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ISO SYSTEM OF LIMITS AND FITS

PART II : INSPECTION OF PLAIN WORKPIECES

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BRIEF HISTORY

The ISO Recommendation R 1938, *ISO system of limits and fits – Part II : Inspection of plain workpieces*, was drawn up by Technical Committee ISO/TC 3, *Limits and fits*, the Secretariat of which is held by the Association Française de Normalisation (AFNOR).

Work on this question led to the adoption of Draft ISO Recommendation No. 1938, which was circulated to all the ISO Member Bodies for enquiry in February 1970. It was approved, subject to a few modifications of an editorial nature, by the following Member Bodies :

Austria	Ireland	Romania
Belgium	Israel	South Africa, Rep. of
Chile	Italy	Switzerland
Czechoslovakia	Japan	Thailand
France	Korea, Rep. of	Turkey
Germany	New Zealand	U.A.R.
Greece	Norway	United Kingdom
Hungary	Poland	U.S.S.R.
India	Portugal	

The following Member Bodies opposed the approval of the Draft :

Australia
Canada
Sweden

This Draft ISO Recommendation was then submitted by correspondence to the ISO Council, which decided to accept it as an ISO RECOMMENDATION.

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ISO SYSTEM OF LIMITS AND FITS

PART II : INSPECTION OF PLAIN WORKPIECES

INTRODUCTION

This ISO Recommendation is a continuation of ISO Recommendation R 286, *ISO system of limits and fits – Part I : General, tolerances and deviations*.

The information concerning the indicating measuring instruments is new whereas that relating to the choice of gauges to be used, including their tolerances and wear margins, is practically the same as in the old ISA System (ISA Bulletin 25 of January 1941).

In particular accepted trespassing of the limits for practical reasons (y or y_1 margin) in the case of grade 8 and lower still remains the rule, but might possibly be reduced or omitted in the future. Present values for tolerances and wear of gauges should be considered as maximum values.

From now on this ISO Recommendation allows the use of new tolerance grades experimentally; these are named grades 6N, 7N, 8N to distinguish them from the preceding 6, 7 and 8 and differ from the latter only by a much lower wear of gauges enabling any margin to be dispensed with (y or $y_1 = 0$).

Numerical values as given in this ISO Recommendation are expressed in terms of the various grades provided for in ISO Recommendation R 286, and are therefore valid only for the ISO system of tolerances or by comparison with this system; all other details of a more general nature may still be applied as a rule to any system of limits for plain workpieces.

As in ISO Recommendation R 286, these numerical values essentially concern diameters not greater than 500 mm. However, values applicable to the limits of workpieces of diameters greater than 500 mm, such as those appearing provisionally in section 3 of ISO Recommendation R 286, are also given here as a supplement and are intended mainly for experimental purposes.

1. SCOPE

This ISO Recommendation relates to the inspection of plain workpieces. It specifies the interpretation to be given to the limits of dimensions to be inspected, and gives the essential details concerning limit gauges and indicating measuring instruments necessary for the inspection of tolerances of the ISO system.

2. GENERAL RULES OF INSPECTION

2.1 Reference temperature and measuring force

ISO Recommendation R 1, *Standard reference temperature for industrial length measurements* fixes this temperature at

20 °C

This is the temperature at which dimensions specified for workpieces and their inspection instruments are defined and at which the inspection should normally be carried out.

In addition all measuring operations provided for in this ISO Recommendation are understood as referred to a zero measuring force.

If the measurement is carried out with a measuring force different from zero its result should be corrected accordingly. This correction however is not required for comparative measurements carried out with the same comparing means and the same comparing force between similar elements of identical material and identical surface roughness.

2.2 Interpretation of size limits (Taylor principle)

In order to guarantee, so far as is practicable, that the functional requirements of the ISO system of limits and fits are attained, the limits of size should be interpreted in the following way within the prescribed length.

For *holes*, the diameter of the largest perfect imaginary cylinder which can be inscribed within the hole so that it just contacts the highest points of the surface should not be a diameter smaller than the GO limit of size. In addition the maximum diameter at any position in the hole must not exceed the NOT GO limit of size.

For *shafts*, the diameter of the smallest perfect imaginary cylinder which can be circumscribed about the shaft so that it just contacts the highest points of the surface should not be a diameter larger than the GO limit of size. In addition the minimum diameter at any position on the shaft must not be less than the NOT GO limit of size.

The above interpretation means that if the size of the hole or shaft is everywhere at its GO limit then the hole or shaft should be perfectly round and straight.

Unless otherwise specified, and subject to the above requirements, departures from true roundness and straightness may reach the full value of the diametral tolerance specified. Typical extreme errors of form permitted by this interpretation are illustrated in Figures 1 and 2. Such extreme errors are unlikely to arise in practice.

The above interpretation of the size limits results from the "Taylor principle", named after the late W. TAYLOR who first laid it down in 1905. It is based on the use of a correct system of limit gauges to inspect shafts and holes. According to this principle a hole should completely assemble with a GO cylindrical plug gauge made to the specified GO limit of the hole, having a length at least equal to the length of engagement of the hole and shaft. In addition the hole is measured or gauged to check that its maximum diameter is not larger than the NOT GO limit. The shaft should assemble completely with a ring gauge made to the specified GO limit of the shaft and of a length at least equal to that of the length of engagement of the shaft and hole. Finally the shaft is measured or gauged to check that its minimum diameter is not smaller than the NOT GO limit.

In special cases the maximum errors of form permitted by the above interpretation may be too large to allow satisfactory functioning of the assembled parts; in such cases separate tolerances should be given for the form, e.g. separate tolerances on circularity or straightness, according to ISO Recommendation R 1101, *Technical drawings – Tolerances of form and of position – Part I : Generalities, symbols, indications on drawings.*

2.3 Exceeding the limits

The above mentioned size limits are those specified in ISO Recommendation R 286, *ISO system of limits and fits – Part I : General, tolerances and deviations*. However, in order to take account of the existing manufacturing techniques of gauges, tolerances of manufacture and wear of limit gauges are such that the limits of specified dimensions for grades 6 to 8 may be exceeded in some cases (y or y_1 margin, see clause 3.9.2.1). In this case if workpieces are inspected during the manufacture by means of indicating measuring instruments instead of limit gauges, the manufacturer may also take into account the same y or y_1 margin as for gauges, in order to establish a uniform acceptance principle.

If inspection should exceptionally be carried out without any margin (y or $y_1 = 0$) in grades 6 to 8 which normally require it, this should be explicitly specified by writing the letter N following the grade number.*

2.4 Choice of inspection method

Workpieces may be inspected either by means of fixed limit gauges or by means of indicating measuring instruments.

Both methods have advantages and drawbacks of their own which it is important to know before selecting one of them.

A system of limit gauges designed in strict conformity with the Taylor principle has the advantage of checking the geometry as well as the sizes of workpieces. However, for practical reasons departures from this principle may be made as stated in clause 3.3 and so the inspection is possibly not so satisfactory as might be expected theoretically.

Furthermore gauges themselves have errors of form and size, and their necessary manufacturing and wear tolerances further reduce the amount of tolerance that remains available on the workpiece.

Measuring instruments give the workpiece size in the measuring position only and do not check the geometry, which requires separate measurements the result of which, in theory, should be correlated to that of the dimensional measurement. This tedious procedure is not necessary provided sufficient reliance can be placed on the manufacturing accuracy to ensure that, in practice, form errors can be ignored.

On the other hand, contrary to what occurs with limit gauges, the use of such instruments has the advantage, when workpieces have very small tolerances, of not reducing the amount of tolerance that remains available on the workpieces. Finally the use of such instruments allows sampling inspection which gives warning when the sizes approach one of the limits during a continuous manufacturing process.

In order to avoid disputes it is recommended that the type of inspection to be used for acceptance be specified on the order.

Unless strictly specified to the contrary a workpiece should be considered as good when the manufacturer can prove that it was recognized as such by the inspection method he chose in conformity with this ISO Recommendation.

* The designation of former grades, with margin, remaining unchanged, it is nevertheless permitted to indicate the distinction more clearly by writing the letter A following their grade number.

3. LIMIT GAUGES

3.1. Gauge types

3.1.1 *Limit gauges* are used to inspect the workpieces. For gauging internal diameters they may be of the following types :

- full form cylindrical plug gauge;
- full form spherical plug or disk gauge;
- segmental cylindrical bar gauge;
- segmental spherical plug gauge;
- segmental cylindrical bar gauge with reduced measuring faces;
- rod gauge with spherical ends.

For gauging external diameters the following gauges may be used :

- full form cylindrical ring gauge;
- gap gauge.

3.1.2 *Reference gauges* or *block gauges* may be used to inspect or adjust limit gauges :

(*a*) *reference gauges* are either reference disks intended for setting gap gauges, or cylindrical ring or plug gauges used for calibrating gauges or indicating measuring instruments;

(*b*) *block gauges* are standards of length having parallel plane end surfaces which are used for calibrating gauges or indicating measuring instruments.

3.2 Application of the Taylor principle

Except for allowable deviations (see clause 3.3) strict application of the Taylor principle leads to using

- for checking the GO limit of the workpiece:

  a plug gauge or a ring gauge having exactly the GO limit diameter and a length equal to the workpiece length (or the engagement length of the fit to be made);

- for checking the NOT GO limit :

  a gauge contacting the workpiece surface only at two diametrically opposite points and having exactly the NOT GO limit diameter.

The GO gauge should perfectly assemble with the workpiece to be inspected and the NOT GO gauge should not be able to pass over or in the workpiece in any consecutive position in the various diametrical directions on the workpiece length.

3.3 Allowable deviation from the Taylor principle

As the application of the Taylor principle is not always strictly compulsory or comes up against difficulties in the convenient use of gauges, certain deviations may be allowed (see clause 3.4).

At the GO limit a full form gauge is not always necessary or used, as for instance in the following cases :

- The length of a GO cylindrical plug or ring gauge may be less than the length of engagement of the mating workpieces if it is known that with the manufacturing process used the error of straightness of the hole or shaft is so small that it does not affect the character of fit of the assembled workpieces. This deviation from the ideal facilitates the use of standard gauge blanks.

- For gauging a large hole a GO cylindrical plug gauge may be too heavy for convenient use, and it is permissible to use a segmental cylindrical bar or spherical gauge if it is known that with the manufacturing process used the error of roundness or straightness of the hole is so small that it does not affect the character of fit of the assembled workpieces.

– A GO cylindrical ring gauge is often inconvenient for gauging shafts and may be replaced by a gap gauge if it is known that with the manufacturing process used the errors of roundness (especially lobing) and straightness of the shaft are so small that they do not affect the character of fit of the assembled workpieces. The straightness of long shafts which have a small diameter should be checked separately.

At the NOT GO limit a two-point checking device is not always necessary or used, as for instance in the following cases :

– Point contacts are subject to rapid wear, and in most cases may be replaced where appropriate by small plane, cylindrical or spherical surfaces.

– For gauging very small holes a two-point checking device is difficult to design and manufacture. NOT GO plug gauges of full cylindrical form have to be used but the user must be aware that there is a possibility of accepting workpieces having diameters outside the NOT GO limit.

– Non-rigid workpieces may be deformed to an oval by a two-point mechanical contact device operating under a finite contact force. If it is not possible to reduce the contact force to almost zero, then it is necessary to use NOT GO ring or plug gauges of full cylindrical form.

Such thin-walled workpieces may be out of round (due to internal stresses or heat treatment). In these cases the NOT GO limit has the meaning that the circumference of the cylinder corresponding to that limit must not be transgressed. Therefore NOT GO gauges of full cylindrical form have to be applied with a force that just suffices to convert the elastic deformation into circularity but does not expand or compress the wall of the workpiece.

Lastly, the sizes of gauges cannot be made exactly to the appropriate workpiece limit : they have to be made to specified tolerances.

3.4 Field of utilisation of the various types of limit gauges

Taking account of the above remarks, recommended types of gauges for various ranges of workpiece nominal dimensions are given in Figures 5 and 6, the meaning of symbols used being given in Figures 3 and 4.

3.5 General design features of limit gauges

No recommendation is given for the details of the designs; these are left to the initiative of the gauge makers or the national standards organizations.

The various types of gauges are illustrated in Figures 3 and 4. The recommended types of gauges for the different ranges of nominal size of the workpieces are shown in Figures 5 and 6. The key to the symbols used in Figures 5 and 6 is given in Figures 3 and 4.

A *full form cylindrical plug gauge* (Fig. 3 A) has a gauging surface in the form of an external cylinder. The method of attaching the gauge to the handle should not affect the size and form of the gauge by producing an undesirable stress.

A small circumferential groove near the leading end of the gauge and a slight reduction in diameter of the remaining short cylindrical surface at the end are recommended to serve as a pilot to facilitate the insertion of the gauge into the workpiece hole.

A *full form spherical plug* or *disk gauge* (Fig. 3 B) has a gauging surface in the form of a sphere from which two equal segments are cut off by planes normal to the axis of the handle.

A *segmental cylindrical bar gauge* (Fig. 3 C) has a gauging surface in the form of an external cylinder from which two axial segments are either relieved (Fig. 3 C (i)) or removed (Fig. 3 C (ii)). This gauge may have reduced measuring faces (Fig. 3 E).

A *segmental spherical plug gauge* (Fig. 3 D) is similar to the gauge shown in Figure 3 B but has two equal segments cut off by planes parallel to the axis of the handle in addition to the segments cut off by planes normal to the axis of the handle.

A *segmental cylindrical bar gauge with reduced measuring faces* (Fig. 3 E) is similar to the gauge shown in Figure 3 C but has reduced measuring faces in a plane parallel to the axis of the handle.

A *rod gauge with spherical ends* (Fig. 3 F) has spherical end surfaces the radius of which should not be greater than half the length of the gauge. The rod may be fixed or adjustable.

A *full form cylindrical ring gauge* (Fig. 4 A) has a gauging surface in the form of an internal cylinder. The wall of the ring gauge shall be thick enough to avoid deformation under normal conditions of use.

A *gap gauge* (Fig. 4 B) has for its working size flat and parallel gauging surfaces (or, alternatively one flat and one spherical or cylindrical surface, or two cylindrical surfaces being parallel to the axis of the shaft being checked). The GO and NOT GO gaps may lie on the same side of the gap gauge. The gap gauge may be fixed or adjustable.

3.6 Materials and further details of gauges

The gauging surfaces shall be of a wear-resistant material such as hardened steel, hard chromium plating of a thickness at least equal to the wear zone of the gauge, or tungsten carbide.

It is advisable that the gauges be insulated, as far as possible, against the warmth of the hand of the user, when this is likely to affect significantly the accuracy of the measurement.

NOT GO gap gauges should bear an identification mark such as a groove or a red colour or an easily visible reduction in the length of the gauging surface. This identification is not necessary if the NOT GO side is self-evident as with the progressive type GO and NOT GO gap gauge.

3.7 Definitions and inspection of gauge sizes

3.7.1 *Cylindrical plug gauges.* The gauge diameter should be measured between a plane and a spherically-ended anvil or between measuring anvils having plane parallel surfaces. The value obtained should be corrected for deformation of the surfaces in contact caused by the measuring force (i.e. the diameter of the gauge is the diameter when the measuring force is zero). The diameter should be measured in at least four positions selected to reveal form errors.

All the measured diameters of the gauge should be on or between the specified limits of size, and the range (i.e. the difference between the maximum and minimum values) should not exceed the form tolerance of the gauge (see clause 3.9.2.3). If the presence of lobing is suspected then it may be checked by a three-point measurement or by a roundness measurement.

3.7.2 *Spherical plug, disk and rod gauges.* The diameter of the spherical part of the gauge should be measured between two parallel planes; these planes need only have a small area (for example the diameter of the plane-ended surface of the anvil of a measuring instrument may only be 5 mm).

The value obtained should be corrected for deformation of the surfaces in contact caused by the measuring force (i.e. the diameter of the gauge is the diameter when the measuring force is zero).

The diameter should be measured in at least four positions, selected to reveal form errors. All the measured diameters of the gauge should be on or between the specified limits of size, and the range (i.e. the difference between the maximum and minimum values) should not exceed the form tolerance of the gauge (see clause 3.9.2.3). If the presence of lobing is suspected then it may be checked by a three-point measurement or by a roundness measurement.

3.7.3 *Cylindrical ring gauges.* The diameter should be measured by means of two spherically-ended anvils positioned in a plane normal to the axis of the ring gauge. When moving the measuring instrument in this plane the greatest distance apart of the two anvils determines the diameter. The value obtained should be corrected for deformation of the surfaces in contact caused by the measuring force (i.e. the diameter of the gauge is the diameter when the measuring force is zero).

The diameter should be measured in at least four positions, selected to reveal form errors. All the measured diameters of the gauge should be on or between the specified limits of size, and the range (i.e. the difference between the maximum and minimum values) should not exceed the form tolerance of the gauge (see clause 3.9.2.3). If the presence of lobing is suspected then it may be checked by a three-point measurement or by a roundness measurement.

3.7.4 *Gap gauges*. The *actual size* of a gap is defined as the perpendicular distance between the gauging surfaces, when no force is exerted on the gauge.

The *working size* of a gap gauge is defined as the diameter of a reference disk over which the gap gauge just passes in a vertical direction under the working load marked on it, or, if this is not indicated, under its own weight. Beforehand, the disk should be greased with a thin film of petroleum jelly and then carefully wiped but not rubbed. The gauging surfaces of the gap gauge should be cleaned. The gap gauge should slide over the disk after having been brought carefully to rest in contact with the disk and then released : inertia forces are thus avoided.

For heavier gap gauges it is recommended that the working load should be less than the weight of the gauge, so that the working size may be determined more accurately. The positions of the places where the forces counter-balancing part of the weight of the gauge are to be applied (see Fig. 7) should be marked on gauges of nominal sizes above 100 mm (4 in).

The working size of a gap gauge is not defined with a zero measuring force, as for the other definitions, because the size of a reference disk is defined with a zero measuring force and the gap gauge may be regarded as a comparator which is intended to transfer (on the particular limit) the size of the reference disk to the workpiece.

In practice a reference disk may be used directly to accept a gap gauge in the case where the disk and the gap gauge are supplied together and the gap gauge has been adjusted to the disk. In other cases the following two alternative procedures are recommended.

(*a*) Determine the successive loads under which the gap gauge will pass over two reference disks of different diameter under the conditions specified in the definition of the working size. The difference in these two loads is taken as a basis for calculating the working size of the gap gauge at its working load.

(*b*) Take a reference disk with a diameter smaller* than the smallest permissible size of the gap gauge. Place gauge blocks successively on the gauging surfaces of the gap gauge, if possible equally distributed so that in one case the sum of the diameter of the reference disk and the gauge blocks is equal to the lowest permissible working size and in the other case to the highest permissible working size of the gap gauge.**

In the first case the gap gauge should pass over the reference disk, and in the second case it should not pass over the reference disk, under the conditions specified in the definition of the working size.

Doubtful cases are decided according to method (*b*) above.***

When the gap gauge is used in a horizontal position, with the axis of the workpiece vertical, its working size is defined as the largest size of a reference disk or gauge block combination over which it can just be moved by hand without excessive force.

The difference between the working size and the actual size of a gap gauge is equal to the amount by which the gauge is deformed by the force applied when determining the working size. The design of the gap gauge should be as rigid as possible in relation to the weight of the gauge so as to keep this difference in size to a minimum.

3.8 Method of use of gauges

The following recommendations relate to the general use of the gauges in the workshop as well as borderline cases.

3.8.1 *Gauges for holes*

3.8.1.1 GO GAUGE. A GO gauge should assemble completely with the hole when applied by hand without using excessive force, and the total length of the hole should be checked. When gauging non-rigid workpieces, such as thin-walled parts, the application of too great a force will enlarge the diameter of the hole. A GO segmental gauge should be applied to the hole in at least two or three axial planes uniformly distributed around the circumference.

* For gap gauges up to 100 mm it is advisable to make the diameter of the disk 5 mm smaller than the nominal size, and for gap gauges over 100 mm, 10 mm smaller than the nominal size.

** Reference disks made to the lowest and highest permissible sizes may also be used.

*** Comparable with the practice in some countries, where the new gap gauge is successively applied on two combinations of block gauges corresponding to the limits for this gap gauge, the gap gauge should be capable of being raised carrying one of these combinations but without carrying the other.

3.8.1.2 NOT GO GAUGE. A cylindrical NOT GO plug gauge should not enter the hole when applied by hand without using excessive force. The hole should be checked from both ends if possible.

A NOT GO gauge with spherical measuring surfaces should be introduced into the hole by tilting it. When it is erected in the hole, contacting the hole on a diameter, it should not be possible to pass it through the hole by hand without using excessive force. This test should be performed at not less than four positions around and along the cylindrical surface of the hole.

3.8.2 *Gauges for shafts*

3.8.2.1 GO GAUGE. The GO gap gauge should pass over a shaft, the axis of which is horizontal, under its own weight or the force marked on the gauge, under the conditions of clause 3.7.4.

The GO gap gauge should pass over a shaft, the axis of which is vertical, when applied by hand without using excessive force. It is recommended that the corresponding reference disk should be used to assess the measuring force.

The above test should be carried out at not less than four positions around and along the shaft.

A cylindrical GO ring gauge should pass over the complete length of the shaft, when applied by hand without using excessive force.

3.8.2.2 NOT GO GAUGE. The NOT GO gap gauge should not pass over a shaft, the axis of which is horizontal, under its own weight or the force marked on the gauge, under the conditions of clause 3.7.4.

The NOT GO gap gauge should not pass over a shaft, the axis of which is vertical, when applied by hand without using excessive force.

The above test should be applied at not less than four positions around and along the shaft.

3.9 Manufacturing tolerances and permissible wear of gauges

3.9.1 *Symbols.* The following symbols are used in this ISO Recommendation :

D = nominal diameter of workpiece, in millimetres

H = tolerance on cylindrical plug or cylindrical bar gauges

H_s = tolerance on spherical gauges

H_1 = tolerance on gauges for shafts

H_p = tolerance on reference disks for gap gauges

y = margin, outside the GO workpiece limit, of the wear limit of gauges for holes

y_1 = margin, outside the GO workpiece limit, of the wear limit of gauges for shafts

z = distance between centre of tolerance zone of new GO gauges for holes and GO workpiece limit

z_1 = distance between centre of tolerance zone of new GO gauges for shafts and GO workpiece limit

α = safety zone provided for compensating measuring uncertainties of gauges for holes of nominal diameter over 180 mm

α_1 = safety zone provided for compensating measuring uncertainties of gauges for shafts of nominal diameter over 180 mm

y' and y'_1 = difference in absolute value between y and α, and y_1 and α_1.

NOTE. – The Member Bodies of ISO are advised to use only these symbols in their corresponding national standards.

3.9.2 *Limit gauges*

3.9.2.1 POSITIONS OF TOLERANCE ZONES AND WEAR LIMITS IN RELATION TO WORKPIECE LIMITS (shown diagrammatically in Figure 9).

3.9.2.1.1 NOT GO LIMIT OF WORKPIECES. The tolerance zone of new NOT GO gauges for nominal sizes up to and including 180 mm is symmetrical to the NOT GO limit. For sizes above 180 mm the tolerance zone is symmetrical to a line lying inside the workpiece tolerance zone at a distance α or α_1 from the NOT GO limit.

3.9.2.1.2 GO LIMIT OF WORKPIECES. A reasonable life for GO gauges is obtained in two ways :

(*a*) by moving the tolerance zone of a new GO gauge inside the workpiece tolerance by an amount z or z_1 ;

(*b*) by allowing a tolerance of wear of the GO gauge outside the GO limit of the workpiece by an amount y or y_1 when this value is not zero.

In the range of sizes of nominal diameter above 180 mm the values of y and y_1 are reduced by the amount of the safety zones α and α_1 respectively so that in these cases the actual wear of the GO gauges is limited to y' and y'_1 respectively outside the GO limit of the workpiece (or to α and α_1 within this limit if y and y_1 are equal to zero).

The values of the y or y_1 margin have been taken as small as possible in order to reduce to a minimum the risk that workpieces with sizes outside the prescribed GO limit be accepted. This margin is therefore provided only in the case of smaller tolerances on workpieces, grades 6 to 8 up to 500 mm, the deletion of this margin being contemplated as a possibility in the future (in connection with the development of low cost low wear gauges).*

However, inspection without the y or y_1 margin is now permitted provided that it is clearly specified. In this case, in order to avoid any mistake, the workpiece tolerance should be conventionally designated by adding the letter N to its designation (for example 10H6N, 15G7N, 20f8N).*

In the range of sizes of nominal diameter above 180 mm, the workpiece tolerance has been reduced, at the GO (with y or y_1 margin) and NOT GO limits, by the amount of the safety zones α and α_1. Manufacturers and users should not forget that due to errors of measurement the sizes of workpieces may fall outside the limits of the gauges by the amount of the safety zones α and α_1 and that the extreme workpiece limits, given by y and y_1, may be reached.

3.9.2.2 TOLERANCES ON SIZE OF WORKING GAUGES. The tolerances on size of working gauges are based on the fundamental tolerances of grades 1 to 7, as given in Table 1.

Values of α, y, z, etc. for the gauges are given in Tables 2 and 2 A.

3.9.2.3 TOLERANCES ON FORM OF WORKING GAUGES. The tolerances on form of working gauges are based on the fundamental tolerances of grades 1 to 5, as given in Table 1.

3.9.2.4 ADJUSTABLE GAUGES OF SIZES ABOVE 180 mm. New GO gauges may be adjusted at any desired value within the limits of α and z or of α_1 and z_1 according to the permissible wear value.

Any trespassing of the GO workpiece limit may be easily avoided by adjusting the new GO gauge within the limit of z or z_1 and by adjusting it anew at the same limit as soon as wear brings its size to the size of the GO workpiece limit with a shift of α or α_1 inwards.

It is advisable to adjust NOT GO gauges to the size of the NOT GO workpiece limit with a shift of α or α_1 inwards.

* See footnote on page 7.

3.9.3 *Reference disks for gap gauges*

3.9.3.1 POSITIONS OF TOLERANCE ZONES WITH RESPECT TO THE WORKPIECE LIMITS (shown diagrammatically in Figure 9).

3.9.3.1.1 NOT GO LIMIT OF WORKPIECE. For nominal sizes up to and including 180 mm the tolerance zone of the reference disk is symmetrical to the NOT GO limit. For sizes above 180 mm the tolerance zone is symmetrical to a line lying inside the workpiece tolerance zone at a distance α_1 from the NOT GO limit.

3.9.3.1.2 GO LIMIT OF WORKPIECE. The tolerance zone of the reference disk for a new gap gauge is symmetrical to the z_1 value.

The tolerance zone of the reference disk for checking wear is located in the following manner :

(*a*) Workpieces of nominal sizes up to and including 180 mm : For tolerance grades 6 to 8 the tolerance zone of the reference disk is symmetrical to the y_1 value. For tolerance grades 9 to 16, y_1 is zero and hence the tolerance zone of the reference disk is symmetrical to the GO limit of the workpiece.

(*b*) Workpieces of nominal sizes above 180 mm : For tolerance grades 6 to 8 the tolerance zone of the reference disk is symmetrical to the y'_1 value ($y'_1 = y_1 - \alpha_1$). For tolerance grades 9 to 16, y_1 is zero and hence the tolerance zone of the reference disk is symmetrical to the α_1 value inside the GO limit of the workpiece.

3.9.3.2 TOLERANCES ON SIZE OF REFERENCE DISKS. The tolerances on size of the reference disks are based on the fundamental tolerances of grades 1 to 3, as given in Table 1.

Values of α_1, y_1, y'_1, z_1, etc. for the reference disks are given in Tables 2 and 2 A.

3.9.3.3 TOLERANCES ON FORM OF REFERENCE DISKS. The tolerances on form of the reference disks are based on the fundamental tolerances of grades 1 to 2, as given in Table 1.

3.9.3.4 RELATION BETWEEN TOLERANCES ON GAP GAUGES AND THEIR REFERENCE DISKS. The relation between the tolerance H_1 of the gap gauge and the tolerance H_p of its reference disk is as follows :

H_1 determines the limits of the value of the working size (see clause 3.7.4) of a gap gauge. The difference between the limits of size given by H_1 for the gap gauge and by H_p for the reference disk represents a safety zone on both sides of H_p to compensate for errors of measurement, in the same way as α and α_1 compensate for errors of measurement for workpieces of diameters over 180 mm. H_1 and H_p are therefore symmetrical (see Fig. 8). Therefore if, according to the definition of working size, gap gauges lie outside the zone H_p but within the zone H_1 they are still to be regarded as correct.

3.9.4 *Reference ring and plug gauges for setting measuring instruments.* The gauges should be made to tolerances on size and form equal to those for reference disks. The tolerance on size is disposed bilaterally with respect to the appropriate test limit of the workpiece. The size of each gauge should be measured across a diameter halfway through the gauge; the axial plane in which this diameter occurs and the measured size of the gauge should be marked on the end face of the gauge.

3.9.5 *Surface finish of gauges.* It is recommended that the arithmetical mean deviation R_a for the surface roughness of a gauge should not exceed 10 % of the corresponding tolerance on the size of the gauge, with preferably a maximum value of 0.2 μm (8 μin).

3.10 Settlement of disputes

Unless the contrary is clearly specified, inspection by limit gauges should be recognized as authoritative for acceptance, and it is agreed that a workpiece is satisfactory if it is recognized as good by a gauge conforming with the requirements of this ISO Recommendation.

To avoid any dispute requiring checking of the conformity of the gauges of the manufacturer, the following procedure is recommended in the use of gauges of the manufacturer and the purchaser.

3.10.1 *Inspection by the manufacturer.* Generally the inspection department that checks the workpieces made in the workshop can use the same types of gauges as those used in the workshop. In order to avoid differences between the results obtained by the workshop and inspection department it is recommended that the workshop uses new or only slightly worn GO gauges while the inspection department uses GO gauges having sizes nearer the permissible wear limit.

3.10.2 *Inspection by the purchaser.* There are three possible procedures for inspection on behalf of the purchaser by an inspector who does not belong to the manufacturing plant concerned :

(*a*) the inspector may gauge the workpieces with the manufacturer's own gauges, provided that he first checks the accuracy of these gauges;

(*b*) the inspector may use his own gauges, made in accordance with this ISO Recommendation, for inspecting workpieces. It is recommended that the GO gauges should have sizes near the wear limit in order to avoid differences between the results obtained by the manufacturer and inspector;

(*c*) the inspector may use his own inspection gauges for checking the workpieces. The disposition of the tolerance zones for these gauges should be such as to ensure that the inspector does not reject workpieces the sizes of which are within the specified limits.

3.11 Marking and designation of gauges

The recommendations relating to the marking and designation of the gauges are limited to the most essential information and it is assumed that there is room enough on the gauges. It is left to individual ISO Member Bodies to make further recommendations for use in their own countries if they so desire.

The information that is recommended is :

(*a*) the nominal size of the workpiece and the ISO symbols for deviation and tolerance (or, if these are not available, the value of the tolerance limit to be checked);

(*b*) a method of distinguishing the GO and NOT GO sides :

red colouring is recommended for the NOT GO side, and it is also possible to distinguish between the GO and NOT GO sides by using different shapes of measuring elements ;

(*c*) the working load, if necessary, for a gap gauge (see clause 3.7.4).

Room should be left for the following information : manufacturer's name or trademark, purchaser's mark and special remarks such as the serial number, workshop where the gauge is used, etc.

In the case of plug gauges of the renewable end type, the marking should appear both on the handle and on the renewable end.

It is unnecessary to indicate the reference temperature of 20 °C.

4. INDICATING MEASURING INSTRUMENTS

4.1 Definitions relating to measurements

4.1.1 *True size.* The size of a dimension which would be obtained by a measurement without any errors.

NOTE. – The nearest value of the true size at a given position on the workpiece is the average of a great number of measurements carried out with the greatest possible accuracy.

4.1.2 *Error of measurement.* The algebraical difference between the measured size and the true size.

NOTE. – Errors of measurement may be caused especially by the measuring equipment, the method of measurement, the operator or the environmental conditions.

Errors of measurement may be separated into systematic errors and random errors, defined as follows :

(*a*) the systematic error remains the same during a single series of measurements and may theoretically be eliminated by a corresponding correction of the measurement result;

(*b*) on the contrary, random error variations are indefinite and may not be eliminated. The resulting measurement uncertainty for a single series of measurements is represented by the standard deviation, as defined below, of the dispersion due to these errors.

4.1.3 *Systematic error*. The algebraical difference between the average of measured values and the true size, in a series of measurements of the size of a dimension, made at one position on the workpiece under the same experimental conditions.

4.1.4 *Random error*. The algebraical difference between the result of one individual measurement and the average of measured values, in a series of measurements made at one position on the workpiece under the same experimental conditions.

4.1.5 *Average*. The arithmetic mean value ($\bar{x}$) of a certain number (n) of values ($x_1, x_2, \ldots x_n$).

4.1.6 *Standard deviation*. A value representing the measuring uncertainty due to random error dispersion and estimated as the square root of the quotient of the sum of the squared differences of the individual results x_i and of their average $\bar{x}$ by the number of measurements minus one :

$$s = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1}}$$

4.2 Types of measuring instruments

Further ISO Recommendations (to supplement ISO Recommendation R 463, *Dial gauges reading in 0.01 mm, 0.001 in and 0.0001 in*) will give the characteristics of the various types of instruments for measuring lengths and the metrological conditions they should satisfy.

Measuring instruments may be divided into two main classes according to the way in which the measurement is carried out, either by comparison with a standard of length built into the instrument itself (for example a micrometer screw as in a hand micrometer, or a linear scale as in a vernier calliper), or by means of a comparator, the size of the workpiece being determined by comparing its size with that of a reference gauge of closely the same size.

4.3 Measuring uncertainty of the instrument

Any measuring instrument has its inherent error, independent of the part to be measured and of exterior conditions of measurement.

This inherent error may be subdivided into a systematic error likely to be compensated by a correction, and a random error giving rise to dispersion.

The random error is an irregular error the value of which cannot be estimated from one single reading but may be estimated as most probable from a number of successive readings. The frequency distribution of successive readings is close to a normal distribution, for which standardized tables are available allowing the determination of the percentage of readings within certain limits on both sides of the average reading (see Fig. 10).

However, it is not practical in the workshop to make the correction for suppressing the systematic error at each position (even if a curve of graduation errors has been plotted initially for each position of the measuring anvil) nor to carry out a sufficient number of readings at this position to deduce an average reading and thus suppress the random error.

It is therefore preferable to assume that each reading is correct within some assumedly constant error margin in the whole range of measurement of the instrument.

It is considered that for a very great number of measurements the systematic errors due to any basic elements of the instrument have an equal probability of being positive or negative and therefore these are considered as random errors.

Their being considered simultaneously with true random errors results in enlarging the distribution curve which thus represents the inherent errors of the instrument.

The corresponding error margin, i.e. the instrument measuring uncertainty, may be expressed in terms of the standard deviations of this curve, as being equal to ± $2s$; for a normal distribution, 95.45 % of readings will not depart from the mean size (true value) by more than twice the standard deviation s.

To obtain a representative value of the measuring uncertainty of a single design of instrument, it is necessary to test a complete lot of instruments, generally in a laboratory : the values thus obtained represent the inherent uncertainty of the instrument.

It is recommended that manufacturers should specify the uncertainty at ± 2s in the directions or specifications for use of newly supplied instruments, and state whether the specified measuring uncertainty is that of the indicating head or of the complete equipment including the indicating head.

4.4 Total measuring uncertainty

In order to be used in the workshop, the above-defined value of the inherent uncertainty of the instrument should be multiplied by a coefficient w taking into account the other systematic and random errors caused by the poorer environmental conditions in the workshop, and the inferior care, experience and ability of the operator.

Hence, for the standard deviation : $s_m = ws$, the value of s_m being the overall measuring uncertainty.

As a rule, $w = 2$ may be chosen (a value greater than 2 would correspond to especially poor conditions, while a lesser value would on the contrary correspond to exceptionally fine conditions, as for example in a room having controlled constant temperature).

4.5 Inspection limits

Due to uncertainty of measurement, if workpiece dimensions are very close to the prescribed limits, the user of the measuring instrument may run the risk of accepting workpieces outside the limits or of rejecting workpieces within these limits.

To reduce this risk to a minimum, the inspection limits should be placed within the specified limits by a conventional amount s_m, equal to the value of the standard deviation of the measuring process (see Fig. 11).

In consequence, in order not to reduce the manufacturing tolerance zone of the workpiece, the measuring instrument should be chosen so that the corresponding value of s_m does not exceed a given maximum s_M for each diameter and tolerance of a part.

The standardized values of s_M are given for guidance in Tables 3 and 3 A for each grade and diameter range.

4.6 Influence of form errors

If the usual type of measuring instrument having two diametrically opposed anvils is used it should be borne in mind that this inspection method satisfies the Taylor principle only for the minimum material limit (NOT GO side of the workpiece).

For this limit it is enough to carry out the inspection at a sufficient number of positions on the workpiece.

On the contrary, at the maximum material limit (GO side of the workpiece), two-point measurements even at several successive positions do not ensure, if the workpiece has form errors (especially lobing), that no point of the surface infringes the perfect inscribed or circumscribed cylinder specified in the Taylor principle.

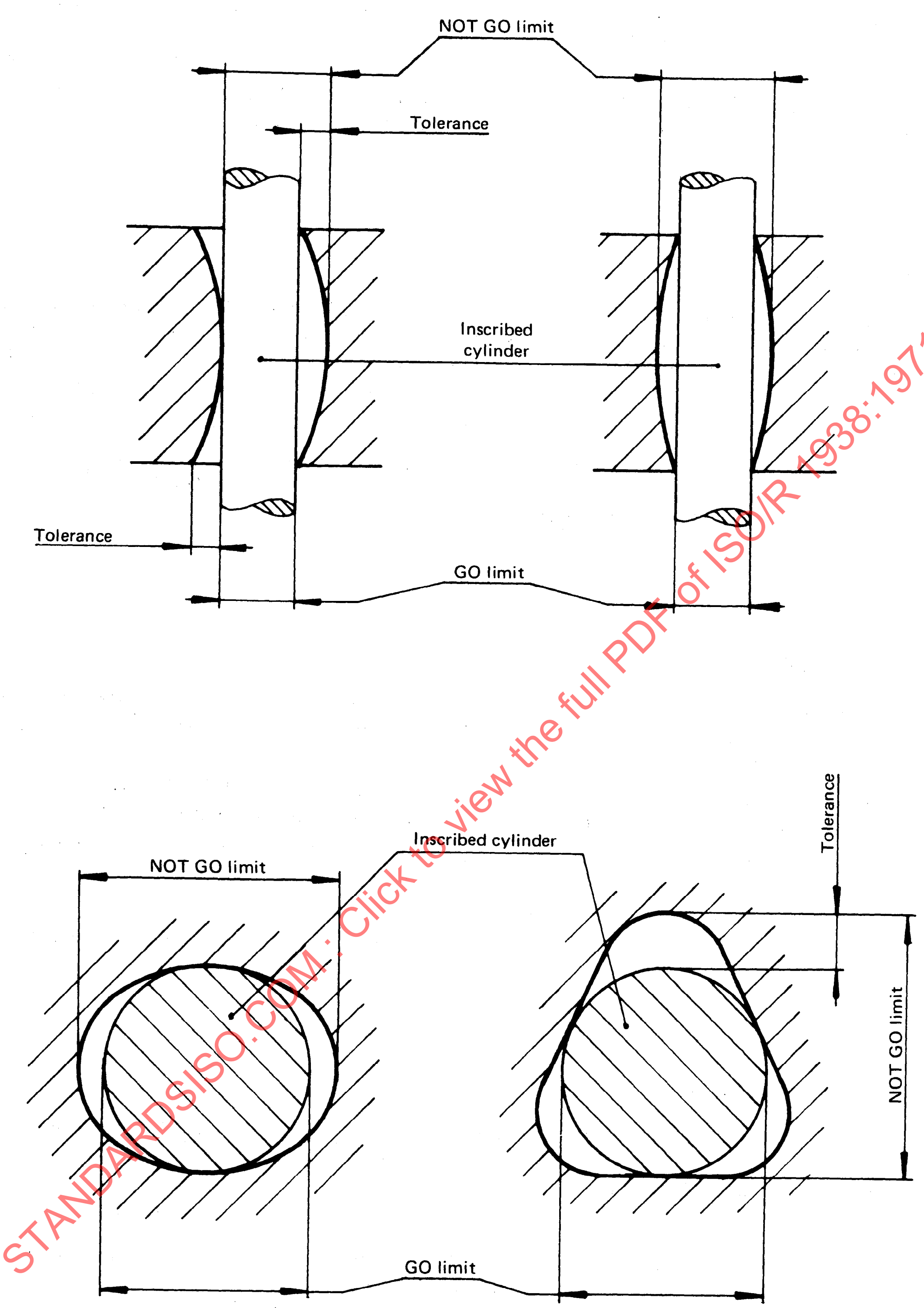


FIG. 1 – Extreme errors of form of hole allowed by the recommended interpretation of the limits of size

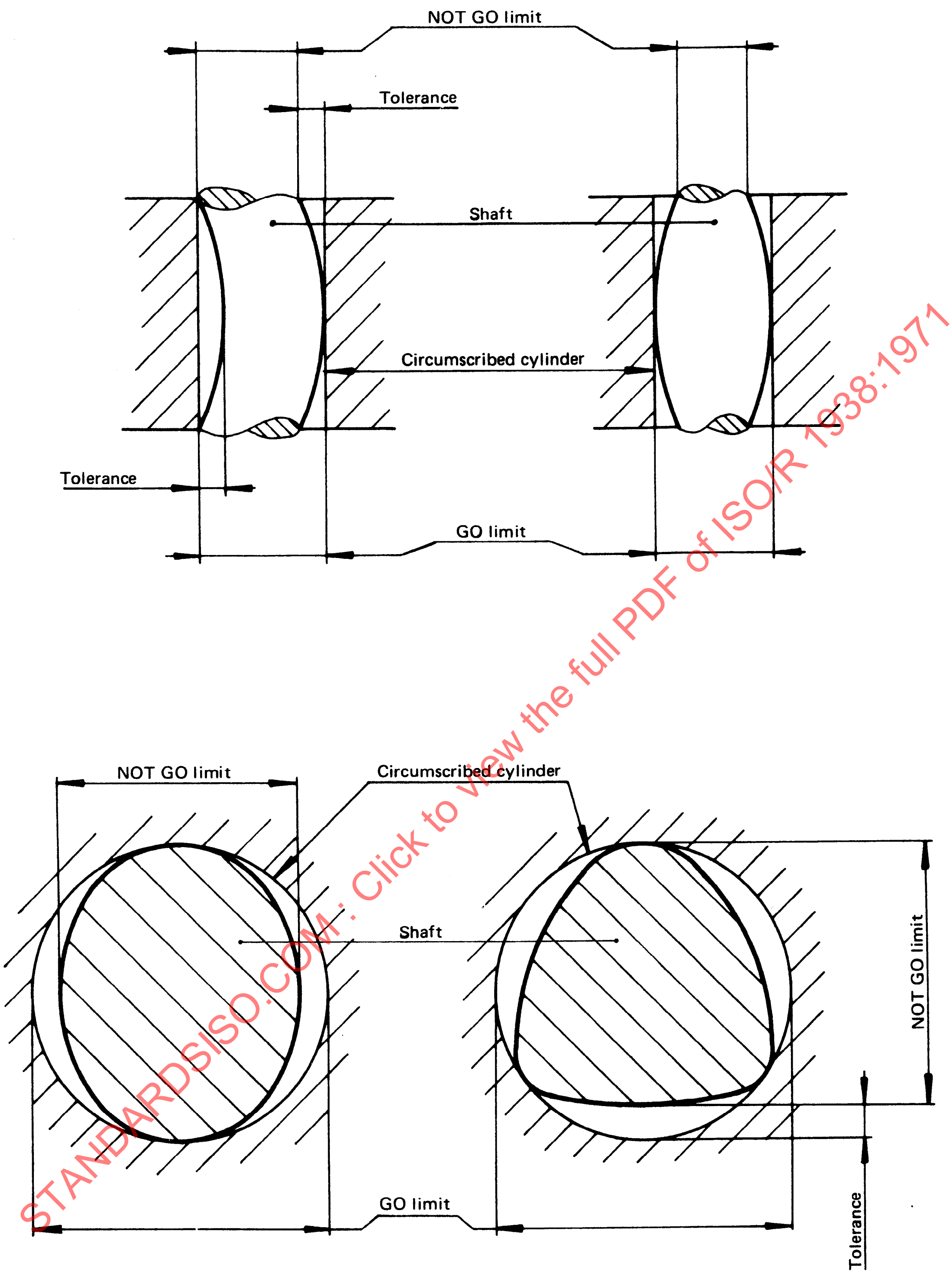


FIG. 2 – Extreme errors of form of shaft allowed by the recommended interpretation of the limits of size

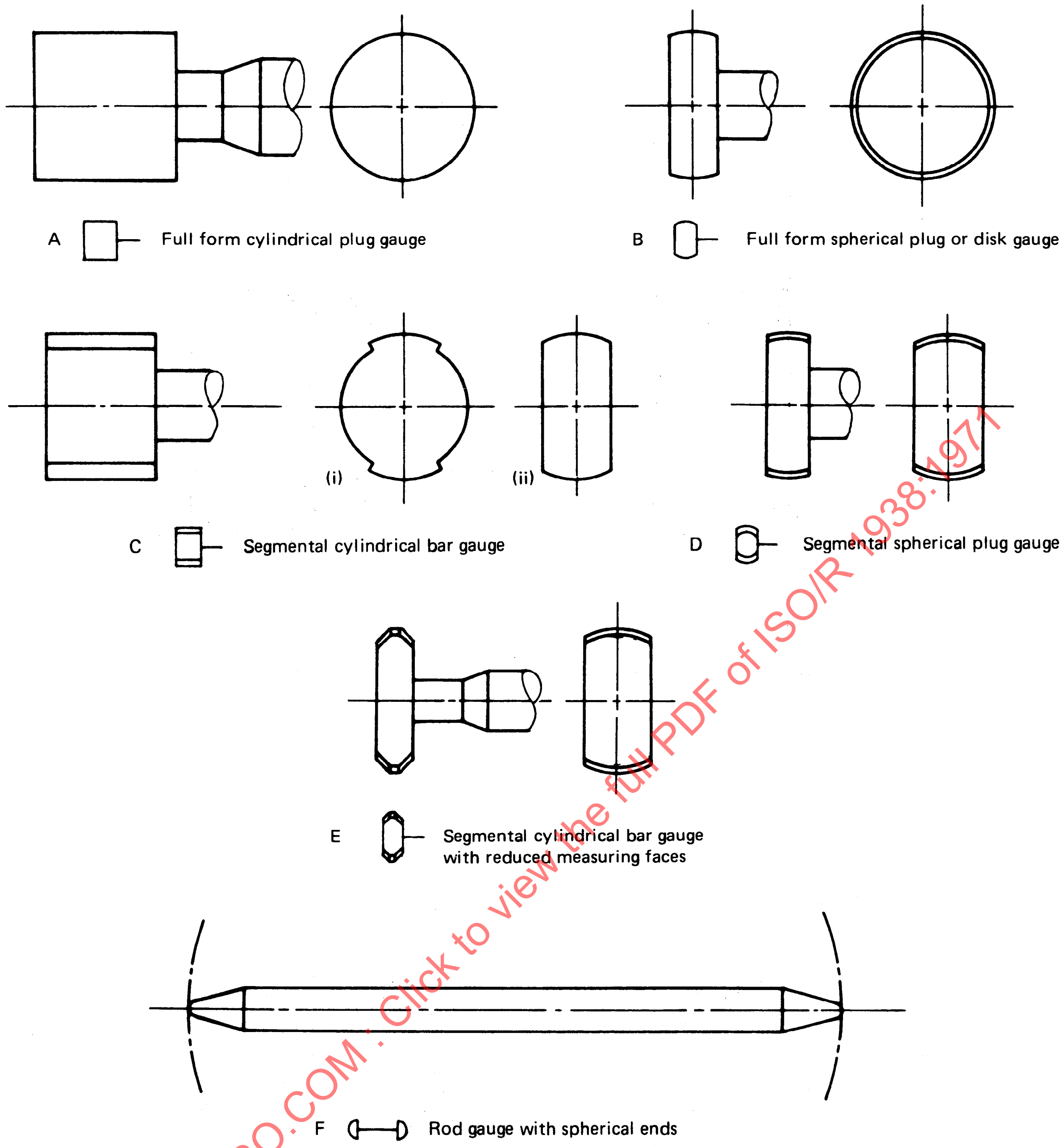


FIG. 3 – Recommended types of gauges for holes (and their corresponding symbols for Fig. 5)

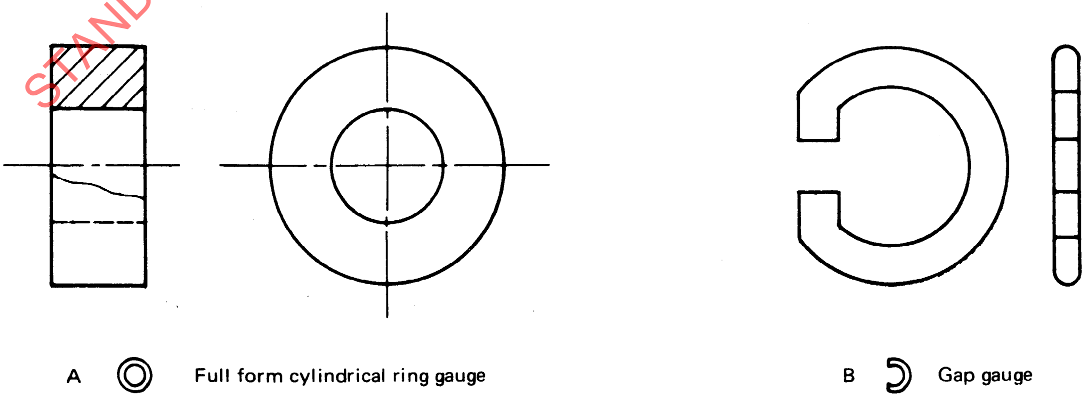


FIG. 4 – Recommended types of gauges for shafts (and their corresponding symbols for Fig. 6)

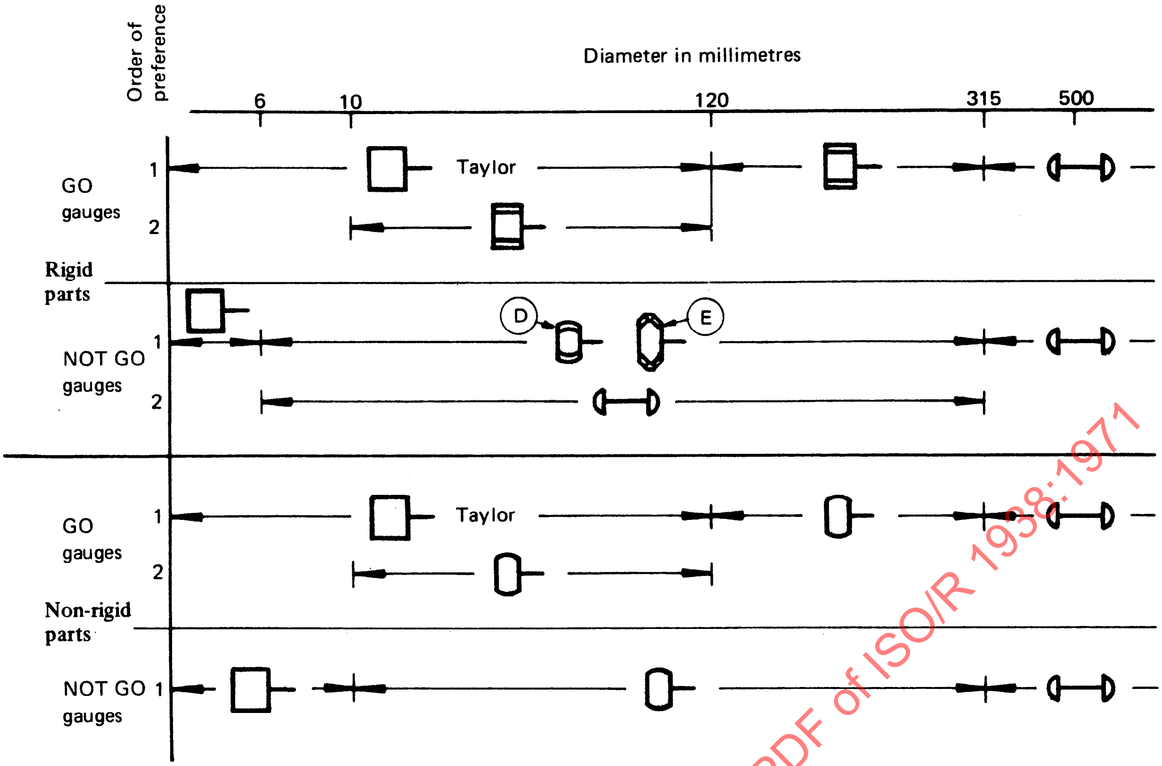


FIG. 5 – Types of gauges used to check holes, in order of preference

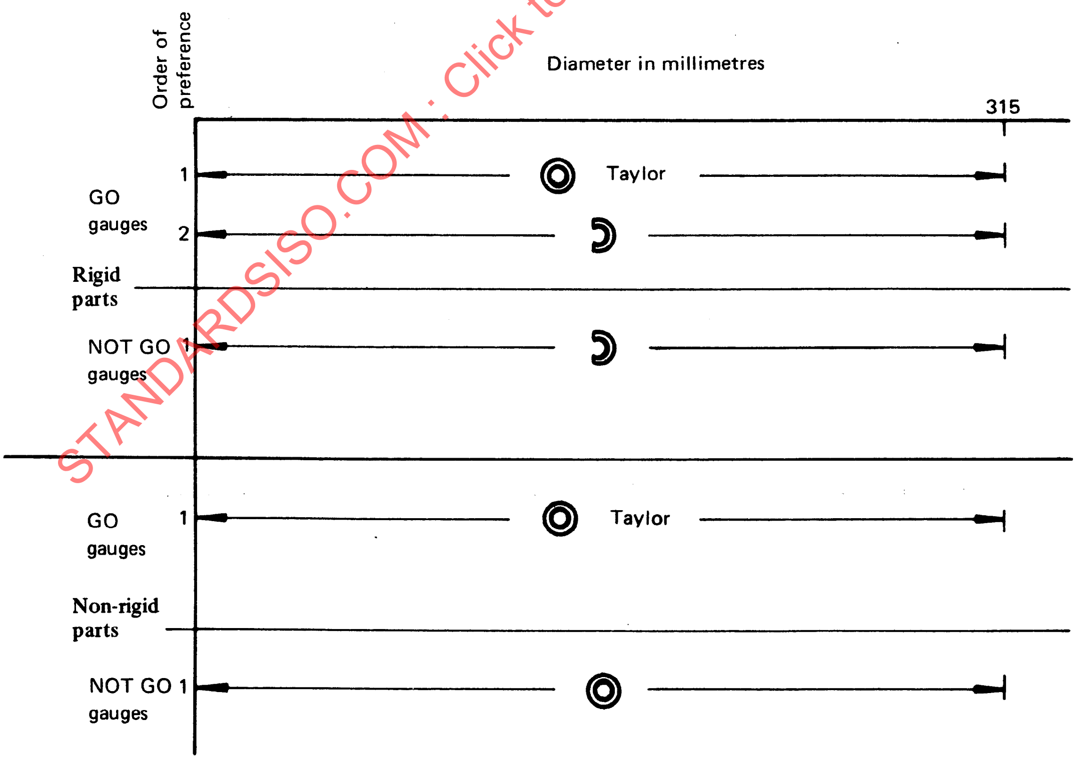


FIG. 6 – Types of gauges used to check shafts, in order of preference

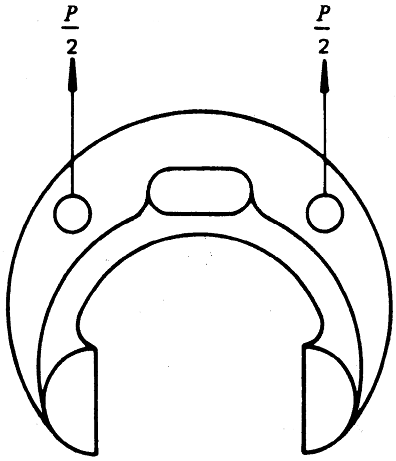
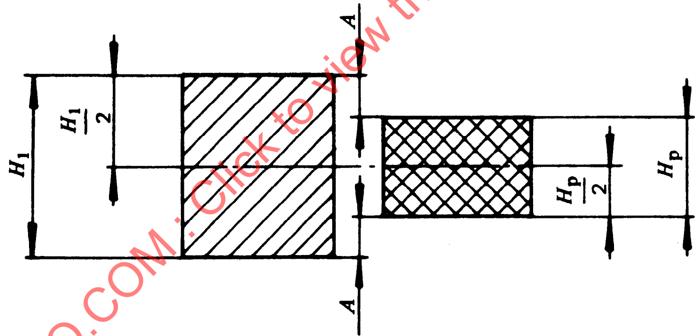


FIG. 7 – **Location of points where forces counterbalancing parts of the weight of the gauge should be applied**



H_1 = Manufacturing tolerance of the gap-gauge
H_p = Manufacturing tolerance of the reference disk
A = Safety zone

FIG. 8 – **Relation between manufacturing tolerances of gap gauges and of reference disks**