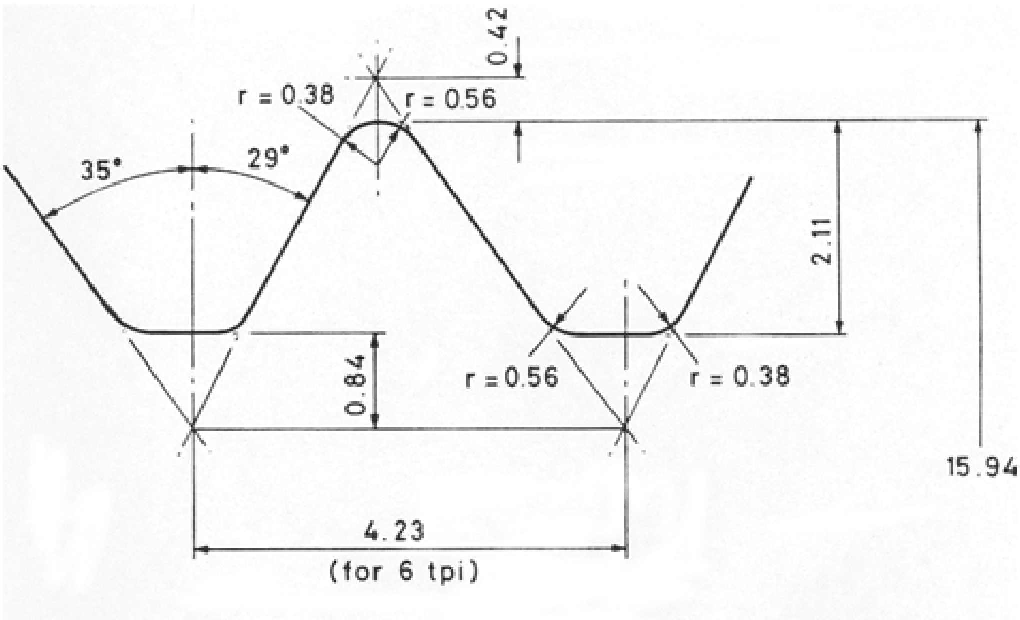


Fig. 47 Basic form of insulator thread (dimensions in mm)

Table 1: Numerical data for B S Insulator Threads

Nominal Size	Basic Major Diameter D	Basic Minor Diameter K	T.P.I. = 1/p	h
	in	in	in	in
1/2	0.502 5	0.374 1	7	0.064 2
5/8	0.627 5	0.461 1	7	0.083 2

B S Pipe Thread (taper)

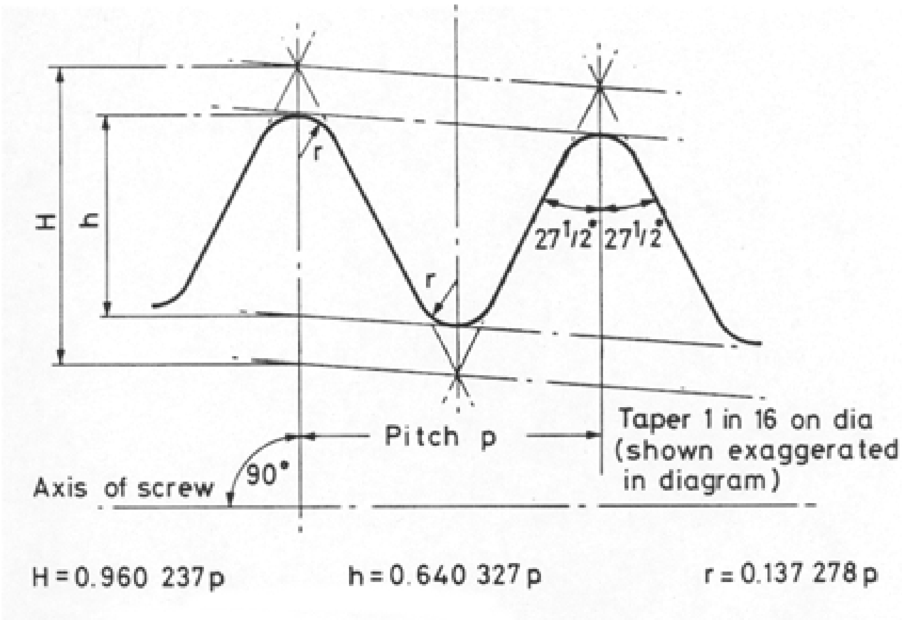


Fig. 48 Basic form of pipe thread (taper)

The table below gives numerical data for B S taper Pipe Threads.

Table 16: Numerical data for taper pipe threads

Threads per inch	Pitch p	H	h	r
	in	in	in	in
28	0.035 71	0.034 3	0.022 9	0.004 9
19	0.052 63	0.050 5	0.033 7	0.007 2
14	0.071 43	0.068 6	0.045 7	0.009 8
11	0.090 91	0.087 3	0.058 2	0.012 5

See BS 21 : 1985 Specifications for pipe threads for tubes and fittings where pressure-tight joints are made on the threads (metric dimensions)

Note: The basic form of the BS PARALLEL Pipe Thread is the Whitworth form.

B.S. Gas Cylinder Thread (Taper)

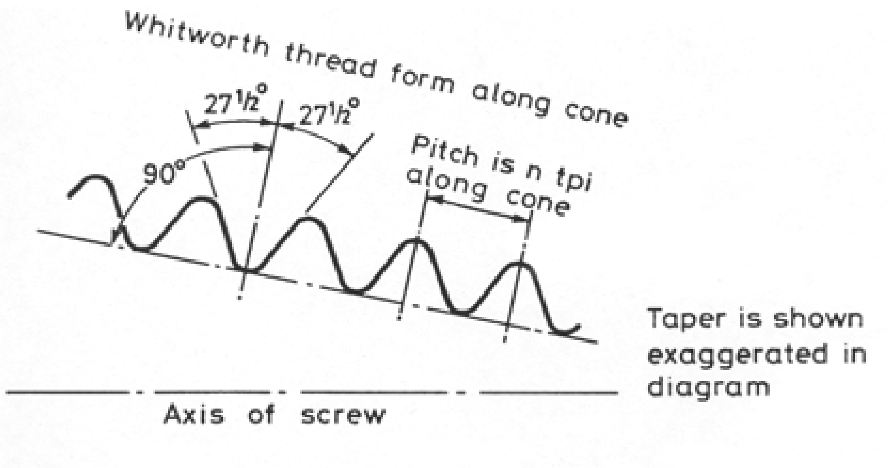


Fig. 49 Basic form of gas cylinder thread (Whitworth form). See BS 341: "Valve fittings for compressed gas cylinders"; for diameters, pitches tapers and gauge designs.

ROUND THREADS FOR FIRE HOSE COUPLINGS

and

UNDERGROUND FIRE HYDRANTS

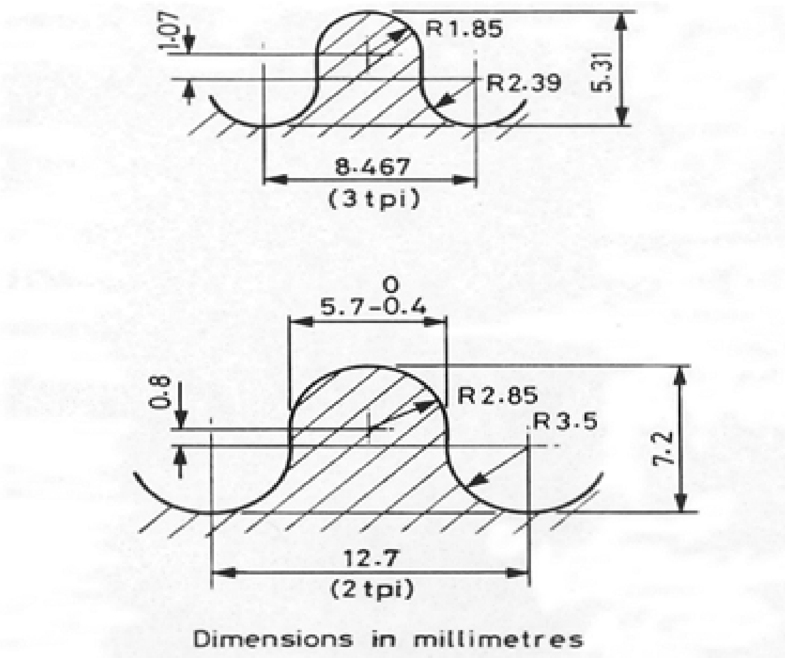


Fig.50 Basic forms of thread for fire hose couplings: see BS 336. For underground fire hydrants, see BS750.

For more details see BS 336: Fire hose couplings an ancillary equipment and BS 750: Underground fire hydrants. Specification for underground fire hydrants and surface frames and covers

APPENDIX 3

EQUIVALENT OF NOMINAL PITCHES OF ISO METRIC AND BA SCREWS IN INCHES; UNIFIED AND WHITWORTH SCREWS IN MILLIMETRES

During the transition from inch measure and traditional screw thread forms to metric measure and a single screw thread form, pitch measuring machines with micrometer screws in inch or alternatively metric, pitch may be used. Equivalent data in inch and metric units is listed in the following tables over the range of 1 to 20 pitches or a length not exceeding 50 mm [2 inches].

Table 17: ISO metric screws. Equivalent pitches in inches

Number of pitches	**Nominal pitch p in mm**												**Number of pitches**
	0.2	**0.25**	**0.3**	**0.35**	**0.4**	**0.45**	**0.5**	**0.6**	**0.7**	**0.75**	**0.8**	**1.0**	
1	0.00787	0.00984	0.01181	0.01378	0.01575	0.01772	0.01969	0.02362	0.02756	0.02953	0.03150	0.03937	1
2	0.01575	0.01969	0.02362	0.02756	0.03150	0.03543	0.03937	0.04724	0.05512	0.05906	0.06299	0.07874	2
3	0.02362	0.02953	0.03543	0.04134	0.04724	0.05315	0.05906	0.07087	0.08268	0.08858	0.09449	0.11811	3
4	0.03150	0.03937	0.04724	0.05512	0.06299	0.07087	0.07874	0.09449	0.11024	0.11811	0.12598	0.15748	4
5	0.03937	0.04921	0.05906	0.06890	0.07874	0.08858	0.09843	0.011811	0.13780	0.14764	0.15748	0.19685	5
6	0.04724	0.05906	0.07087	0.08268	0.09449	0.10630	0.11811	0.14173	0.16535	0.17717	0.18898	0.23622	6
7	0.05512	0.06890	0.08268	0.09646	0.11024	0.12402	0.13780	0.16535	0.19291	0.20669	0.22047	0.27559	7
8	0.06299	0.07874	0.09449	0.11024	0.12598	0.14173	0.15748	0.18898	0.22047	0.23622	0.25197	0.31496	8
9	0.07087	0.08858	0.10630	0.12402	0.14173	0.15945	0.17717	0.21260	0.24803	0.26575	0.28346	0.35433	9
10	0.07874	0.09843	0.11811	0.13780	0.15748	0.17717	0.19685	0.23622	0.27559	0.29528	0.31496	0.39370	10
11	0.08661	0.10827	0.12992	0.15157	0.17323	0.19488	0.21654	0.25984	0.30315	0.32480	0.34646	0.43307	11
12	0.09449	0.11811	0.14173	0.16535	0.18898	0.21260	0.23622	0.28346	0.33071	0.35433	0.37795	0.47244	12
13	0.10236	0.12795	0.15354	0.17913	0.20472	0.23031	0.25591	0.30709	0.35827	0.38386	0.40945	0.51181	13
14	0.11024	0.13780	0.16535	0.19291	0.22047	0.24803	0.27559	0.33071	0.38583	0.41339	0.44094	0.55118	14
15	0.11811	0.14764	0.17717	0.20669	0.23622	0.26575	0.29528	0.35433	0.41339	0.44291	0.47244	0.59055	15
16	0.12598	0.15748	0.18898	0.22047	0.25197	0.28346	0.31496	0.37795	0.44094	0.47244	0.50394	0.62992	16
17	0.13386	0.16732	0.20079	0.23425	0.26772	0.30118	0.33465	0.40157	0.46850	0.50197	0.53543	0.66929	17
18	0.14173	0.17717	0.21260	0.24803	0.28346	0.31890	0.35433	0.42520	0.49606	0.53150	0.56693	0.70866	18
19	0.14961	0.18701	0.22441	0.26181	0.29921	0.33661	0.37402	0.44882	0.52362	0.56102	0.59843	0.74803	19
20	0.15748	0.19685	0.23622	0.27559	0.31496	0.35433	0.39370	0.47244	0.55118	0.59055	0.62992	0.78740	20

Table 17: ISO metric screws. Equivalent pitches in inches (continued)

Number of pitches	**Nominal pitch p in mm**													**Number of pitches**
	1.25	**1.5**	**1.75**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**	**8**	
1	0.04921	0.05906	0.06890	0.07874	0.09843	0.11811	0.13780	0.15748	0.17717	0.19685	0.21654	0.23622	0.31496	1
2	0.09843	0.11811	0.13780	0.15748	0.19685	0.23622	0.27559	0.31496	0.35433	0.39370	0.43307	0.47244	0.62992	2
3	0.14764	0.17717	0.20669	0.23622	0.29528	0.35433	0.41339	0.47244	0.53150	0.59055	0.64961	0.70866	0.94488	3
4	0.19685	0.23622	0.27559	0.31496	0.39370	0.47244	0.55118	0.62992	0.70866	0.78740	0.86614	0.94488	1.25984	4
5	0.24606	0.29528	0.34449	0.39370	0.49213	0.59055	0.68898	0.78740	0.88583	0.98425	1.08268	1.18110	1.57480	5
6	0.29528	0.35433	0.41339	0.47244	0.59055	0.70866	0.82677	0.94488	1.06299	1.18110	1.29921	1.41732	1.88976	6
7	0.34449	0.41339	0.48228	0.55118	0.68898	0.82677	0.96457	1.10236	1.24016	1.37795	1.51575	1.65354		7
8	0.39370	0.47244	0.55118	0.62992	0.78740	0.94488	1.10236	1.25984	1.41732	1.57480	1.73228	1.88976		8
9	0.44291	0.53150	0.62008	0.70866	0.88583	1.06299	1.24016	1.41732	1.59449	1.77165	1.94882			9
10	0.49213	0.59055	0.68898	0.78740	0.98425	1.18110	1.37795	1.57480	1.77165	1.96850				10
11	0.54134	0.64961	0.75787	0.86614	1.08268	1.29921	1.51575	1.73228	1.94882					11
12	0.59055	0.70866	0.82677	0.94488	1.18110	1.41732	1.65354	1.88976						12
13	0.63976	0.76772	0.89567	1.02362	1.27953	1.53543	1.79134							13
14	0.68898	0.82677	0.96457	1.10236	1.37795	1.65354	1.92913							14
15	0.73819	0.88583	1.03346	1.18110	1.47638	1.77165								15
16	0.78740	0.94488	1.10236	1.25984	1.57480	1.88976								16
17	0.83661	1.00394	1.17126	1.33858	1.67323									17
18	0.88583	1.06299	1.24016	1.41732	1.77165									18
19	0.93504	1.12205	1.30906	1.49606	1.87008									19
20	0.98425	1.18110	1.37795	1.57480	1.96850									20

Table 18: BA Screws. Equivalent pitches in inches

Number of pitches	BA No. and nominal pitch p in mm									Number of pitches
	OBA 1.0	1BA 0.9	2BA 0.81	3BA 0.73	4BA 0.66	5BA 0.59	6BA 0.53	7BA 0.48	8BA 0.43	
	Equivalent nominal pitch p in inches									
1	0.03937	0.03543	0.03189	0.02874	0.02598	0.02323	0.02087	0.01890	0.01693	1
2	0.07874	0.07087	0.06378	0.05748	0.05197	0.04646	0.04173	0.03780	0.03386	2
3	0.11811	0.10630	0.09567	0.08622	0.07795	0.06968	0.06260	0.05669	0.05079	3
4	0.15748	0.14173	0.12756	0.11496	0.10394	0.09291	0.08346	0.07559	0.06772	4
5	0.19685	0.17717	0.15945	0.14370	0.12992	0.11614	0.10433	0.09449	0.08465	5
6	0.23622	0.21260	0.19134	0.17244	0.15591	0.13937	0.12520	0.11339	0.10157	6
7	0.27559	0.24803	0.22323	0.20118	0.18189	0.16260	0.14606	0.13228	0.11850	7
8	0.31496	0.28346	0.25512	0.22992	0.20787	0.18583	0.16693	0.15118	0.13543	8
9	0.35433	0.31890	0.28701	0.25866	0.23386	0.20906	0.18780	0.17008	0.15236	9
10	0.39370	0.35433	0.31890	0.28740	0.25984	0.23228	0.20866	0.18898	0.16929	10
11	0.43307	0.38976	0.35079	0.31614	0.28583	0.25551	0.22953	0.20787	0.18622	11
12	0.47244	0.42520	0.38268	0.34488	0.31181	0.27874	0.25039	0.22677	0.20315	12
13	0.51181	0.46063	0.41457	0.37362	0.33780	0.30197	0.27126	0.24567	0.22008	13
14	0.55118	0.49606	0.44646	0.40236	0.36378	0.32520	0.29213	0.26457	0.23701	14
15	0.59055	0.53150	0.47835	0.43110	0.38976	0.34843	0.31299	0.28346	0.25394	15
16	0.62992	0.56693	0.51024	0.45984	0.41575	0.37165	0.33386	0.30236	0.27087	16
17	0.66929	0.60236	0.54213	0.48858	0.44173	0.39488	0.35472	0.32126	0.28780	17
18	0.70866	0.63780	0.57402	0.51732	0.46772	0.41811	0.37559	0.34016	0.30472	18
19	0.74803	0.67323	0.60591	0.54606	0.49370	0.44134	0.39646	0.35906	0.32165	19
20	0.78740	0.70866	0.63780	0.57480	0.51969	0.46457	0.41732	0.37795	0.33858	20

Table 19: Unified, whitworth and other screws in inch measures. Equivalent pitches in mm

Number of pitches	**Nominal pitch p expressed as threads per inch**													**Number of pitches**
	3	**3.25**	**3.5**	**4**	**4.5**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	
	Equivalent nominal pitch p in inches													
1	8.4667	7.8154	7.2571	6.3500	5.6444	5.0800	4.2333	3.6286	3.1750	2.8222	2.5400	2.3091	2.1167	1
2	16.9333	15.6308	14.5143	12.7000	11.2889	10.1600	8.4667	7.2571	6.3500	5.6444	5.0800	4.6182	4.2333	2
3	25.4000	23.4462	21.7714	19.0500	16.9333	15.2400	12.7000	10.8857	9.5250	8.4667	7.6200	6.9273	6.3500	3
4	33.8667	31.2615	29.0286	25.4000	22.5778	20.3200	16.9333	14.5143	12.7000	11.2889	10.1600	9.2364	8.4667	4
5	42.3333	39.0769	36.2857	31.7500	28.2222	25.4000	21.1667	18.1429	15.8750	14.1111	12.7000	11.5455	10.5833	5
6		46.8923	43.5429	38.1000	33.8667	30.4800	25.4000	21.7714	19.0500	16.9333	15.2400	13.8545	12.7000	6
7				44.4500	39.5111	35.5600	29.6333	25.4000	22.2250	19.7556	17.7800	16.1636	14.8167	7
8					45.1556	40.6400	33.8667	29.0286	25.4000	22.5778	20.3200	18.4727	16.9333	8
9						45.7200	38.1000	32.6571	28.5750	25.4000	22.8600	20.7818	19.0500	9
10							42.3333	36.2857	31.7500	28.2222	25.4000	23.0909	21.1667	10
11							45.5667	39.9143	34.9250	31.0444	27.9400	25.4000	23.2833	11
12								43.5429	38.1000	33.8667	30.4800	27.7091	25.4000	12
13								47.1714	41.2750	36.6889	33.0200	30.0182	27.5167	13
14									44.4500	39.5111	35.5600	32.3273	29.6333	14
15									47.6250	42.3333	38.1000	34.6364	31.7500	15
16										45.1556	40.6400	36.9455	33.8667	16
17										47.9778	43.1800	39.2545	35.9833	17
18											45.7200	41.5636	38.1000	18
19											48.2600	43.8727	40.2167	19
20												46.1818	42.3333	20

Table 19: Unified, whitworth and other screws in inch measures. Equivalent pitches in mm (continued)

Number of pitches	Nominal pitch p expressed as threads per inch													Number of pitches
	13	14	16	18	19	20	22	24	26	28	32	36	40	
	Equivalent nominal pitch p in mm													
1	1.9538	1.8143	1.5875	1.4111	1.3368	1.2700	1.1545	1.0583	0.9769	0.9071	0.7938	0.7056	0.6350	1
2	3.9077	3.6286	3.1750	2.8222	2.6737	2.5400	2.3091	2.1167	1.9538	1.8143	1.5875	1.4111	1.2700	2
3	5.8615	5.4429	4.7625	4.2333	4.0105	3.8100	3.4636	3.1750	2.9308	2.7214	2.3812	2.1167	1.9050	3
4	7.8154	7.2571	6.3500	5.6444	5.3474	5.0800	4.6182	4.2333	3.9077	3.6286	3.1750	2.8222	2.5400	4
5	9.7692	9.0714	7.9375	7.0556	6.6842	6.3500	5.7727	5.2917	4.8846	4.5357	3.9688	3.5278	3.1750	5
6	11.7231	10.8857	9.5250	8.4667	8.0211	7.6200	6.9273	6.3500	5.8615	5.4429	4.7625	4.2333	3.8100	6
7	13.6769	12.7000	11.1125	9.8778	9.3579	8.8900	8.0818	7.4083	6.8385	6.3500	5.5562	4.9389	4.4450	7
8	15.6308	14.5143	12.7000	11.2889	10.6947	10.1600	9.2364	8.4667	7.8154	7.2571	6.3500	5.6444	5.0800	8
9	17.5846	16.3286	14.2875	12.7000	12.0316	11.4300	10.3909	9.5250	8.7923	8.1643	7.1438	6.3500	5.7150	9
10	19.5385	18.1429	15.8750	14.1111	13.3684	12.7000	11.5454	10.5833	9.7692	9.0714	7.9375	7.0556	6.3500	10
11	21.4923	19.9571	17.4625	15.5222	14.7053	13.9700	12.7000	11.6417	10.7462	9.9786	8.7312	7.7611	6.9850	11
12	23.4462	21.7714	19.0500	16.9333	16.0421	15.2400	13.8545	12.7000	11.7231	10.8857	9.5250	8.4667	7.6200	12
13	25.4000	23.5857	20.6375	18.3444	17.3789	16.5100	15.0091	13.7583	12.7000	11.7929	10.3188	9.1722	8.2550	13
14	27.3538	25.4000	22.2250	19.7556	18.7158	17.7800	16.1636	14.8167	13.6769	12.7000	11.1125	9.8778	8.8900	14
15	29.3077	27.2143	23.8125	21.1667	20.0526	19.0500	17.3182	15.8750	14.6538	13.6071	11.9062	10.5833	9.5250	15
16	31.2615	29.0286	25.4000	22.5778	21.3895	20.3200	18.4727	16.9333	15.6308	14.5143	12.7000	11.2889	10.1600	16
17	33.2154	30.8429	26.9875	23.9889	22.7263	21.5900	19.6273	17.9917	16.6077	15.4214	13.4938	11.9944	10.7950	17
18	35.1692	32.6571	28.5750	25.4000	24.0632	22.8600	20.7818	19.0500	17.5846	16.3286	14.2875	12.7000	11.4300	18
19	37.1231	34.4714	30.1625	26.8111	25.4000	24.1300	21.9364	20.1083	18.5615	17.2357	15.0812	13.4056	12.0650	19
20	39.0769	36.2857	31.7500	28.2222	26.7368	25.4000	23.0909	21.1667	19.5385	18.1429	15.8750	14.1111	12.7000	20

APPENDIX 4

VIRTUAL DIFFERENCES IN PITCH DIAMETER CORRESPONDING TO MEASURED ERRORS IN PITCH

The subject is explained in Section 3.3 of Part 1. The virtual difference is to be taken as + for diameter of external threads and - for diameter of internal threads, i.e. virtually an addition of metal in both cases.

Table 20: 0.001 to 0.010 mm pitch errors

Error in pitch	**Corresponding virtual difference in pitch diameter**			
	ISO metric & Unified	**Whitworth**	**BA**	**Acme**
mm	**mm**	**mm**	**mm**	**mm**
0.001	0.0017	0.0019	0.0023	0.0039
0.002	0.0035	0.0038	0.0045	0.0077
0.003	0.0052	0.0058	0.0068	0.0116
0.004	0.0069	0.0077	0.0091	0.0155
0.005	0.0087	0.0096	0.0114	0.0193
0.006	0.0104	0.0115	0.0136	0.0232
0.007	0.0121	0.0134	0.0159	0.0271
0.008	0.0139	0.0154	0.0182	0.0309
0.009	0.0156	0.0173	0.0205	0.0348
0.010	0.0173	0.0192	0.0227	0.0387

Table 21: 0.000 to 05 inch to 0.0005 inch pitch errors

Error in pitch	**Corresponding virtual difference in pitch diameter**			
	ISO metric & Unified	**Whitworth**	**BA**	**Acme**
inch	**inch**	**inch**	**inch**	**inch**
0.000 05	0.000 09	0.000 10	0.000 11	0.000 19
0.000 1	0.000 17	0.000 19	0.000 23	0.000 39
0.000 15	0.000 26	0.000 29	0.000 34	0.000 58
0.000 2	0.000 35	0.000 38	0.000 45	0.000 77
0.000 25	0.000 43	0.000 48	0.000 57	0.000 97
0.000 3	0.000 52	0.000 58	0.000 68	0.001 16
0.000 35	0.000 61	0.000 67	0.000 80	0.001 35
0.000 4	0.000 69	0.000 77	0.000 91	0.001 55
0.000 45	0.000 78	0.000 86	0.001 02	0.001 74
0.000 5	0.000 87	0.000 96	0.001 14	0.001 93

Note: Although the Tables enable the virtual difference in pitch diameter to be read for pitch errors of up to 0.010 mm and 0.0005 inch, pitch errors should be restricted as much as possible in manufacture.

APPENDIX 5

VIRTUAL DIFFERENCES IN PITCH DIAMETER CORRESPONDING TO MEASURED ERRORS IN FLANK ANGLES

The subject is explained in section 3.4 of Part 1. The tables which follow give the virtual difference in pitch diameter for the arithmetical sum of the errors in flank angles. The method using the table is given in a footnote in each case.

Table 22: ISO metric thread. Nominal flank angle Virtual difference in pitch diameter corresponding to sum of errors of flank angles

Virtual difference in pitch diameter mm	**Total error of flank angle in degrees**																									**Virtual difference in pitch diameter**
0.001	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.04	0.05	0.06	0.07	0.09	0.11	0.12	0.12	0.14	0.17	0.19	0.22	0.24	0.29	0.35	0.43	0.001
0.002	0.02	0.03	0.03	0.03	0.04	0.04	0.05	0.06	0.07	0.09	0.10	0.12	0.14	0.17	0.22	0.23	0.25	0.3	0.3	0.4	0.4	0.5	0.6	0.7	0.9	0.002
0.003	0.03	0.04	0.05	0.05	0.06	0.07	0.07	0.09	0.10	0.13	0.15	0.17	0.21	0.3	0.3	0.3	0.4	0.4	0.5	0.6	0.7	0.7	0.9	1.0	1.3	0.003
0.004	0.04	0.06	0.06	0.07	0.08	0.09	0.10	0.12	0.14	0.17	0.20	0.23	0.27	0.3	0.4	0.5	0.5	0.6	0.7	0.8	0.9	1.0	1.2	1.4	1.7	0.004
0.005	0.05	0.07	0.08	0.09	0.10	0.10	0.12	0.14	0.17	0.22	0.25	0.29	0.35	0.4	0.5	0.6	0.6	0.7	0.9	1.0	1.0	1.2	1.4	1.7	2.2	0.005
0.006	0.07	0.09	0.09	0.10	0.12	0.13	0.15	0.17	0.21	0.3	0.3	0.35	0.42	0.5	0.7	0.7	0.7	0.9	1.0	1.2	1.3	1.5	1.7	2.1	2.6	0.006
0.007	0.08	0.10	0.11	0.12	0.14	0.15	0.17	0.20	0.24	0.3	0.3	0.41	0.49	0.6	0.8	0.8	0.9	1.0	1.2	1.4	1.5	1.7	2.0	2.4	3.0	0.007
0.008	0.09	0.12	0.13	0.14	0.15	0.17	0.20	0.23	0.28	0.3	0.4	0.46	0.56	0.7	0.9	0.9	1.0	1.2	1.4	1.5	1.7	2.0	2.3	2.8	3.5	0.008
0.009	0.10	0.13	0.14	0.16	0.17	0.20	0.22	0.26	0.31	0.4	0.4	0.52	0.63	0.8	1.0	1.0	1.1	1.3	1.6	1.7	2.0	2.2	2.6	3.1	3.9	0.009
0.010	0.10	0.14	0.16	0.17	0.19	0.22	0.24	0.28	0.35	0.4	0.5	0.58	0.69	0.9	1.1	1.2	1.2	1.4	1.7	1.9	2.2	2.5	2.9	3.5	4.3	0.010
Nominal pitch in mm	8	6	5.5	5	4.5	4	3.5	3	2.5	2	1.75	1.5	1.25	1	0.8	0.75	0.7	0.6	0.5	0.45	0.4	0.35	0.3	0.25	0.2	**Nominal pitch in mm**

Notes:

(1) The angles of the opposite flanks should be measured each with respect to the axis of the screw or to the major diameter. The errors of the flank angles should then be calculated and these errors added together irrespective of sign. The corresponding virtual difference in pitch diameter can then be obtained form the table above. The + sign is to be applied in the case of screw plus and the – sign in the case of screw rings.

Example: Screw 0.75 mm pitch. Flank angles measure 29.8° and 30.3°. Combined error in angle is 0.2° + 0.3°, ie. 0.5°. The corresponding virtual difference in pitch diameter is found from the table to be + 0.0004 mm for a screw plug and – 0.0004 mm for the screw ring.

(2) The tabulated total error of flank angles is expressed to 0.1° in general and to 0.01° in places for illustration.

(3) The tabulation enables the virtual difference in pitch diameter to be read up to 0.010 mm [0.0004 inch]: nevertheless every effort should be made in manufacture to generate correct flank angles.

Table 23: Unified thread. Nominal Flank Angles 30.0. Virtual difference in pitch diameter corresponding to sum of errors of flank angles

Corresponding virtual difference in pitch diameter	**Total error of flank angles in degrees**																			**Corresponding virtual difference in pitch diameter**
inch																				**inch**
0.00005	0.02	0.02	0.02	0.03	0.03	0.04	0.04	0.05	0.05	0.05	0.06	0.07	0.08	0.09	0.11	0.13	0.15	0.17	0.18	0.00005
0.0001	0.04	0.04	0.05	0.06	0.06	0.07	0.08	0.09	0.10	0.11	0.13	0.15	0.2	0.2	0.2	0.3	0.3	0.3	0.4	0.0001
0.00015	0.06	0.06	0.07	0.08	0.10	0.11	0.12	0.14	0.15	0.16	0.3	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.6	0.00015
0.0002 (0.005 mm)	0.07	0.08	0.09	0.11	0.13	0.15	0.17	0.2	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.5	0.6	0.7	0.7	0.0002 (0.005 mm)
0.00025	0.09	0.10	0.11	0.14	0.16	0.18	0.21	0.2	0.3	0.3	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.8	0.9	0.00025
0.0003	0.11	0.12	0.14	0.17	0.19	0.22	0.25	0.3	0.3	0.3	0.4	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	0.0003
0.00035	0.13	0.14	0.16	0.19	0.22	0.26	0.29	0.3	0.4	0.4	0.4	0.5	0.6	0.6	0.8	0.9	1.0	1.2	1.3	0.00035
0.0004 (0.010 mm)	0.14	0.17	0.19	0.22	0.26	0.29	0.33	0.4	0.4	0.4	0.5	0.6	0.7	0.7	0.9	1.0	1.2	1.3	1.5	0.0004 (0.010 mm)
Threads per inch	4	4 ½	5	6	7	8	9	10	11	12	14	16	18	20	24	28	32	36	40	**Threads per inch**

Notes:

(1) The angles of the opposite flanks should be measured each with respect to the axis of the screw or to the major diameter. The errors of the flank angles should then be calculated and these errors added together irrespective of sign. The corresponding virtual difference in pitch diameter can then be obtained from the table above. The + sign is to be applied in the case of screw plugs and the – sign in the case of screw rings.

Example: Screw 10 threads per inch. Flank angles measure 29.9° and 30.3°. Combined error in angle is 0.1° + 0.3°, ie. 0.4°. The corresponding virtual difference in pitch diameter is found from the table to be + 0.0004 in for a plug and – 0.0004 in for a ring.

(2) The tabulated total error of flank angles is expressed to 0.1° in general and to 0.01 at places for illustration.

(3) The tabulation enables the virtual difference in pitch diameter to be read up to 0.0004 inch [0.01 mm]: nevertheless every effort should be made in manufacture to generate correct flank angles.

Table 24: Unified thread. Nominal Flank Angles 27.5°. Virtual difference in pitch diameter corresponding to sum of errors of flank angles

Virtual difference in pitch diameter	**Total error of flank angles in degrees**																							**Virtual difference in pitch diameter**
inch																								**inch**
0.00005	0.02	0.02	0.02	0.03	0.03	0.04	0.04	0.05	0.05	0.06	0.07	0.08	0.09	0.09	0.10	0.10	0.11	0.12	0.13	0.14	0.15	0.17	0.19	0.00005
0.0001	0.04	0.04	0.04	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.4	0.0001
0.00015	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.5	0.5	0.6	0.00015
0.0002	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.4	0.5	0.5	0.5	0.6	0.6	0.7	0.8	0.0002
(0.005 mm)																								(0.005 mm)
0.00025	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.5	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.9	1.0	0.00025
0.0003	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.4	0.5	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.9	0.9	1.0	1.1	0.0003
0.00035	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.5	0.6	0.6	0.6	0.7	0.7	0.8	0.8	0.9	1.0	1.1	1.2	1.3	0.00035
0.0004	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.5	0.5	0.6	0.7	0.7	0.8	0.8	0.9	1.0	1.1	1.1	1.2	1.4	1.5	0.0004
(0.010 mm)																								(0.010 mm)
Threads per inch	4	4 ½	5	6	7	8	9	10	11	12	14	16	18	19	20	22	24	26	28	30	32	36	40	**Threads per inch**

Notes:

(1) The angles of the opposite flanks should be measured each with respect to the axis of the screw or to the major diameter. The errors of the flank angles should then be calculated and these errors added together irrespective of sign. The corresponding virtual difference in pitch diameter can then be obtained from the table above. The + sign is to be applied in the case of screw plugs and the – sign in the case of screw rings.

Example: Screw 10 threads per inch. Flank angles measure 27.4° and 37.8°. Combined error in angle is 0.10 + 0.30, ie 0.4. The corresponding virtual difference in pitch diameter is found from the table to be + 0.0004 inch for a screw plug and – 0.0004 inch for a screw ring.

(2) The tabulated total error of flank angles is expressed to 0.1° in general and to 0.01° at places for illustration.

(3) The tabulation enables the virtual difference in pitch diameter to be read up to 0.0004 inch [0.01 mm]: nevertheless every effort should be made in manufacture to generate correct flank angles.

Table 25: Unified thread. Nominal Flank Angles 23.75°. Virtual difference in pitch diameter corresponding to sum of errors of flank angles

Virtual difference in pitch diameter	**Total error of flank angles in degrees**																**Virtual difference in pitch diameter**
mm																	**mm**
0.001	0.11	0.12	0.14	0.15	0.17	0.19	0.21	0.23	0.26	0.28	0.31	0.35	0.39	0.44	0.48	0.52	0.001
0.002	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.5	0.5	0.6	0.6	0.7	0.8	0.9	1.0	1.0	0.002
0.003	0.3	0.4	0.4	0.5	0.5	0.6	0.6	0.7	0.8	0.8	0.9	1.1	1.2	1.3	1.4	1.6	0.003
0.004	0.4	0.5	0.5	0.6	0.7	0.7	0.8	0.9	1.0	1.1	1.3	1.4	1.6	1.8	1.9	2.1	0.004
0.005 (0.0002 in)	0.6	0.6	0.7	0.8	0.8	0.9	1.0	1.1	1.3	1.4	1.6	1.8	2.0	2.2	2.4	2.6	0.005 (0.0002 in)
0.006	0.7	0.7	0.8	0.9	1.0	1.2	1.2	1.4	1.5	1.7	1.9	2.1	2.4	2.6	2.9	3.1	0.006
0.007	0.8	0.8	1.0	1.1	1.2	1.3	1.5	1.6	1.8	2.0	2.2	2.5	2.7	3.1	3.3	3.7	0.007
0.008	0.9	1.0	1.1	1.2	1.3	1.5	1.7	1.8	2.0	2.3	2.5	2.8	3.1	3.5	3.8	4.2	0.008
0.009	1.0	1.1	1.2	1.4	1.5	1.7	1.9	2.1	2.3	2.5	2.8	3.2	3.5	4.0	4.3	4.7	0.009
0.010 (0.0004 in)	1.1	1.2	1.4	1.5	1.7	1.9	2.1	2.3	2.6	2.8	3.1	3.5	3.9	4.4	4.8	5.2	0.010 (0.0004 in)
Threads per inch	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	**Threads per inch**

Notes:

(1) The angles of the opposite flanks should be measured each with respect to the axis of the screw or to the major diameter. The errors of the flank angles should then be calculated and these errors added together irrespective of sign. The corresponding virtual difference in pitch diameter can then be obtained from the table above. The + sign is to be applied in the case of screw plugs and the – sign in the case of screw rings.

Example: Screw No.3BA. Flank angles measure 23.35° and 25.05°. Combined error in angle is 0.4° + 0.3°, ie. 0.7°. The corresponding virtual difference in pitch diameter is found from the table to be + 0.0045 mm for a plug and – 0.0045 mm for a ring.

(2) The tabulated total error of flank angles is expressed to 0.1° in general and to 0.01° at places for illustration.

(3) The tabulation enables the virtual difference in pitch diameter to be read up to 0.01 mm [0.00004 inch]: nevertheless every effort should be made in manufacture to generate correct flank angles.

Table 26: Unified thread. Nominal Flank Angles 14.5° Virtual difference in pitch diameter corresponding to sum of errors of flank angles

Virtual difference in pitch diameter	**Total error of flank angles in degrees**										**Virtual difference in pitch diameter**
inch											**inch**
0.00005	0.01	0.01	0.01	0.01	0.02	0.02	0.03	0.03	0.04	0.04	0.00005
0.0001	0.01	0.02	0.02	0.03	0.03	0.04	0.06	0.07	0.08	0.09	0.0001
0.00015	0.02	0.03	0.03	0.04	0.05	0.07	0.08	0.10	0.12	0.13	0.00015
0.0002 (0.0 5 mm)	0.02	0.03	0.04	0.06	0.07	0.09	0.11	0.13	0.16	0.18	0.0002 (0.0 5 mm)
0.00025	0.03	0.04	0.06	0.07	0.08	0.11	0.14	0.17	0.19	0.22	0.00025
0.0003	0.03	0.05	0.07	0.08	0.10	0.13	0.17	0.20	0.23	0.27	0.0003
0.00035	0.04	0.06	0.08	0.10	0.12	0.16	0.20	0.23	0.27	0.31	0.00035
0.0004 (0.010 mm)	0.04	0.07	0.09	0.11	0.13	0.18	0.22	0.27	0.31	0.35	0.0004 (0.010 mm)
Threads per inch	2	3	4	5	6	8	10	12	14	16	**Threads per inch**

Notes:

(1) The angles of the opposite flanks should be measured each with respect to the axis of the screw or to the major diameter. The errors of the flank angles should then be calculated and these errors added together <u>irrespective of sign</u>. The corresponding virtual difference in pitch diameter can then be obtained from the table above. The + sign is to be applied in the case of screw plugs and the – sign in the case of screw rings.

Example: Screw 14 threads per inch. Flank angles measure 14.4° and 14.7°. Combined error in angle is 0.1° + 0.2°, ie. 0.3°. The corresponding virtual difference in pitch diameter is found from the table to be + 0.0004 in for a plug and – 0.0004 in for a screw ring.

(2) The tabulated total error of flank angles is expressed to 0.01° to match the sensitivity of the virtual pitch diameter of the Acme thread to angle error.

(3) The tabulation enables the virtual difference in pitch diameter to be read up to 0.0004 inch (0.01 mm): nevertheless every effort should be made in manufacture to generate correct flank angles.

APPENDIX 6

CYLINDERS FOR MEASUREMENT OF PITCH DIAMETER

"Best size" for common symmetrical thread forms.

A description is given in Section 7.2 of the measurement of pitch diameter of plug screw gauges by engaging a micrometer calliper over small cylinders placed between the flanks. Ideally the cylinders should be of selected diameter to ensure contact at the pitch line so that the result is not influenced by deviation of the included thread angle from nominal, see Section 8.5 for detailed description. The formulae for the "best sizes" of thread measuring cylinders are listed in Table 27; the example of "best sizes" for ISO metric threads is given in Table 28.

Table 27: Pitch line contact of thread measuring cylinders

Form of thread	Diameter of "best size" cylinder
ISO metric) Unified)	0.57735 p
Whitworth	0.56369 p
BA	0.5462 p
Acme	0.51645 p

Table 28: "Best size" diameters of cylinders for ISO metric threads

Pitch of ISO metric thread	Best size diameter of thread measuring cylinder	Pitch of ISO metric thread	Best size diameter of thread measuring cylinder
mm	**mm**	**mm**	**mm**
0.2	0.1155	1.25	0.7217
0.25	0.1443	1.5	0.8660
0.3	0.1732	1.75	1.0104
0.35	0.2021	2	1.1547
0.4	0.2309	2.5	1.4434
0.45	0.2598	3	1.7320
0.5	0.2887	3.5	2.0207
0.6	0.3464	4	2.3094
0.7	0.4041	4.5	2.5981
0.75	0.4330	5	2.8868
0.8	0.4619	5.5	3.1754
1	0.5774	6	3.4641
		8	4.6188

Thread measuring cylinders made to "best size" within close limits may be purchased for standard pitches of each of the common thread forms. However it is common practice to use cylinders designated for one pitch and thread form for nearby pitch line measurement on a different thread form. The inaccuracy likely to be introduced into pitch diameter measurement by this practice depends upon the error of included thread angle. Lists are given in BS5590 Screw thread metric series measuring cylinders of the versatility of cylinders for measuring threads other than the one designated, and the influence of angle errors is indicated. BS5590 specified limits of diameter and other accuracy requirements. In this connexion it should be mentioned that thread measuring cylinders have long been known as "wires". However there must be no misunderstanding for only if the cylinders are precisely circular in section, straight, well finished, wear resistant, and of the appropriate diameter can precise measurement of pitch diameter be ensured.

Notes

1) Early accounts of screw thread measurement will be found to refer to "best size" cylinders and this was largely in the context of predominating Whitworth threads, i.e. limits for cylinders for Whitworth threads were adjusted to permit the same cylinders to be used on other threads, contacting reasonably near the pitch line. In those times cylinders were lapped individually by hand. In more recent times improved methods have enabled production of thread measuring cylinders in batches very close to any desired nominal size, e.g. as derived from Table 20. Thus, over the years, "best size" has come to have different meanings in different circumstances. The references to "Best size" throughout these Notes on Screw Gauges are according to the usage in BS5590.

2) Deviation from nominal size of included angle and straightness of the flanks can be explored by using cylinders larger or smaller than best size. Care must be taken to ensure that such cylinders are in contact with the flanks and in the case of smaller cylinders they must project above the gauge crests. The relationship between apparent pitch diameters measured with oversize or undersize cylinders and deviation of angle is described in Section 8.6.

"Best size" for asymmetrical thread forms

It is impossible to select a diameter of cylinder which will ensure contact on opposite flanks at the pitch line of an asymmetrical thread form. There are options one of which should be agreed by the gauge manufacturer with the gauge purchaser.

Option 1 is to choose a diameter of cylinder which makes contact at the pitch line on one nominated flank.

Option 2 is to choose a diameter to make contact on one flank above the pitch line, and on the other flank, equally below the pitch line.

Option 3 is in a case like the buttress thread where asymmetry is such that the point of contact on one flank has significantly more influence on measured pitch diameter than the contact on the other flank, then the diameter of cylinder may be chosen so that the displacements of the contacts from the pitch line are in a particular ratio. Consider the buttress thread with its 7° and 45° flank angles; contact on the 45° flank is considered to be more influential on pitch diameter than on the almost upright 7° flank. The USA specification H.28 recommends that this be recognised by allowing a displacement of contact on the on the 7° flank from the pitch line of twice as much above the pitch line as the displacement below the pitch line on the 45° flank: accordingly best size is given by $W=0.54147p$. On the other hand BS1657 Buttress threads uses option 1, the nominated flank being the 7° one, and accordingly $W=0.43766p$.

Confusing as these options may appear, there are other considerations. In the case of buttress threads on flank is for driving, the other is trailing i.e. clearing; hence close fitting of diameters may not be required. Threads of sturdy proportions used for quick action, i.e. with coarse pitch, multi starts, small diameter, results in helix angles larger than 5°. The subject of cylinder contact with flanks of steep helices is an advanced field of thread measurement and calls for treatment beyond the scope of these Notes. Some guidance is given in Section 8.2 and Appendix 7 where the aspects of contact and corrections to pitch diameter measurement are outlined.

APPENDIX 7

RAKE CORRECTION *c* TO PITCH DIAMETER MEASUREMENT

The correction c to be applied to measurements of pitch diameter due to the lifting of thread measuring cylinders by the helical flanks of the thread is explained in Section 8.2 of PART II. The following tables give *c* for standard sizes of common threads i.e. of small helix angle. Ring screw gauges when measured with a spherical or quasi-spherical stylus are subject to very similar corrections and they too are listed.

Throughout this report distinction is made between screws with helix angles up to about 5° from those with increasingly steeper helix angles. The latter situation is mentioned after the tables.

Table 29: ISO metric threads

Normal Size			Plug	Ring
Dia mm		**Pitch mm**	**Unit 0.000 1 mm**	
1	x	0.25	8	*
2	x	0.4	8	*
4	x	0.7	11	*
6	x	1	14	16
7	x	1	10	11
8	x	1.25	16	17
9	x	1.25	12	13
10	x	1.5	17	19
11	x	1.5	14	15
12	x	1.75	19	21
14	x	2	21	23
16	x	2	16	17
18	x	2.5	24	27
20	x	2.5	20	21
22	x	2.5	16	17
24	x	3	23	25
27	x	3	18	20
30	x	3.5	24	25
33	x	3.5	19	21
36	x	4	24	26
39	x	4	21	22
42	x	4.5	25	27
45	x	4.5	22	23
48	x	5	27	28
52	x	5	23	24
56	x	5.5	26	27
60	x	5.5	22	24
64	x	6	26	27
68	x	6	22	24
72	x	6	20	21
76	x	6	18	19
80	x	6	16	17
85	x	6	14	15
90	x	6	13	13
95	x	6	11	12
100	x	6	10	10
105	x	6	9	9
110	x	6	8	9
115	x	6	8	8
129	x	6	7	7
125	x	6	6	7

Table 30: BA threads

Designating No.	Plug Unit 0.000 01 in
0	7
1	7
2	6
3	6
4	6
5	5
6	5
7	5
8	5
9	5
10	4
11	4
12	4
13	3
14	4
15	3
16	3
17	3
18	3
19	3
20	2
21	2
22	2
23	2
24	2
25	2

*** Small rings are not measured directly**

Rake Corrections c

Table 31: Unified, Whitworth, and Acme thread forms

Designated Nominal Size	UNC		UNF		BSW		BSF		BSP (parallel)		Acme	
	Plug	Ring	Plug	Ring	Plug	Ring	Plug	Ring	Plug	Ring	Plug	Ring
in	Unit 0.000 01 in											
1/8 *					6				2	2		
3/16 *					13			5				
7/32 *									5			
¼	11	12	4	4	12	13	5	6	3	3	48	52
9/32							4	4				
5/16	9	10	4	4	10	11	5	6			45	48
3/8	9	10	3	3	10	11	5	5	2	2	89	97
7/16	10	11	3	3	11	12	5	5			63	68
½	9	10	2	3	13	15	5	6	3	3	47	50
9/16	9	10	3	3	10	11	4	4	1	1		
5/8	10	11	2	2	11	12	5	5	2	2	59	62
11/16					9	10	4	4				
¾	9	10	2	2	10	11	6	6	2	2	98	106
7/8	9	10	2	2	10	11	5	6	1	1	70	74
1	10	11	3	3	11	12	5	6	2	2	53	55
1 1/8	12	12	2	2	13	14	6	6			148	158
1 ¼	9	10	2	2	10	11	5	5	1	1	117	124
1 3/8	12	13	2	1			6	6			95	101
1 ½	10	11	1	1	11	12	5	5	1	1	79	83
1 5/8							4	4				
1 ¾	13	14			14	15	5	5	1	1	57	59
2	14	14			15	16	4	4	1	1	43	44
2 ¼	11	11			17	18	5	5	1	1	82	85
2 ½	12	13			14	14	4	4	0	0	65	68
2 ¾	10	11			17	18	3	3	0	0	54	55
3	8	9			14	15	5	5	0	0	158	166
3 ¼	7	7			15	16	4	4				
3 ½	6	6			13	13	5	5	0	0		
3 ¾	5	5			14	15	4	4				
4	5	5			12	13	4	4	0	0	86	89
4 ¼							4	5				
4 ½					11	11					67	69
5					10	10			0	0	54	55
5 ½					10	10						
6					9	10						

*** Small rings are not measured directly**

<u>Rake Corrections c</u>

Table 32 standard and special Buttress screw plugs to BS 1657
Corrections for best size cylinders

Standard Buttress Thread										Special Buttress Thread							
Nominal Size	**3**	**4**	**6**	**8**	**10**	**12**	**16**	**20**	**tpi**	**3**	**4**	**6**	**8**	**10**	**12**	**16**	**20**
in	**Unit 0.000 01**																
1			18	7	4	2	1	0				14	6	3	2	1	0
1 1/8			14	6	3	2	1	0				11	4	2	1	0	0
1 ¼			11	5	2	1	0					9	4	2	1	0	
1 3/8			9	4	2	1	0					7	3	2	1		
1 ½			8	3	2	1						6	2	1	1		
1 ¾			6	2	1	1						4	2	1	0		
2			4	2	1	0						3	1	1	0		
2 ¼			3	1	1	0						3	1	0			
2 ½			3	1	1							2	1	0			
2 ¾			2	1	0							2	1				
3			2	1	0							1	1				
3 ½			1	0	0							1	0				
4			1	0								1	0				
4 ½		3	1	0	0	0	0				2	1	0	0	0	0	
5		2	1	0	0	0	0				2	0	0	0	0	0	
5 ½		2	0								1	0					
6		2	0								1						
7	3	1	0	0	0	0				2	1	0	0	0	0		
8	2	1	0	0	0	0				2	1	0	0	0	0		
9	2	1								1	0						
10	1	0								1	0						

Corrections for internal threads are within 0.000 01 in of the above figures.

Rake Correction c to Pitch Diameter Measurements of Non Standard Screw Threads

Section 8.2 describes formulae for calculating rake corrections. As helix angles become steeper it is possible for a thread measuring cylinder to contact a flank at two points and thereby to give an incorrect register for pitch diameter measurement: in such cases it is necessary to use spheres such as a precision steel balls instead of cylinders. The criteria for detecting double contact are developed in the Paper by R Marriner and Mrs Wood.

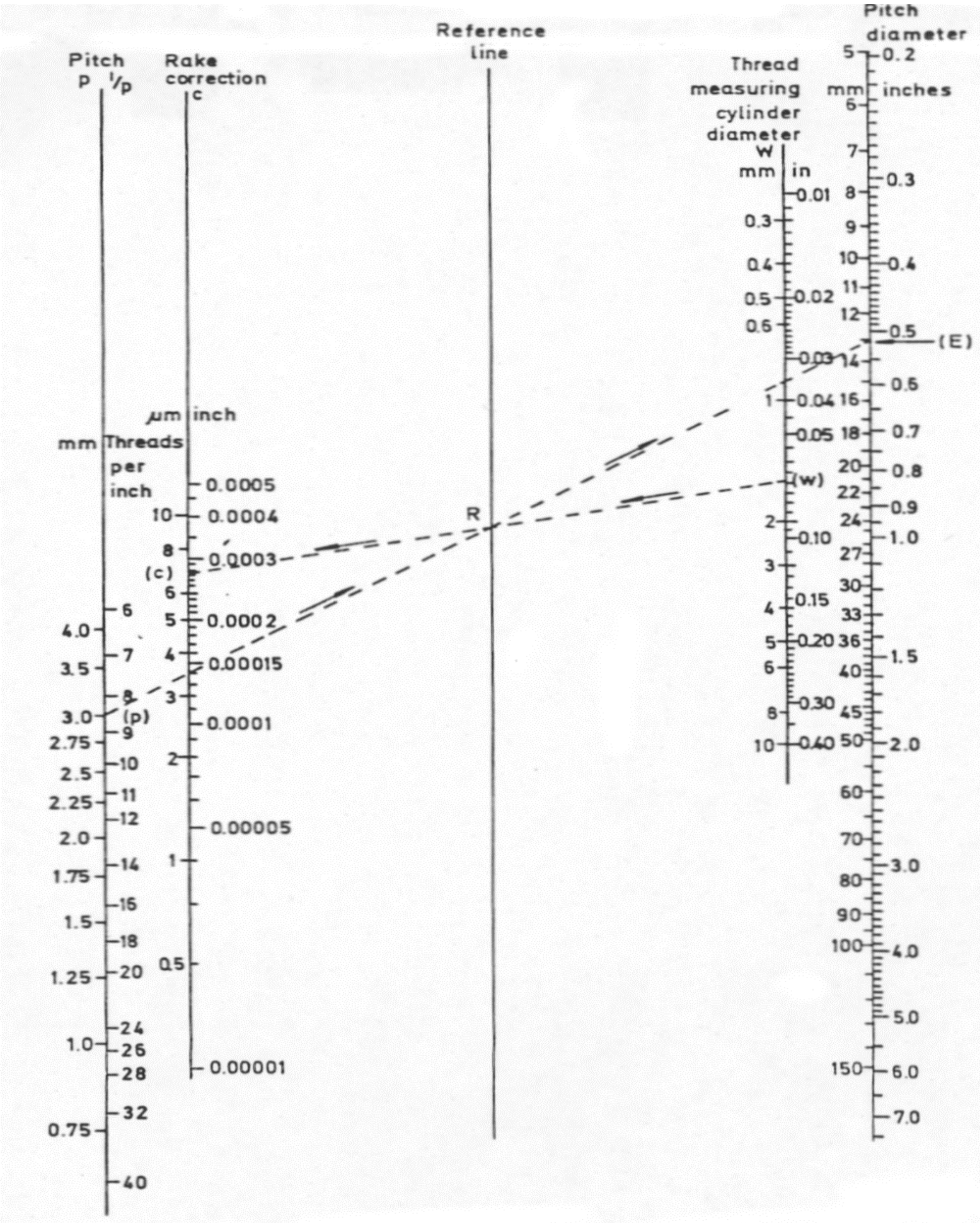


Fig. 51 Nomogram for determining rake correction for ISO metric and Unified threads of moderate rake angle.

Example Screw 15 mm x 3 mm pitch (dia. 13.951 mm).
Dia. Of cylinders 0.068 inches.

Join appropriate (P) on "Pitch" line to (E) on "Pitch Dia." line and obtain a point (P) on the "Reference Line". Required correction (0.000 27 inches) is found where line from point on "Cylinder Diameter" line passing through strikes "Rake Correction" line at (G).

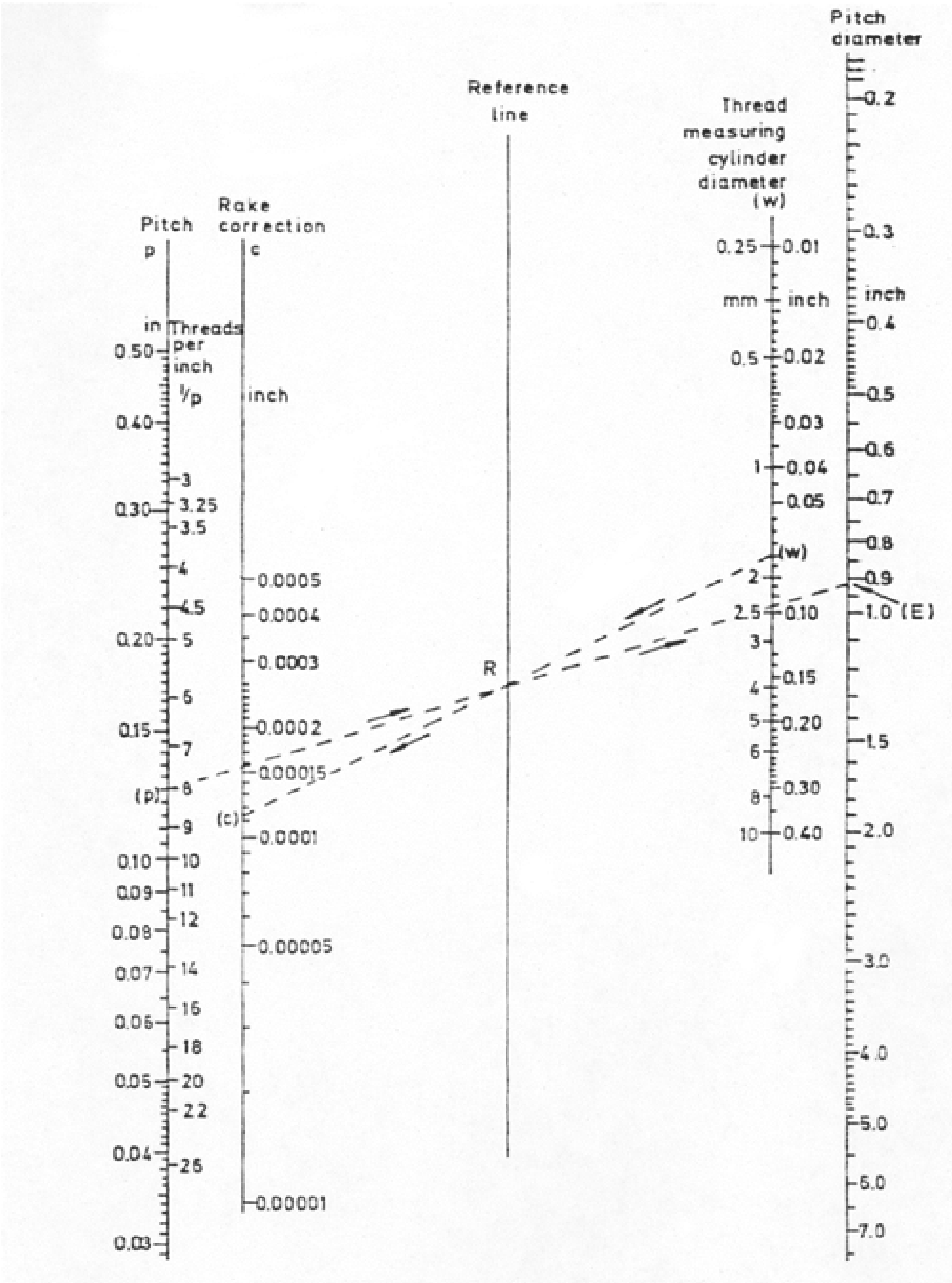


Fig. 52 Nomogram for determining rake correction for Whitworth threads of moderate angle.

Example Screw 1 inch x 8 T.P.I. (effective dia. 0.910 inches).
Dia. of cylinder, 0.070 inches.

Join appropriate point (P) on “Pitch” line to (E) on “Pitch Dia.” line and obtain a point (R) on the “Reference Line”. Required correction (0.000 11 inches) is found where line form point on “Cylinder Diameter” line passing through (R) strikes “Rake Correction” line at (W).

APPENDIX 8

COMPRESSION CORRECTION *e* TO PITCH DIAMETER MEASUREMENT

The correction *e* to be applied to measurements of pitch diameter due to differential compression of the measuring cylinders when across a plain cylindrical standard as compared with the wedging action of screw thread flanks is explained in Section 8.3 of PART II.

The following charts give *e* for common threads. Reference should be made to NPL for assistance with examples beyond the charts.

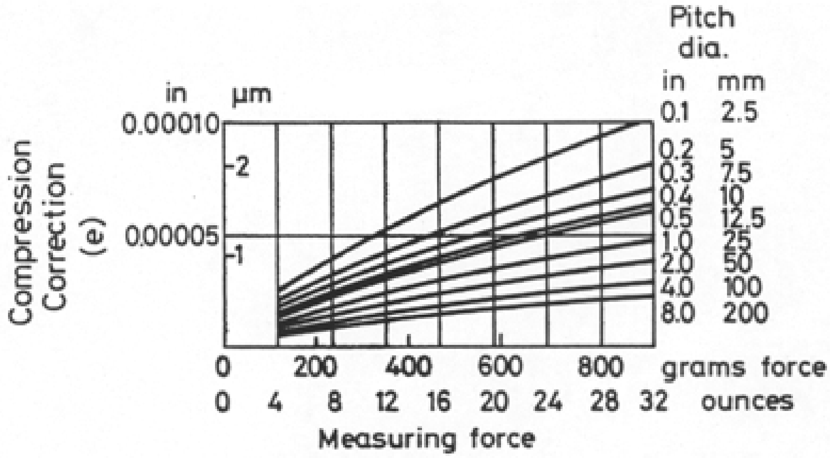


Fig 53 Compression corrections for various measuring forces on Unified, Metric, American National screws of moderate rake angle.

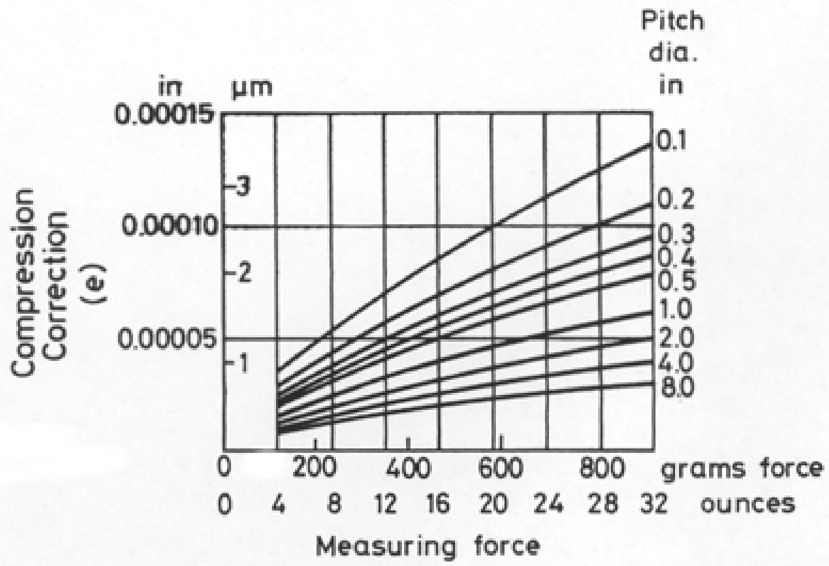


Fig 54 Compression corrections for various measuring forces on Whitworth screws of moderate rake angle

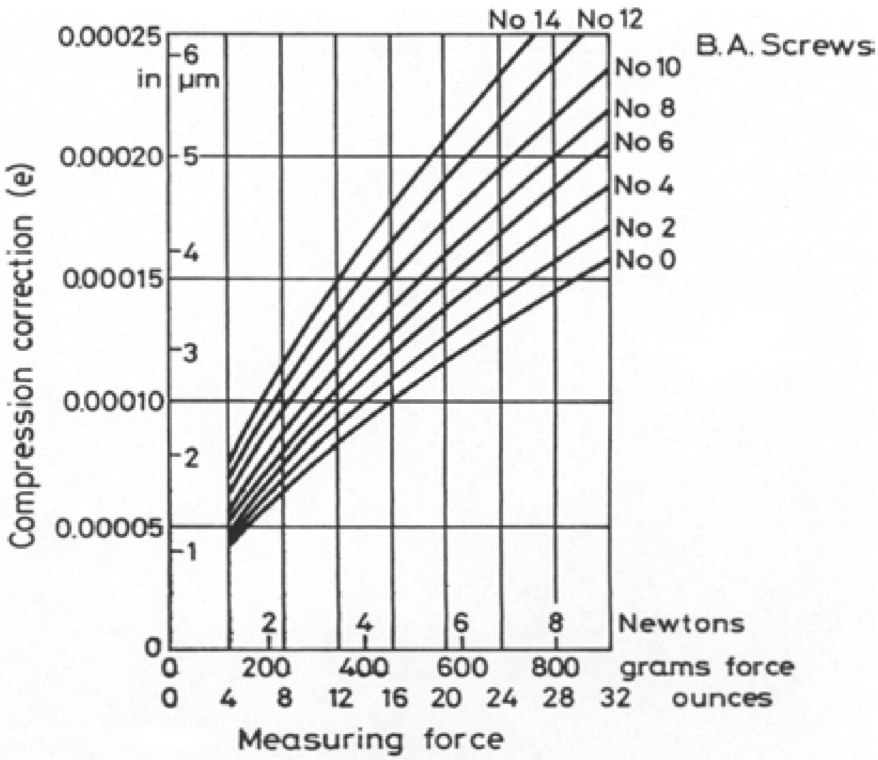


Fig.55 Compression corrections for various measuring forces on B.A. Screws

APPENDIX 9

DIMENSIONS OF VEE-PIECES FOR MINOR DIAMETER MEASUREMENT

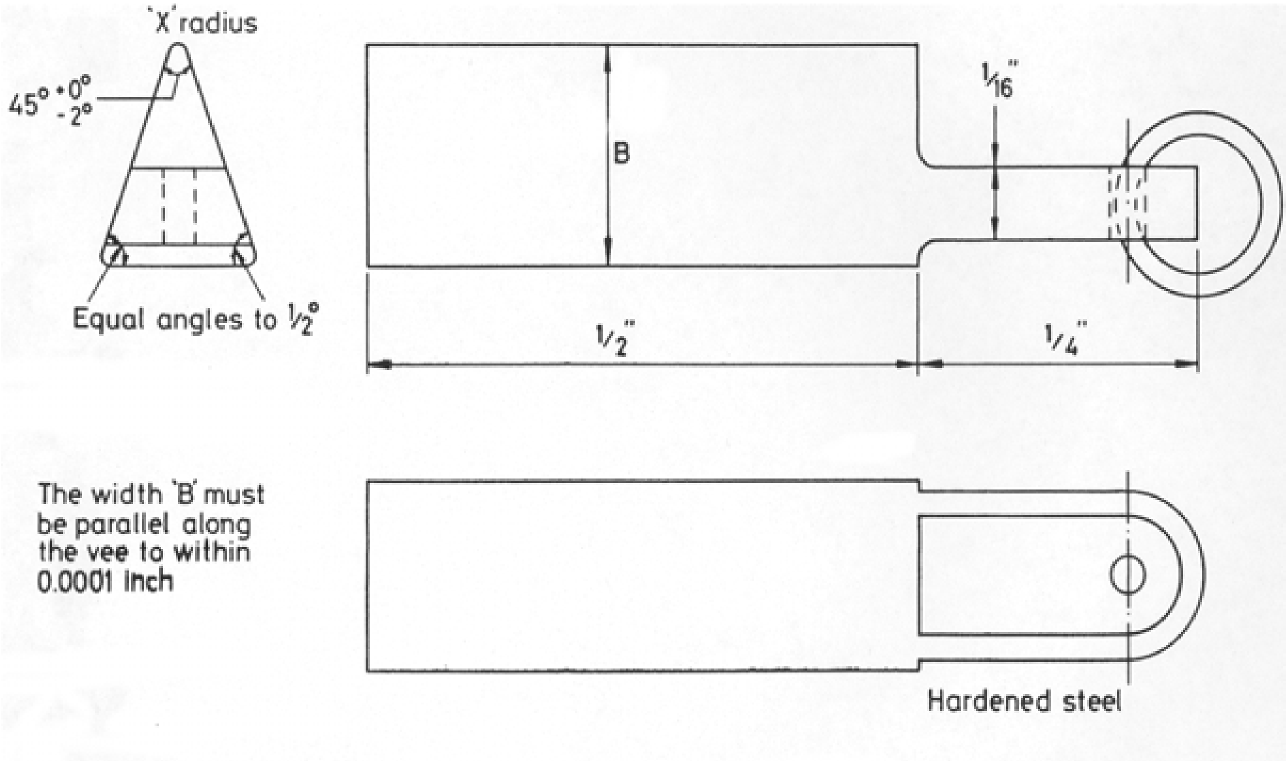


Fig.56 Vee-pieces

Table 33: Vee pieces

Designation	Limits for "radius X"	Dimension B not less than	Suitable for screws		
			Unified	Whitworth	B.A.
	in	in	tpi	tpi	No
A	0.0005 to 0.0010	0.12	-	-	12 to 9
B	0.0015 to 0.0020	0.12	40 to 28	40 to 28	8 to 3
C	0.0035 to 0.0040	0.17	24 to 14	26 to 14	2 to 0
D	0.0080 to 0.0090	0.17	13 to 4	12 to 4	-

APPENDIX 10

DIMENSIONS OF FIXED TAPER BLOCKS FOR MEASUREMENT OF TAPER SCREW PLUG GAUGES

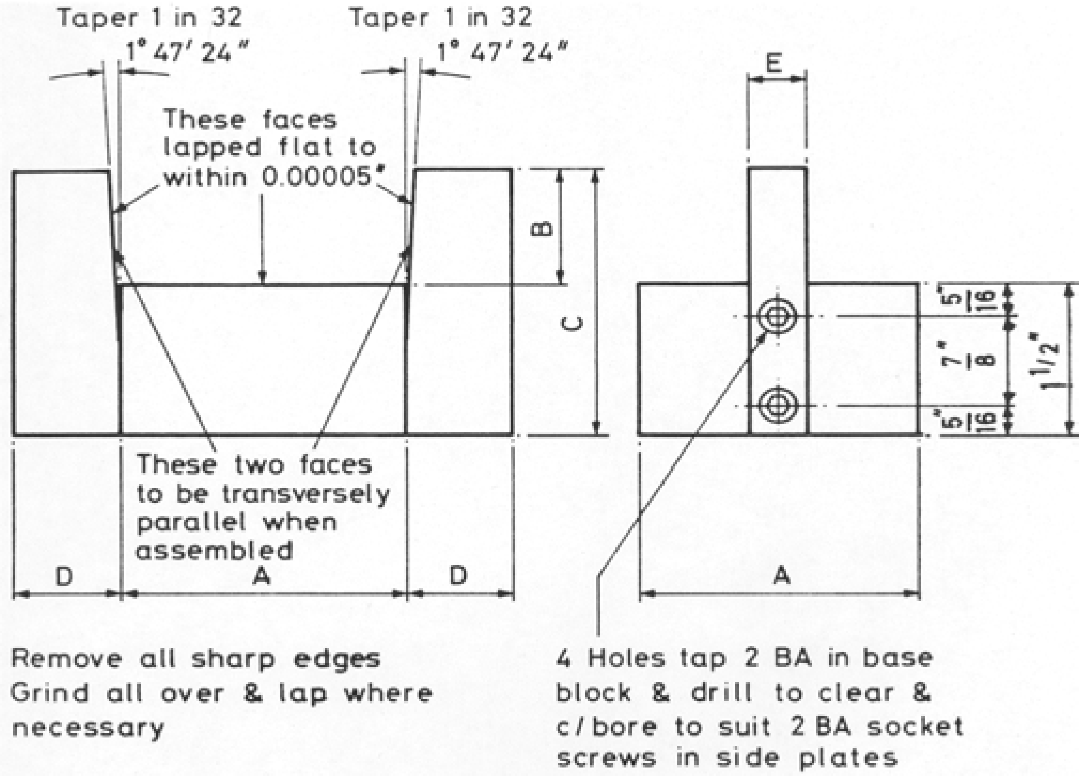


Fig. 57 Dimensions of fixed taper blocks for measurement ~~of~~ BS pipe taper screw plug gauges

Table 34: Sets of blocks for measuring BS Screw Plug Gauges

	Dimensions				
For BS Pipe sizes designated	**A**	**B**	**C**	**D**	**E**
in	**in**	**in**	**in**	**in**	**in**
1/8, ¼, 3/8	1 5/16	5/8	2 1/8	7/8	7/16
½, ¾, 1	1 9/16	7/8	2 3/8	7/8	7/16
1 ¼, 1 ½, 2	2 9/16	1 1/8	2 5/8	1	½
2 ½, 3, 3 ½	4 5/32	1 ½	3	1 1/8	½
4, 5,	6 11/16	1 ¾	3 ¼	1 1/8	½

PART V: PLATES

Plate 1 A selection of screw gauges

Plate 1A An illustration of the range of sizes of screw gauges

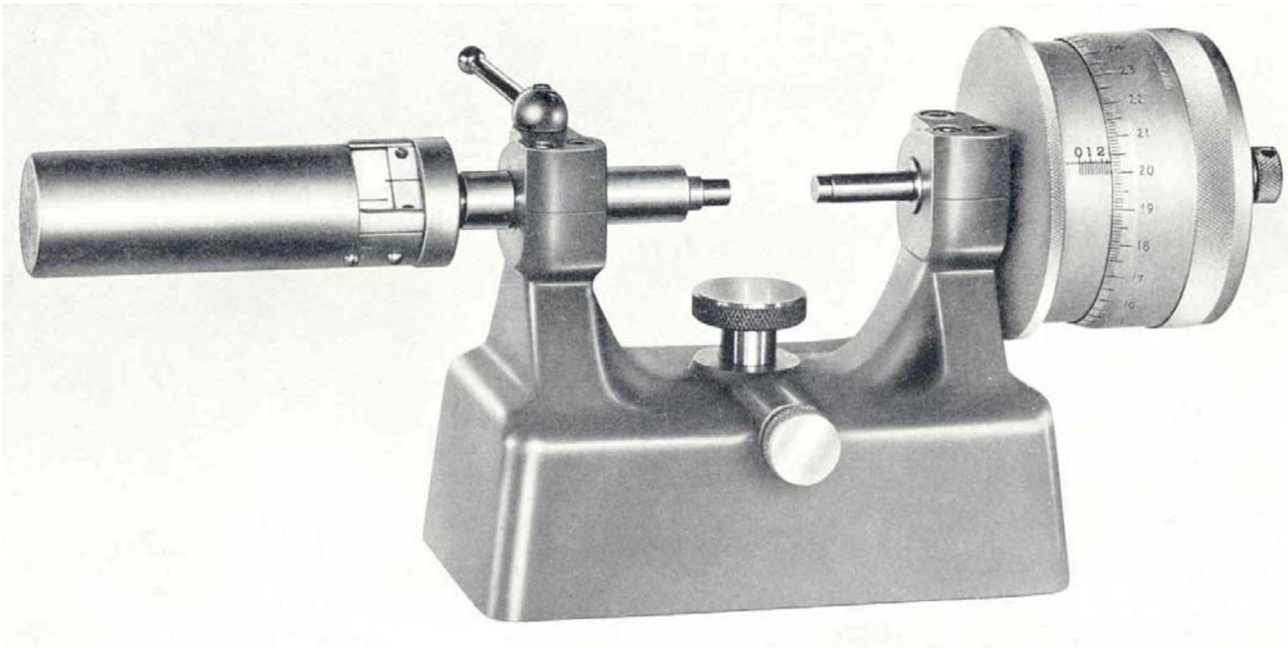


Plate 2 Bench micrometer of NPL design

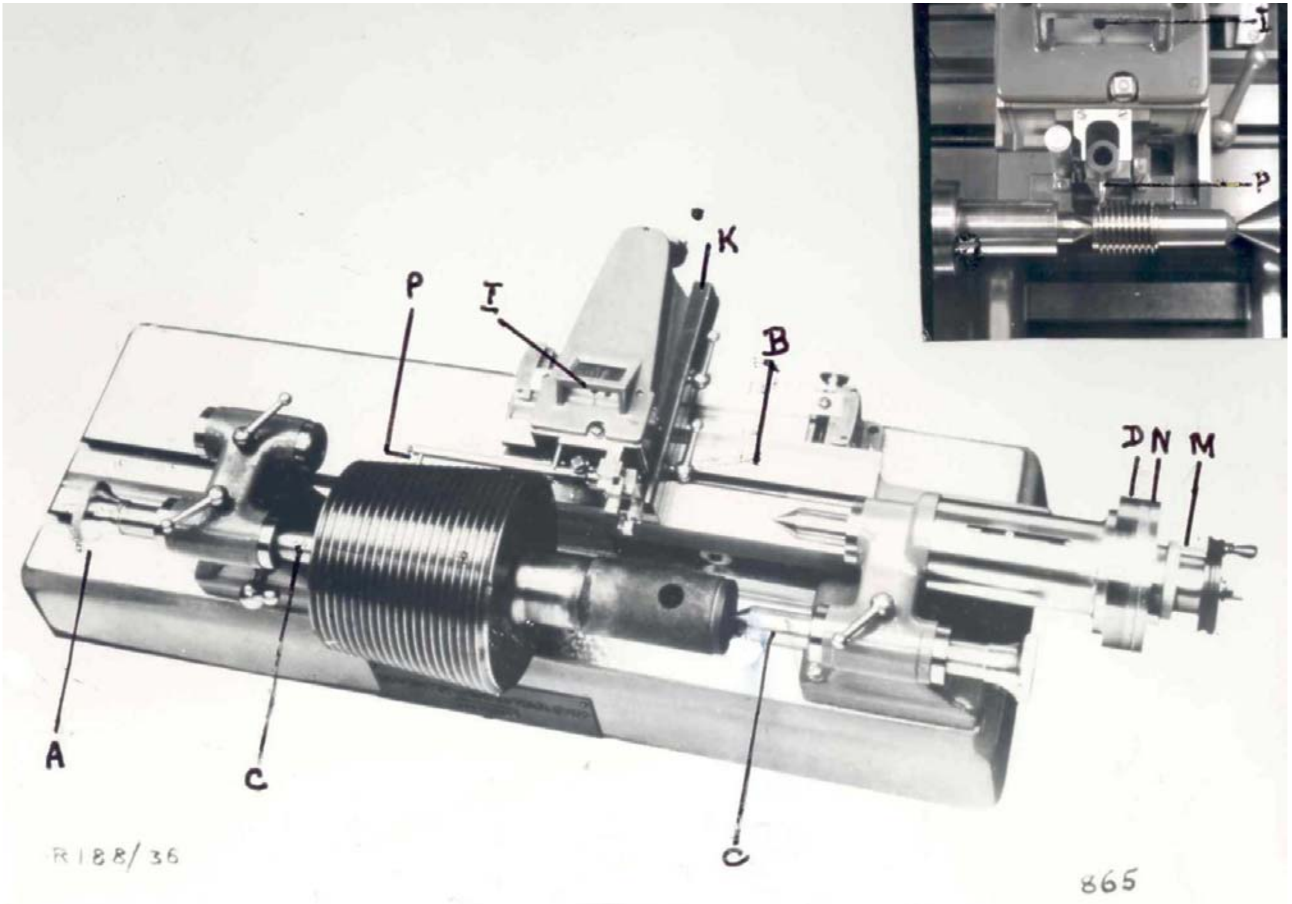


Plate 3 A screw pitch measuring machine

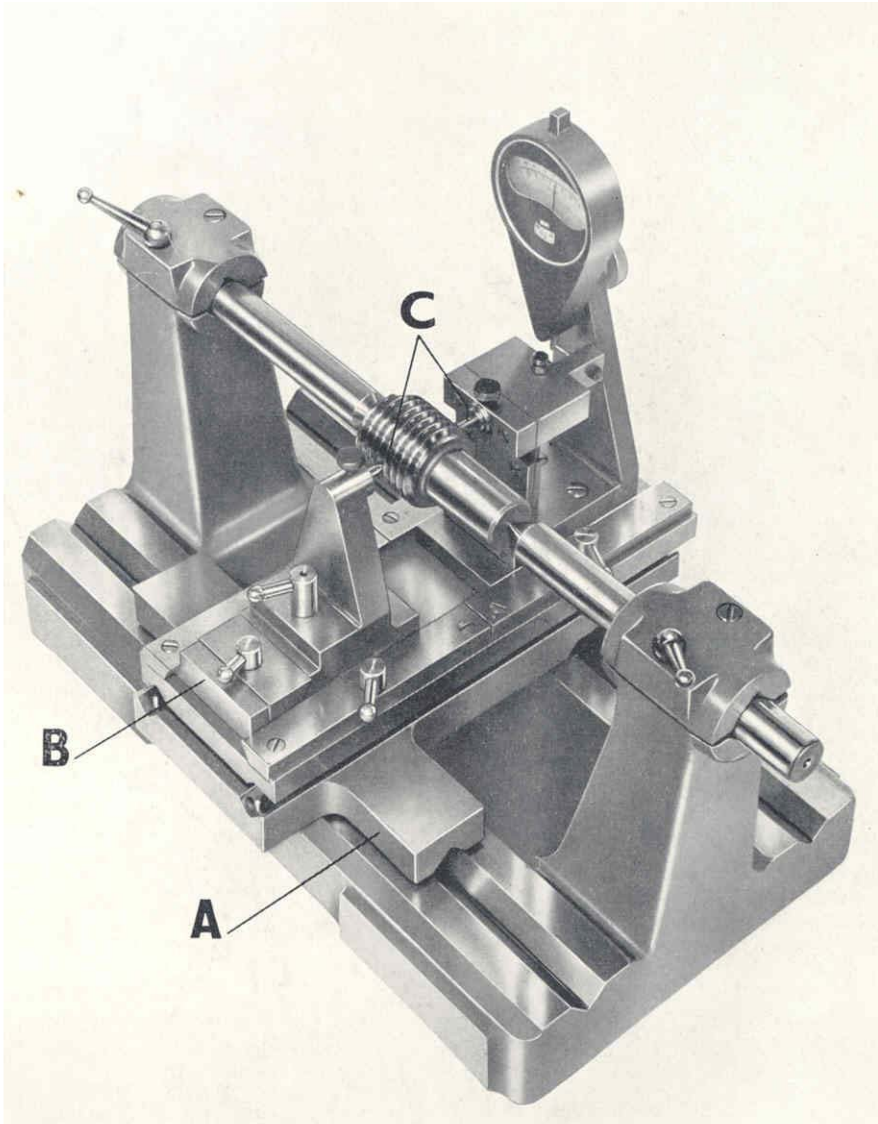


Plate 4 "Drunkenness" Measuring Machine of NPL Design

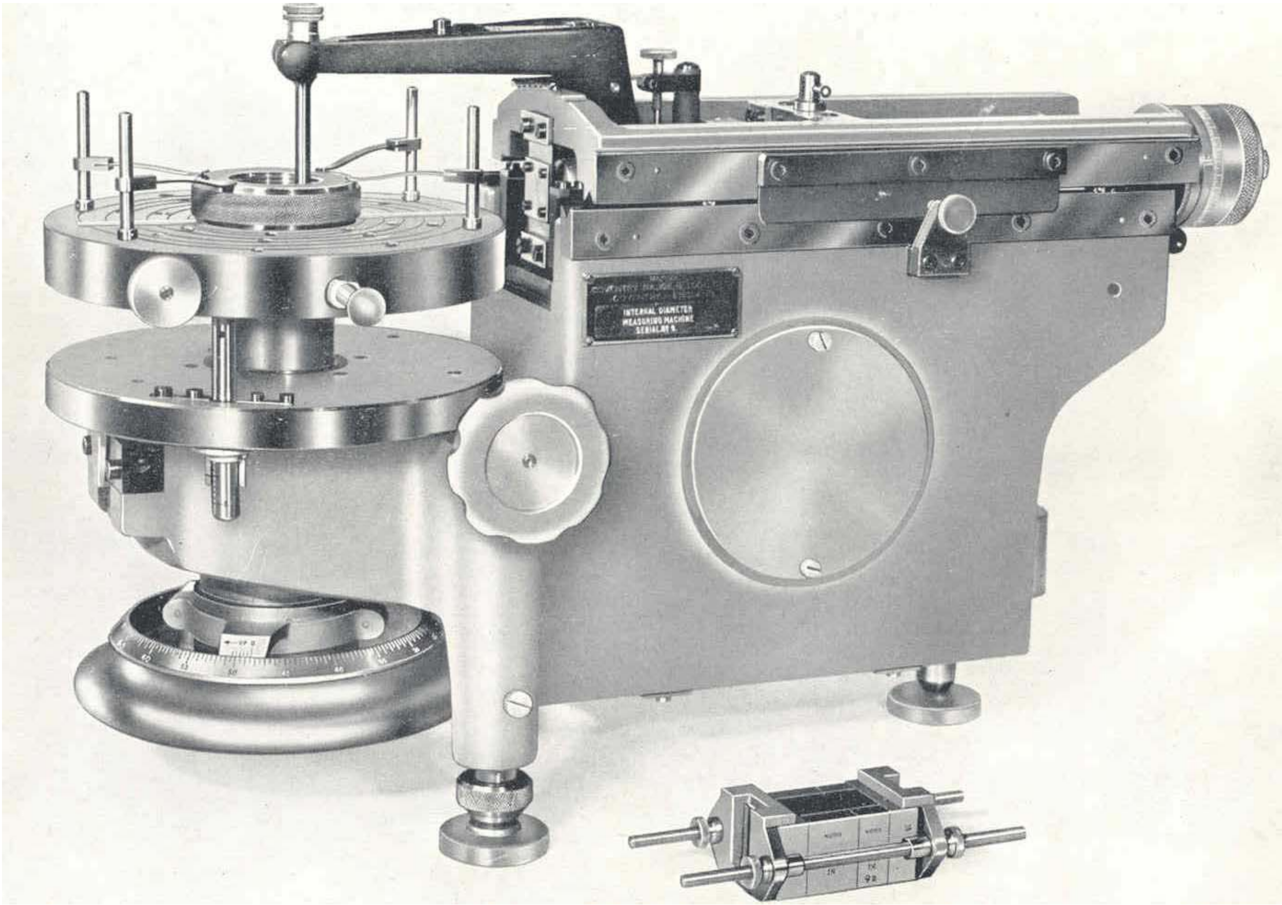


Plate 5 “Matrix Internal” Diameter Measuring Machine

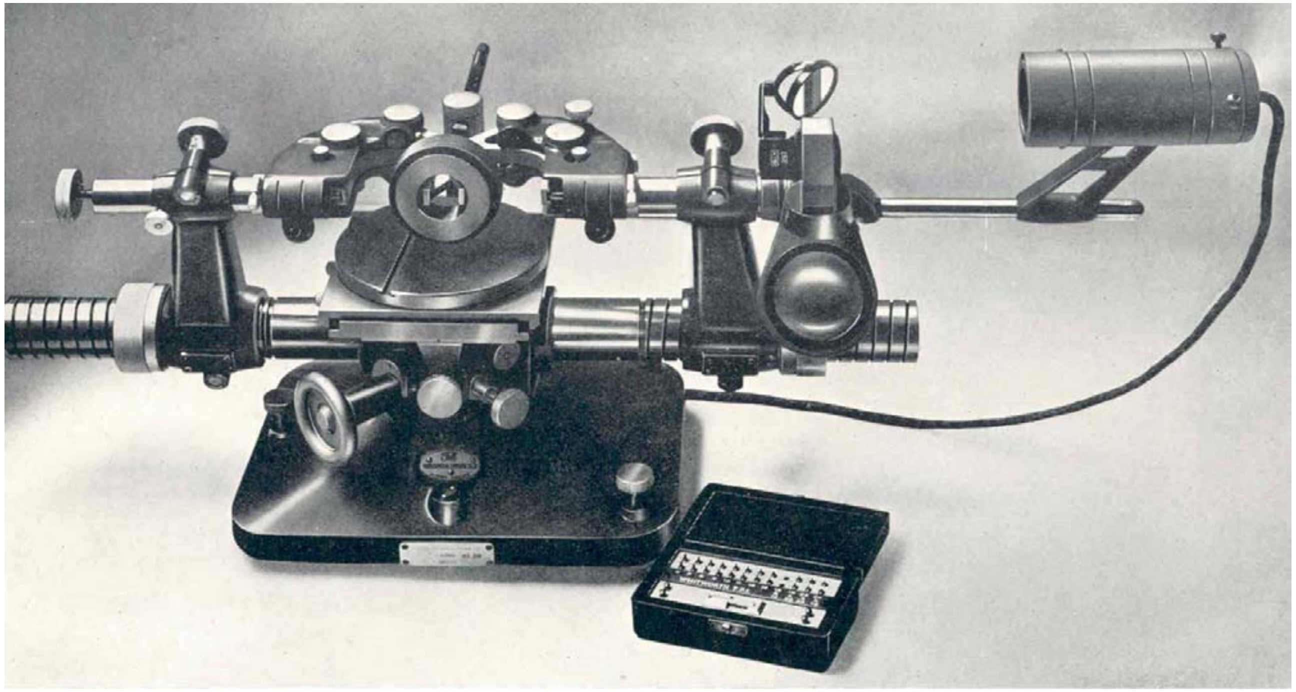


Plate 6 Horizontal comparator for measuring diameters of internal threads

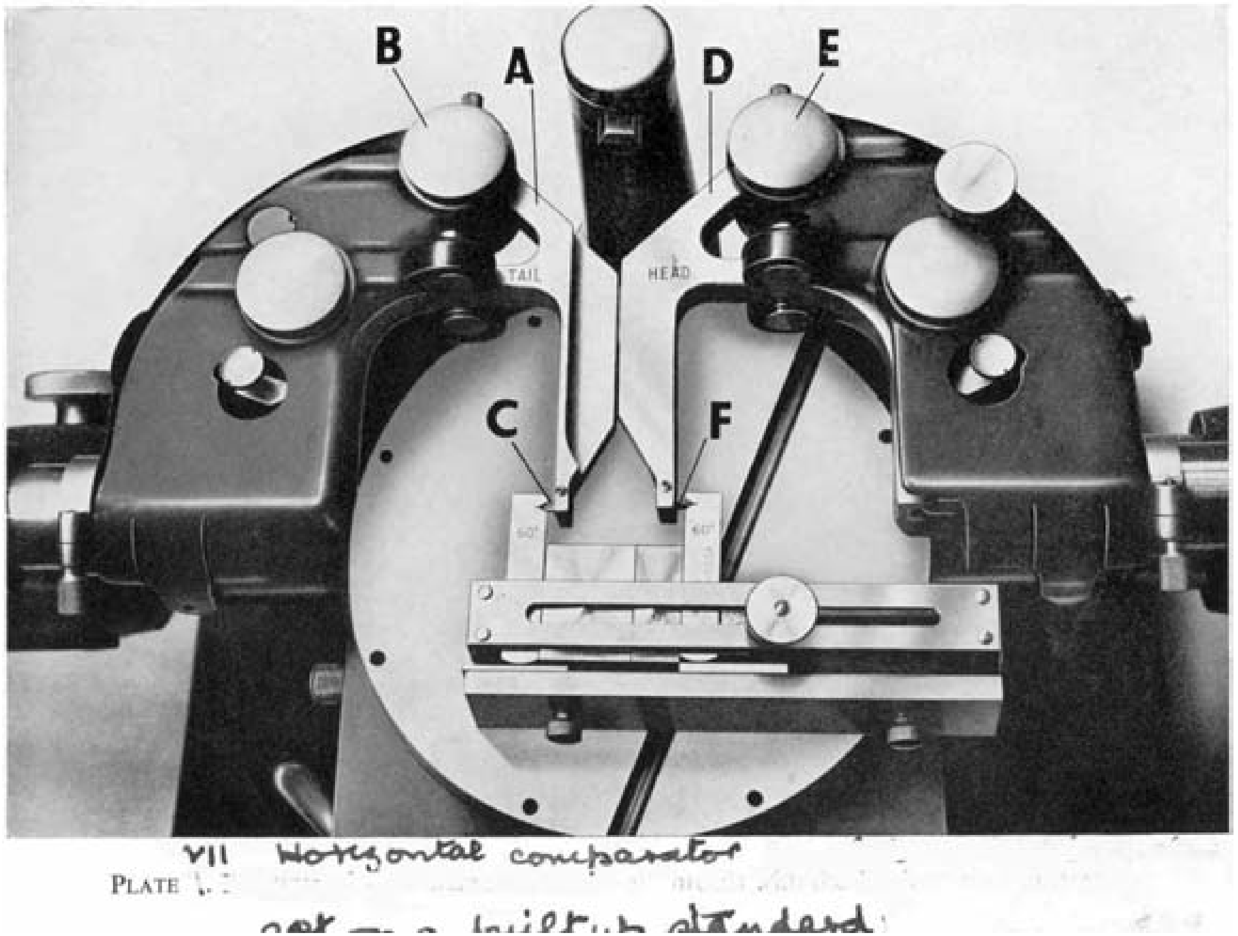


Plate 7 Principle of Measurement of Internal Threads with the Horizontal Comparator

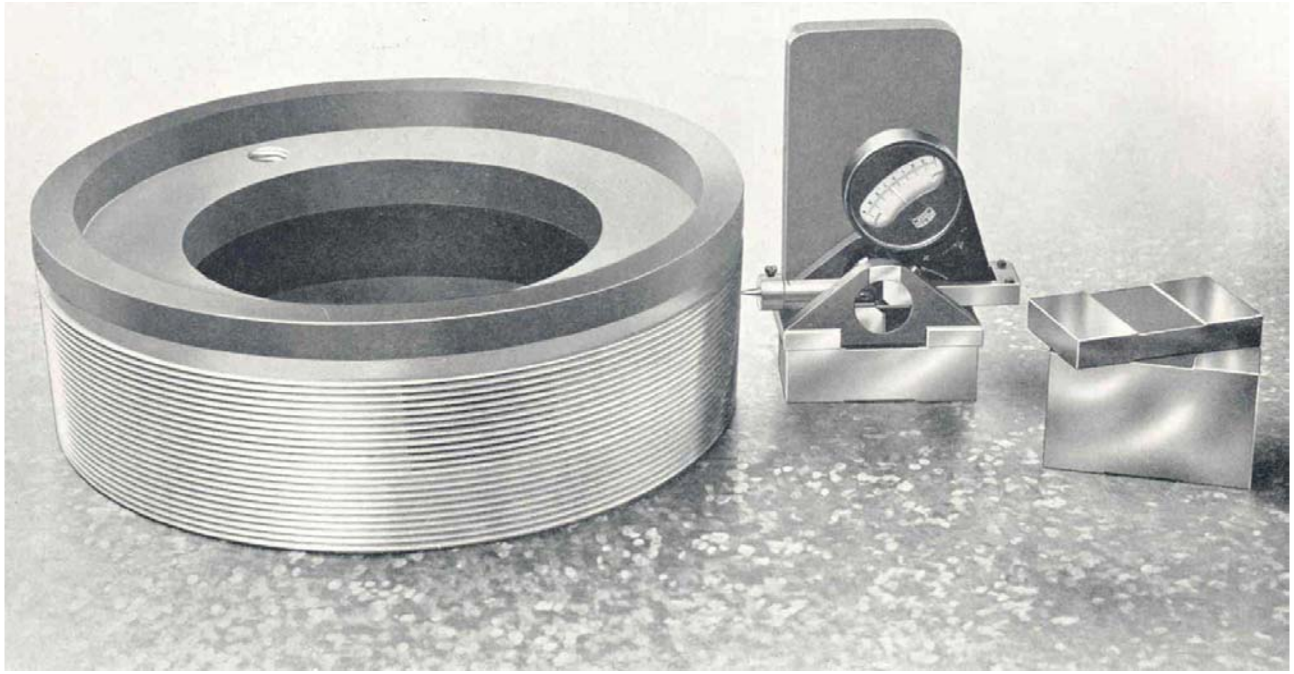


Plate 8 Pitch Indicator of NPL design

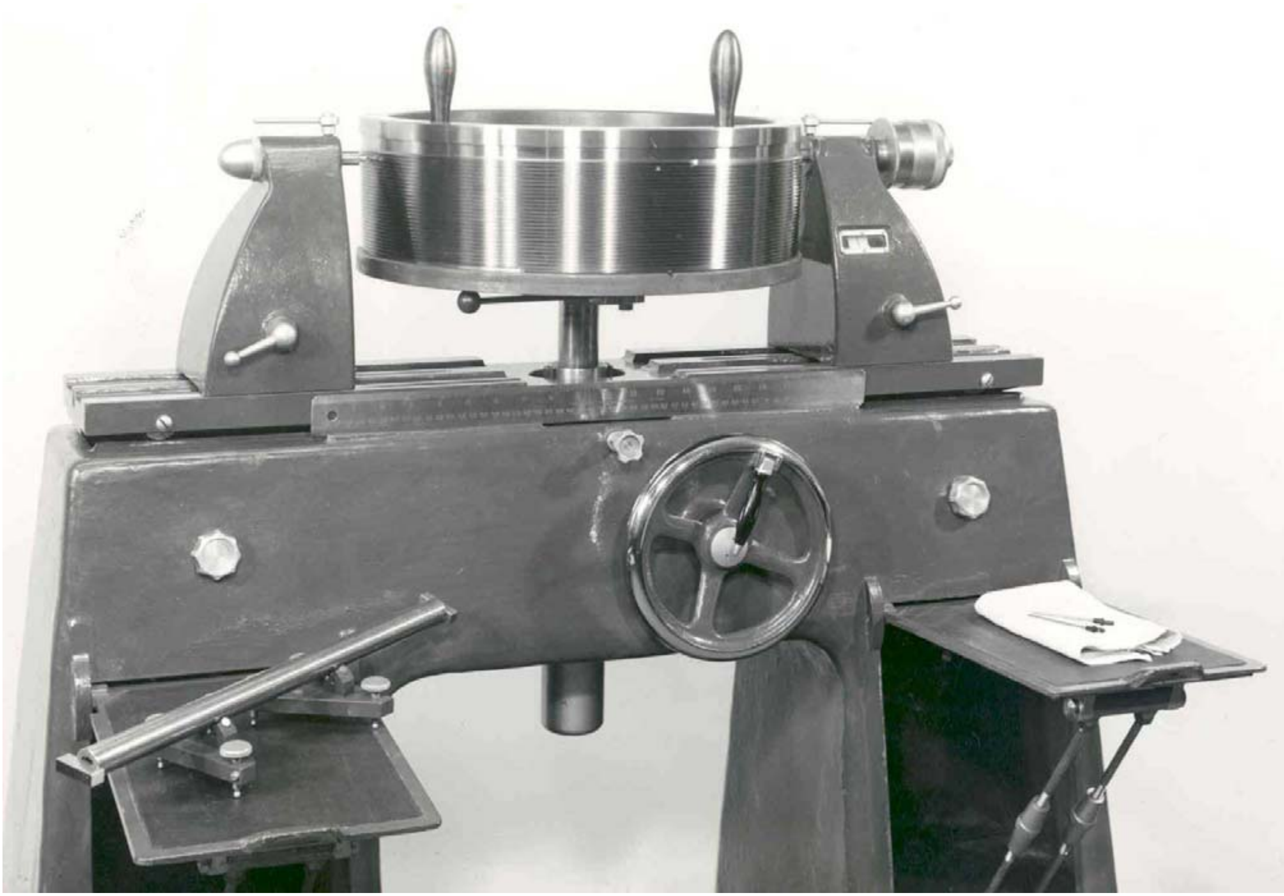


Plate 9 Floor mounted diameter measuring machine

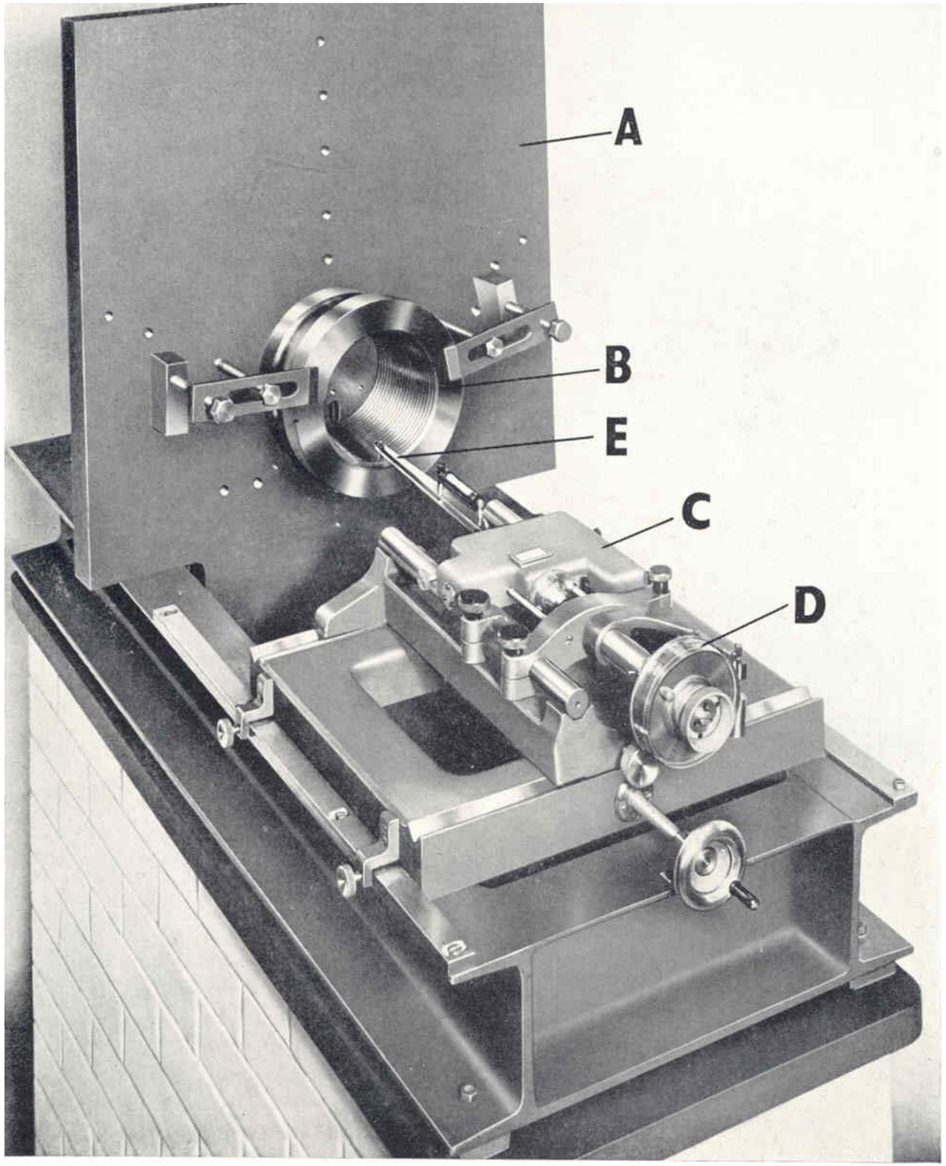


Plate 10 Pitch Measuring Machine for Large Taper Screws