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MIL-HDBK-682(AT)
12 July 1991
SUPERSEDING
(See 6.3)

MILITARY HANDBOOK

TOLERANCING, DIMENSIONING, AND GAGING TECHNIQUES FOR THE DESIGN OF INSPECTION EQUIPMENT

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FOREWORD

1. This military handbook is approved for use by the U.S. Army Tank-Automotive Command, Department of the Army, and is available for use by all Departments and Agencies of the Department of Defense.

2. Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to: U.S. Army Tank-Automotive Command, ATTN: AMSTA-GDS, Warren, MI 48397-5000, by using the self-addressed Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

3. This handbook reiterates the basic policy of DOD, which is to place responsibility for design, supply, and maintenance of inspection equipment on the production contractors. The contractors are required to make their inspection equipment available to the Government for verification and inspection purposes.

4. This handbook is published for information and guidance of product assurance, engineering, maintenance, procurement, and contractor personnel. It serves as a textbook for training of personnel responsible for specifying or reviewing methods of inspection and test procedures in product assurance programs. It provides designs and quality standards that can be applied throughout the life cycle of an item, i.e. development, production, repair parts, and rebuild. The intent is to avoid duplication of inspection equipment design effort and to prove designs during early phases of an item. This handbook specifies methods for providing proven design information on a timely basis during mobilization or other emergency when qualified engineers are not available.

5. Inspection requirements for the overall product assurance program encompass the development phase, production engineering phase, and operational maintenance phase of the product life cycle. During the development phase, preliminary inspection equipment will be designed in the form of sketches and breadboard construction. During the production engineering phase, inspection equipment requirements will be finalized and will be based on the data originated during the development phase. Inspection equipment designs for operational maintenance will employ these same principles. While this handbook is applicable to all phases, it will be most useful in the production engineering phase. The greatest content coverage is in this area.

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1. SCOPE

1.1 Scope. This handbook defines and amplifies policies and concepts used in technical data formulation and gaging techniques for the acceptance of tank-automotive materiel. The scope of this handbook is limited to inspection equipment design.

1.2 Purpose. The purpose of this handbook is to acquaint inspection engineering contractors with above policies and concepts. It also provides guidelines to Government personnel for evaluation of inspection equipment designs submitted by the production contractor for approval. Pertinent problem areas are highlighted and guidelines for their solution are established. It is assumed that the user meets the qualifications of a competent inspection equipment designer who is not necessarily familiar with applicable requirements and regulations.

1.3 Objectives. The primary objective is to have all necessary inspection equipment fully qualified at the start of production, available, and compatible with the method and rate of production. While the amount of Government inspection equipment will be substantially reduced, Government inspection designs, which have been proven during earlier production and development phases, will be available for subsequent production. These designs will be usable in a number of ways. They may be utilized for direct construction or as the basis for a design modified to meet particular production requirements. When the production contractor already owns inspection equipment that the contractor considers suitable, the Government designs will serve as a basis for comparison to determine the equipment's adequacy. In this manner, the production contractor's equipment will be used to a far greater extent than was previously possible. The Government designs will further serve as the basis for the design and/or manufacture of inspection equipment for operational maintenance and rebuild.

1.4 Inspection equipment terms. The terms inspection equipment and design of inspection equipment are used interchangeably with the terms gaging equipment and design of gaging equipment in this handbook.

2. APPLICABLE DOCUMENTS

2.1 Government documents.

2.1.1 Specifications, standards, and handbooks. The following specifications, standards, and handbooks form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those listed in the issue of the Department of Defense Index of Specifications and Standards (DODISS) and supplement thereto, cited in the solicitation (see 6.2).

SPECIFICATIONS

MILITARY

DOD-D-1000	- Engineering Drawings and Associated Lists.

STANDARDS

MILITARY

DOD-STD-100	- Engineering Drawing Practices.
MIL-STD-961	- Military Specifications and Associated Documents Preparation of.

(Unless otherwise indicated, copies of federal and military specifications, standards, and handbooks are available from the Navy Publication and Printing Service Office, Standardization Documents Order Desk, Bldg 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.)

2.1.2 Other Government documents, drawings, and publications. The following other Government documents, drawings, and publications form a part of this document to the extent specified herein. Unless otherwise specified, the issues are those cited in the solicitation.

ARMY REGULATIONS

AMCR 11-26	- Configuration Management.
AMCR 702-2	- Inspection Equipment Design.

PAMPHLETS

TACOM

11-44	- Handbook for Preparation of Engineering Drawings and Associated Lists.
11-45	- Handbook for Configuration Control and Status Accounting.

DRAWINGS

7395223	- Drafting Practices - Inspection Equipment Design.

(Copies of drawings, publications, and other Government documents required by the contractors in connection with specific acquisition functions should be obtained from the contracting activity or as directed by the contracting officer.)

2.2 Non-Government publications. The following document(s) form a part of this document to the extent specified herein. Unless otherwise specified, the issues of the documents which are DOD adopted are those listed in the issue of the DODISS cited in the solicitation (see 6.2).

AMERICAN NATIONAL STANDARDS INSTITUTE (ANSI)

ANSI Y14.5	- Dimensioning and Tolerancing.
ANSI/ASME B46.1	- Surface Texture.

(Application for copies should be addressed to ASME, 345 East 47th Street, New York, NY 10017, or from ANSI, 1430 Broadway, New York, NY 10018.)

(Non-Government standards and other publications are normally available from the organizations that prepare or distribute the documents. These documents also may be available in or through libraries or other informational services.)

2.3 Order of precedence. In the event of a conflict between the text of this document and the references cited herein, the text of this handbook takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

3. DEFINITIONS

3.1 Maximum material condition (MMC). The condition in which a feature of size contains the maximum amount of material within the stated limits of size - for example, minimum hole diameter, maximum shaft diameter.

3.2 Quality assurance provisions (QAPs). QAPs are documents which establish uniform inspection and test procedures for items procured by the Government for issue to the user.

3.3 Regardless of feature size (RFS). The term used to indicate that a geometric tolerance or datum reference applies at any increment of size of the feature within its size tolerance.

3.4 Tolerance. The total amount by which a specific dimension is permitted to vary. The tolerance is the difference between the maximum and minimum limits.

3.4.1 Unilateral tolerance. A tolerance in which variation is permitted in one direction from the specified dimension.

3.4.2 Bilateral tolerance. A tolerance in which variation is permitted in both directions from the specified dimension.

3.5 Total indicator reading. The total movement of an indicator when appropriately applied to a surface to measure its variations.

3.6 Surface texture. Surface texture is the repetitive or random deviation from the normal surface that forms the three-dimensional topography of the surface. Surface texture includes roughness, waviness, lay, and flaws. Reference ANSI/ASME B46.1 for further definition and measurement of surface texture.

4. TOLERANCING AND DIMENSIONING

4.1 Application. This section covers a discussion on drafting practices related to tolerancing and dimensioning drawings as required to assure the adequacy of gages designed to inspect and verify product conformance to specified requirements.

4.1.1 Base documents. All special inspection equipment designs are primarily based on two documents:

a. The product drawing (see 4.1.1.1).
b. Related quality assurance provisions (QAPs) (see 4.1.1.2).

In addition, these designs may be based in a general procurement specification (see 4.1.1.3) - either as a sole reference, or in conjunction with the drawing and/or other documents.

4.1.1.1 Product drawing. The product drawing is the primary procurement documents on which all other procurement documents must be based. The single exception may be the procurement specification which may sometimes contain certain requirements which originated prior to the product drawing. However, the greater part of its data is also based on the product drawing.

4.1.1.2 Quality assurance provisions. QAP preparation is based on a review of the product drawing to determine which of its characteristics must be inspected, and that the methods for their inspection are adequate. Each selected characteristic is listed and, as necessary, further defined in the QAP. The QAP also identifies those characteristics which require special inspection equipment designs. Such identification, however, does not restrict the production contractor from using open set-up inspection if he can prove inspection adequacy does not suffer in the process. By the same token, if the QAP calls for the use of standard inspection equipment on open set-up, this does not prevent the production contractor from using special inspection equipment of equal or superior accuracy and sophistication. The purpose for describing the method of inspection on the QAP is to assure a minimum degree of acceptable accuracy, and provide a practical method of accomplishment. For example, a QAP might list a snap gage as an acceptable method of inspection for a dimension having a tolerance of .005. This would not prevent the production contractor from using a dial snap gage, an air gage, or even a micrometer as a proper method of inspection. However, it would preclude the use of an outside caliper or a machinist's scale for this purpose.

4.1.1.3 Procurement specification. While based primarily on the product drawing, the procurement specification often contains test data determined during the development phase of the product. Product requirements are specified in section three of these documents and the method of inspection is covered in section four. In reviewing these documents, any quality assurance provision listed in section four must have a corresponding requirement in section three (see MIL-STD-961 for more detailed instructions).

4.2 Review of base documents. Before proceeding with the special inspection equipment design, the designer must make three determinations as listed in items a through c.

a. First, ascertain that conflict does not exist between any of the documents on which the design is to be based - such as the product drawing and the QAP. The documents may supplement or complement each other, but must not disagree.

b. Next, determine whether or not the inspection characteristic is adequately specified for purposes of inspection. All related documents must be considered as a whole for this determination because of their complementary nature.

c. Finally, determine whether or not the inspection characteristic is specified in such a manner as to be practical for inspection purposes. The system of dimensioning based on maximum material condition (MMC) as described in ANSI Y14.5 will have considerable influence on this determination. In case of failure to comply, engineering change proposal (ECP) action should be initiated (see 4.6).

4.3 Conflict between complementary documents. Areas in which conflict is most likely to be encountered are listed in items a through c.

a. Selection of implied datum surfaces.

b. Improper application of rules where regardless of feature size (RFS) or MMC is not directly specified.

c. Improper interpretation of both specified and implied geometric tolerances.

4.3.1 Implied datum surfaces. Datum referencing is covered in ANSI Y14.5. When the locating datum surface is not clearly specified in the product drawing, there is always a possibility of ambiguity in its determination (see figure 1). If reasonable doubt exists which could affect the design of the special inspection equipment, it must be clarified by ECP action. While figure 1 is actually an example of inadequate specification, it also serves as an explanation of the conflict shown between the product drawing in figure 2 and the characteristic described in the excerpt from its related QAP. The disagreement between the two documents over the identity of the locating datum must be corrected prior to starting the design of the concentricity gage. This is necessary because the gage designer would not necessarily know which document was correct.

4.3.2 Improper application of RFS or MMC. The rules for applicability of RFS and MMC are given in ANSI Y14.5. When the drawing fails to specify to the contrary, these rules are applicable as stated. Whenever there is reasonable doubt as to the applicability of any of these general rules to an inspection characteristic, ECP action should be initiated.

4.3.3 Improper interpretation of geometric tolerances. Specified form tolerances are defined in ANSI Y14.5. The product drawing should be studied quite closely to determine the true intent of the product designer. In this manner, the true requirements of the special inspection equipment designs will also be established. Any conflict between implied and specified tolerances of form, either between documents or within a single document, should be cause for ECP action.

4.4 Required inspection data.

4.4.1 Adequacy of required inspection data on drawings of machined item. An inspection characteristic in a drawing of a machined item is adequate if the inspection data listed in items a through g is clearly specified.

a. Locating datum surfaces are identified which establish location of the product in all planes necessary for inspection.

b. Location of those datum surfaces is established relative to one another.

c. Sizes and tolerances are established for all features involved in the inspection characteristic.

d. Relationship of all pertinent features is clearly identified as RFS or MMC.

e. Surfaces for applied measurement are clearly identified and distinguished from surfaces of location.

f. Size and/or tolerance of the inspection characteristic is clearly established.

g. Required surface finishes are correctly identified and numerically quantified, if required.

4.4.2 Adequacy of required inspection data in envelope type drawings. Envelope type drawings of assembled components specify a wide variety of test data. This same problem is inherent in procurement specifications. Because of this, the adequacy of these documents must be determined and described in a very general manner. The adequacy of inspection data should include, but is not limited to, items a through c and be clearly specified.

a. Controls must be established for all variables which could affect the accuracy of the test results.

b. In most cases, either a MIN or MAX control needs to be assigned to each variable. In some instances, it will be essential that both high and low limits be established for the control of these variables. Each variable must be analyzed to determine that the control will assure the needs of the Government.

c. Well defined criteria for acceptance or rejection of the product must be established. Again, in some instances both high and low limits will be necessary. In most cases, however, only a MIN or MAX value will be required. Each criterion must be judged on its own merit relative to the needs of the Government.

4.4.2.1 Variables. Paragraph 4.4.2 deals in generalities rather than with a specific component assembly. A list of specific variables which may be encountered is not feasible. The items listed in a through s contain variables most likely to be encountered.

a. Mounting interface (size, configuration, etc.)

b. Mounting position (vertical, horizontal, etc.)

c. Speed (input, and/or output)

d. Lubrication (quantity and type)

e. Temperature (internal, external, ambient)

f. Temperature rise above ambient (relative to time)

g. Pressure (internal, external, ambient)

h. psi, psia, psig

i. Pressure differential (rise or drop)

j. Flow rate

k. Test fluid

l. Viscosity

m. Voltage

n. Amperage

o. Input energy

p. Output load

q. Duty cycle

r. Filtration

s. Duration of test.

4.4.2.2 Unacceptable forms of variables. The terms and phrases listed in items a through h are frequently used relative to the variables listed in 4.4.2.1 as a basis for acceptability. However, these and similar terms are inadequate for inspection and require further definition.

a. Noise must not be excessive.

b. Examine for signs of excessive wear.

c. Excessive leakage will not be permissible.

d. Slight leakage will be permissible.

e. Examine for signs of excessive heat.

f. Excessive arcing will be cause for rejection.

g. Must not show signs of lack of lubrication.

h. Must shift freely.

4.5 Practical inspection methods. The inspection data requirement must be specified in such a manner as to make its inspection practical. If a method of inspection is defined in a supplementary or complementary document, it should be analyzed to assure that it will adequately inspect the specified requirement from a practical standpoint. Regardless of how elaborately a requirement may be specified, it is useful only if it can be accurately verified by practical inspection methods.

4.5.1 Envelope type drawings. Evaluation of the adequacy of envelope type drawings that contain mounting data and other similar information is described in 4.5.2. Other than this information, the functional and performance data is too extensive for detailed coverage in this handbook.

4.5.2 Drawings of machined items. There are two areas in which improper selection of the method of dimensioning frequently makes inspection impractical. The first involves the specification of concentricity, perpendicularity, or parallelism relative to a locating datum diameter which is short compared with its diametral size. The second area consists of the failure to apply the MMC form of dimensioning to static, non-interference fit conditions. Other conditions exist but the majority of the problems encountered will relate to these two areas.

4.5.2.1 Short pilot diameters - functional surfaces. It is important to select datums that are functional in order for a practical method of inspection to be achieved. For example, figure 3 depicts a removable bearing mount such as might be found in a large transfer case. It utilizes a short pilot diameter and a large mounting flange to establish its location and position when installed in the transfer case housing. Since this part serves as a mount for an anti-friction bearing, it must also serve to accurately locate and align that bearing relative to the transfer case housing.

4.5.2.1.1 Frequently used control method. A method frequently used to specify control over these requirements is shown in figure 4. Under this method, the pilot diameter noted in figure 3 is designated as locating datum diameter "A", and the bearing diameter is held concentric to "A" within .002 TIR. Both the mounting flange and the bearing seat are held perpendicular to datum diameter "A" within .002. A review of this system of control shows that all functional surfaces are identified and their functional relationships are controlled. This drawing meets all the requirements of 4.4 for adequacy relative to the inspection characteristic of concentricity of the bearing diameter relative to the pilot diameter. The drawing in figure 4 meets all the requirements of 4.4 and is therefore adequately specified; however, it is specified in such a manner as to make inspection impractical. The pilot diameter, by itself, is too short to be used for alignment of any special inspection equipment. All three positional controls which utilize the pilot diameter "A" as their locating datum are specified in such a manner as to make inspection impractical. While it is true that the pilot diameter is the functional locating diameter, it is also true that the mounting surface serves for alignment of the mount. If the method of dimensioning is to be completely functional, it must establish both the pilot diameter and the mounting surface of the flange as the locating datum.

4.5.2.1.2 Proper form of dimensioning. The proper form of dimensioning under these conditions is shown in figure 5. Both the pilot diameter and the mounting surface of the flange are identified as locating datums. They are used to locate the bearing mount in the housing of the transfer case and must be used to locate the special inspection equipment required. In the case of the bearing diameter, note the combined specification of concentricity and perpendicularity. The bearing diameter (regardless of its feature size) must be concentric about the axis of datum diameter "A" (regardless of its feature size) within .002 TIR when that axis is extended perpendicular to datum surface "B". From this, it is quite apparent that this method for dimensioning the locating of the bearing diameter is fully functional and the applicable method of inspection must also be functional. This, however does not assure alignment. Alignment of the bearing will be influenced by the shoulder of the bearing diameter. Alignment of the shoulder is dependent on the mounting surface of the flange. Considered this way, parallelism between the two is all that is necessary to control the bearing alignment. The only functional relationship which lacks a specified control is perpendicularity of datum diameter "A" to datum surface "B". In this particular instance, the functional influence between the two is insufficient to warrant a specified control because the pilot diameter is so short.

4.5.2.1.3 Other variations. The problem of short pilot diameter covered in 4.5.2.1 through 4.5.2.1.2 is only one basic example. Although this example is one of the most common encountered, it is far from the only one. The variations to the form illustrated are numerous. All these variations will be readily recognized by remembering that a short diameter can only serve to locate in a single plane, and cannot be used to assure precision alignment. Another surface must be utilized for that alignment - both alignment of the product and alignment of the inspection equipment.

4.5.2.2 MMC system of dimensioning. MMC is identified in ANSI Y14.5, as MAXIMUM MATERIAL CONDITION. It is further defined in ANSI Y14.5 as "The condition where a feature of size contains the maximum amount of material within the stated limits of size. For example, minimum hole diameter, maximum shaft diameter". This is not the full meaning of MMC. While much reference is made to MMC in ANSI Y14.5, and many of its applications are illustrated, the full meaning and its far reaching effects are not found in that document. Regardless of this fact, ANSI Y14.5 provides a basic introduction. It will be necessary to study ANSI Y14.5 quite thoroughly before proceeding further. In addition to the coverage in ANSI Y14.5, it is necessary to know the basis for the establishment of MMC as a system of dimensioning, rather than merely its definition. Once this is known, the type of situation for which it is functionally applicable will be more readily recognizable.

4.5.2.2.1 Fit. For two parts to fit together properly, it is not necessary that their true size be known. As long as the desired fit is known, they can be machined by trial-and-error until the fit is satisfactory.

4.5.2.2.2 Fit and strength. To assure both fit and strength, the size must also be established, but usually not to a high degree of precision. For example, the strength of a two inch diameter shaft would not change appreciably if the size were to vary by .015 inch.

4.5.2.2.3 Fit, strength, and interchangeability. When fit, strength, and production interchangeability are required, precision becomes an absolute necessity. If production interchangeability is to be assured, the product designer must depict all necessary measurements and the degree of precision required of the product drawing. These specifications must be assigned to permit practical measurements. If the need is for a round shaft to fit into a round hole, only size tolerance may be important. If it is to rotate in that hole, it may be necessary to control form tolerance of roundness and straightness, as well as the size tolerance. Since the tolerances of both form and size relate only to a single feature (the diameter), the relationship is still relatively simple.

4.5.2.2.4 Geometric relationships of keyed shaft. If this same shaft is to be keyed to a pulley or gear, a complex relationship develops in that we have two features (the key and the shaft) which are affected by both size and relative position. The key must fit with the keyway; the shaft must fit with the hole. The position of both the key relative to the shaft and the keyway relative to the hole can affect the fit of both features (see figure 6). Reconsidering the basic example of the round shaft fitting the round hole, it can be seen that the measurement is very simple. Adding the requirement of roundness and straightness, the measurement still remains relatively simple. When two features are combined in such a manner as to statically interrelate size and positional tolerances, proper specification and measurement become extremely complex. In figure 6, a common and fairly simple example of such a complex relationship is shown. The dimensioning and tolerancing at the top views show that these parts should fit together with a clearance of .001 on each side if position tolerance is zero. The views in the middle show that each part was machined to its Maximum Material Condition, and both the key and keyway have been positioned .0011 inch off-center. The bottom view shows the two parts assembled with interference. Because the dimensions and clearances are given in different planes, precise calculation of the interference would be extremely difficult. Therefore, positive assurance of a precise clearance is equally difficult.

a. Careful analysis of figure 6 reveals one interesting fact. Interference would not be present if any of the information in items (1) through (6) were true.

(1) If keyway was larger.
(2) If hole was larger.
(3) If key was smaller.
(4) If shaft was smaller.
(5) If keyway was better positioned.
(6) If key was better positioned.

b. This proves that interrelationship between size tolerance and position tolerance is important.

4.5.2.2.5 Geometric relationships of mounting hole patterns. Another example of this complex interrelationship is found in mounting hole patterns. This very common example is given coverage in ANSI Y14.5. It is recommended that the reader review that portion of ANSI Y14.5.

4.5.2.2.6 Similarities. It should be apparent that the keyed shaft in figure 6 and mounting hole patterns have many things in common. These similarities are based on the fact that their functional requirements are basically identical, as shown in items a through b.

a. Interchangeable mating parts must assemble together freely or with no more interference than that intended by the designer.

b. The clearance between individual features of interchangeable mating parts must not be greater than that intended by the designer.

4.5.2.2.6.1 Mounting hole patterns. In the case of the mounting hole patterns, it is important that the holes in mating parts match location closely enough to permit easy assembly of all the bolts. At the same time, no hole may be permitted to become large enough to significantly reduce the area of contact with the bolt head or nut.

4.5.2.2.6.2 Keyed shaft. In the case of the keyed shaft, a free fit is usually desirable for purposes of assembly or disassembly. There are exceptions in which the fit between the shaft and the hole is either a transition fit or an interference fit for purposes of alignment. Since pulsating or reciprocal loads are frequently encountered, free play or backlash between the key and keyway must not be excessive.

4.5.2.2.7 Analysis. Many methods used to dimension the location of mounting hole patterns are frequently complex and result in accumulation of location tolerances. This is particularly true of irregular hole patterns. There is a simplicity advantage of true position tolerancing. Enlarging the holes to the maximum size automatically increases the allowable positional tolerance. Reviewing figure 6, it is quite obvious that if the key and keyway locations were controlled as illustrated in figure 7, interference would be avoided. However, the method of control shown in figure 8 accomplishes this same intent, but liberalizes these tolerances without reducing the quality of the product.

4.5.2.2.8 Primary advantage of MMC dimensioning. Liberalization of tolerances with no sacrifice to product quality illustrates the primary advantage of MMC dimensioning. Compared to this, advantages of convenience and simplicity of inspection are of secondary importance. The overall effect of MMC dimensioning relative to the Government is reduced cost of procurement with no reduction of quality. If any situation is encountered in which MMC dimensioning is functionally applicable, almost any other form of dimensioning used shall be cause for initiating ECP action. Unless prevented by very unusual circumstances, the MMC form of dimensioning must be applied to all static relationships in which two or more features are involved and both the size and positional tolerances controlling those relationships are completely interrelated.

4.6 Engineering change proposal (ECP) action. If the combined documents fail to comply with any of the requirements of 4.2, initiation of an ECP is mandatory. Until that ECP action is satisfactorily completed by correction of the offending documents, no special inspection equipment design should be started for that inspection characteristic. If cancellation of a request for a special inspection equipment design becomes necessary due to an unsatisfied ECP, the inspection engineering representative must be notified of this fact. Such notification will serve to point out a potential problem area so that action may be taken with the project engineer to rectify the situation. See TACOM pamphlet 11-45 for additional instructions.

5. INSPECTION EQUIPMENT DESIGNS

5.1 Inspection. This section covers a discussion on the fundamental rules for the design of inspection gages, on inspection gage categories, and on test, measuring and inspection equipment.

5.1.1 Extreme limits and tolerance. All designs of inspection equipment used to establish the acceptability of a product for the Government are based on fixed limit considerations. These are the extreme limits of acceptability specified for each inspection characteristic of the product. The permissible tolerance of a given characteristic is the difference between its extreme limits of acceptability.

5.1.1.1 Fundamental design rule. The fundamental rule governing the design of such equipment is that the equipment must never accept a product which exceeds those established limits. It is impossible to construct inspection equipment without consideration of possible error tolerance in final readout. To assure adherence to the fundamental rule, this potential error must be subtracted from the product tolerance. The end result will be that the inspection equipment may reject products which are barely within their established limits.

5.1.1.1.1 Tolerance limitations. Since any tolerance of the inspection equipment is subtracted from the product tolerance - the more liberal the inspection equipment tolerance, the less liberal the effective product tolerance and the more costly the product. For this reason, Government owned inspection equipment designs and/or equipment should not employ a tolerance in the final readout in excess of 10 percent of the product tolerance being inspected. Under no circumstance should this final readout tolerance exceed 25 percent of the product tolerance being inspected. If this cannot be achieved, inspection must be regarded as being impractical and an Engineering Change Proposal should be initiated to resolve the problem and effect a solution. Inspection equipment designs and/or equipment owned by the production contractor are not subject to these restrictions of percentage of tolerance because the production contractor must be given complete control over decisions affecting production economy. However, the fundamental rule in 5.1.1.1 is fully applicable to the contractor's designs and/or equipment.

5.1.1.1.2 Proven acceptability - rejection indicated. If approved inspection equipment is properly maintained within its specified calibration limits, and properly used, any product characteristic accepted by that equipment has been proven to be within its specified limits. However, because of the inspection equipment tolerance, rejection of a product characteristic by this equipment does not necessarily prove that the product is not within its specified limits. In cases involving a dispute of this nature, the rejected product will still be acceptable if it can be proven by any adequate means of inspection to be within its specified limits. The primary objective of the inspection equipment design must be to prove acceptability and indicate probable rejection of a product.

5.1.2 Establish limits - refinements optional. It is essential that all inspection equipment designs based on fixed product limit considerations must be capable of accurately establishing those limits in accordance with the rules established in this section. This is a mandatory requirement of all such designs - both those of the contractor and those of the Government. From the standpoint of the Government, it is totally unnecessary that the design incorporate any ability to establish actual values either within or beyond those limits. This is a requirement rather than a limitation. As such, it does not exclude the use of dial indicators or air gages for example, and insist on the substitution of flush pin or snap gage type devices. Instead, it permits and encourages the use of the latter types of devices which detect only when limits are exceeded rather than those which accurately determine intermediate values. When an inspection equipment design includes the ability to accurately determine intermediate values in addition to the required determination of the specified limit values, such a design exceeds the requirements of the Government but is not in conflict with them.

5.1.3 Maximum and minimum limits. In most instances, both maximum and minimum limits will be specified for an inspection value. Occasionally, only a maximum or minimum value will be specified and the unspecified limit merely implied. If only a maximum limit is specified, the minimum limit is implied to be zero. If only a minimum limit is specified, the maximum limit is implied to be infinity. Almost all cases in which only a maximum or minimum limit is specified involve practical considerations which prevent the limits of zero or infinity from being seriously considered as a limit. In those cases, the inspection equipment design need only ascertain the specified limit, and selection of the inspection equipment tolerance becomes an intangible which must be left to the discretion of the equipment designer. However, the fundamental rule of 5.1.1.1 is still fully applicable.

5.2 Inspection equipment categories. Inspection equipment falls into three general categories: gages, test equipment and measuring equipment. Gages are subcategorized as measuring RFS (Regardless of Feature Size) or MMC (Maximum Material Condition) and are further subcategorized as standard or special. Test equipment is subcategorized as commercial standard, special detailed design, or the type specified by a specification control drawing which may incorporate commercial equipment, the production contractor's equipment, or a combination of both. Measuring equipment compares a standard (traceable to the National Bureau of Standards) to the particular parameter and allows a form of readout to be available for accept/reject criteria.

5.3 Gages defined. Of the three categories, gages will be the most frequent concern of the inspection equipment designer. For this publication, a gage is defined as any device or mechanism used to assure the acceptability of products in accordance with their specified requirements relative to feature size, shape, and/or relative position. They should be designed and utilized to locate the datum surface(s) in order to effect a form of measurement from there to the measuring surface(s). Being devices for measurement, they are used to measure either without regard to feature size (RFS), or relative to the maximum material condition (MMC).

5.3.1 Datum surfaces. Datums are points, lines, planes, cylinders, etc. which are assumed to be exact for purposes of computation or reference, and from which the location of features of a part may be established. Datum surfaces are those surfaces utilized to establish datums. At least two, and often three datum surfaces are usually necessary to establish location of the gage relative to the product in the three basic planes for purposes of measurement. Exceptions are found in the measurement of a simple feature size such as diameter or thickness, where only one plane is involved. For a primary datum surface which is nominally flat, the datum must be assumed to be a plane established by the contacting points of the actual product surface with a reference plane such as an inspection surface plate or a precision flat rest surface of a gage (see figure 9). Similar analogies should be applied to other regular and well defined shapes, such as cylinders, cones, and spheres.

5.3.2 Measuring surfaces. All physical measurements involve two or more points, lines, planes, cylinders, etc. whose locations are established by surfaces. 5.3.1 defines one or more of these as a datum surface(s). The remaining surfaces involved in the same measurement are the measuring surfaces. In figure 10, for example, only two surfaces are involved. The surface designated as datum "A" contacts the rest surface of the gage. The remaining surface is then the measuring surface for inspection.

5.3.3 RFS gages. Gages designed to make precise measurements which are independent of size changes in the product feature from sample to sample are known as RFS type gages. They measure regardless of feature size. They are characterized by locating the gage with expanding devices, tapered devices, vee blocks, spring loaded devices, etc. They frequently utilize dial indicator type devices for measurement because of the ability to quickly reset to zero and isolate total variation rather than reference to an exact dimension (see figure 11).

5.3.3.1 Applicability to inspection requirements. Gages of the RFS type are automatically applicable to the inspection requirements of concentricity, straightness, symmetry, and coaxial relationships unless specified otherwise. The same ruling applies to requirements of roundness, flatness, parallelism, angularity, and perpendicularity, provided the form tolerance falls entirely within the tolerance zone for feature size. They are also applicable to any requirement in which it is specifically noted. Generally, these requirements will be specified on the product drawing for a control involving dynamic function or static interference fits.

5.3.3.2 Advantages of RFS gages. While the basic advantage is being able to perform a reasonable, functional measurement accurately, and independent of feature size variations, there are other advantages worth mentioning. One advantage is that the user is able to readily analyze the principle of operation and can troubleshoot production problems which arise. Most of these devices either do employ or can readily employ dial indicators or similar devices which not only determine if the part is within limits, but the magnitude and direction of error. These devices can usually be easily recalibrated because wear adjustments are an inherent part of the design. The basic advantage is that these gages fit the needs of the Government as tools to perform a reasonable, functional measurement accurately and independently of feature size variations. The ease of recalibration is also of considerable interest to the Government relative to later usage of the gages on rebuild programs. The other advantage would primarily interest only the production contractor directly, although the analytical abilities of the gage design can result in cost savings relative to production procurement.

5.3.3.3 Disadvantages of RFS gages. The RFS type gage is generally costly to build, time consuming to operate, readily subject to operator error, and requires more frequent calibration surveillance due to the incorporation of wear adjustments.

5.3.4 MMC gages. Gages designed to check the position tolerance of the product feature(s) while simultaneously relating its position tolerance with its size tolerance in a manner which allows either tolerance to interrelate with the other by substitution according to the manner in which the tolerance is specified, are known as MMC type gages.

5.3.4.1 Basic example (product). Figure 12 illustrates a product drawing requirement for the location and size of two holes. The two holes are basically to be .750/.760 diameter when located within cylindrical zones of .010 diameter established at a center distance of exactly 2.000 inches. ANSI Y14.5, applicability of MMC or RFS, applies to this requirement making the location tolerance only applicable at MMC. Essentially, this means that the specified distance of 1.990/2.010 need only apply when the holes are .750 in. diameter. If the holes are larger, the center distance may vary beyond those limits by a corresponding amount. If the actual center distance is closer to the basic center distance than the extreme limits specified, the holes could be correspondingly less than the .750 diameter specified. Table I illustrates this interrelationship of tolerances.

TABLE I. Interrelationship of tolerances.

ACTUAL DIAMETER OF HOLES	PERMISSIBLE CENTER DISTANCE RANGE
.750	1.990/2.010
.751	1.989/2.011
.752	1.988/2.012
.755	1.985/2.015
.760	1.980/2.020
ACTUAL CENTER DISTANCE	**PERMISSIBLE HOLE DIAMETER RANGE**
1.990 or 2.010	.750/.760
1.991 or 2.009	.749/.760
1.992 or 2.008	.748/.760
1.995 or 2.005	.745/.760
2.000	.740/.760

5.3.4.1.1 Analysis. Analysis of items a through c can help determine the purpose of each involved dimensional tolerance or size.

a. True position tolerance - to assure bolt clearance at the minimum permissible hole diameter (MMC of hole).

b. Minimum hole diameter (MMC) - to assure bolt clearance at the extreme limits of hole position center distance.

c. Maximum hole diameter - to assure enough remaining metal for adequate support of the bolt load.

The first two items may be interrelated because their purposes are so closely interrelated. In fact, any attempt to separate them can only result in unnecessary restrictions and correspondingly increased production costs. It is also readily apparent that the maximum hole diameter is completely independent of the other two, therefore, its limit does not change in table I.

5.3.4.1.2 Basic example (hole location gage). Figure 13 illustrates the hole location gage which is the basic inspection device that will adequately and efficiently ascertain that the hole location at MMC is as specified. The .740 diameter pins may be either fixed to the plate or removable as desired. Their mounting center distance must be maintained within the closest limits practical (not greater than .0005), and diameter tolerance must be in the plus direction in conformance with the fundamental design rule (see 5.1.1.1). The addition of a separate not go plug gage of .760 diameter-maximum completes the inspection requirements. If the product sample assembles with the hole location gage without excessive applied force, sufficient bolt clearance is assured. If the not go plug gage will not enter any of the holes, none of them are oversize and both requirements are fulfilled.

5.3.4.2 MMC gage use. The MMC type of gage is used whenever tolerances of feature sizes and positions are completely interrelated in such a manner as to permit the variation of one to affect the requirement of the other. MMC tolerancing automatically applies to any true position callout which does not specifically state to the contrary. It can also apply to flatness, straightness, angularity, perpendicularity, parallelism, concentricity, roundness, symmetry, or any combination of these when so designated. For example, figures 14 and 16 illustrate the pintle mount used for machine guns. Concentricity is often incorrectly specified in the conventional manner as shown in figure 14. Figure 15 illustrates the types of gages required to inspect the RFS condition specified in figure 14. Concentricity should be specified in a manner similar to that shown in figure 16 in which case inspection could be accomplished by the MMC gages illustrated in figure 17.

5.3.4.3 MMC gage type nomenclature. While in rare instances, a dial indicator or similar device may be incorporated into an MMC type gage, almost all MMC gages are of the "receiver" type. They are so named because they act as a receiver to the product sample. A pure receiver gage ascertains that the inspection characteristic being checked is correct if the product sample will assemble with the gage without the application of undue force. Other names under which this type of gage is commonly known are "Functional Gage" and "Go Composite Gage".

5.3.4.4 Advantages of MMC type gages. MMC type gages are relatively inexpensive to design and construct because they usually do not require moving parts or costly mechanisms. Production inspection time is reduced to an absolute minimum because complex relationships are simultaneously inspected by the simple expedient of assembling the product sample with the gage. Compensatory tolerances of size and location are automatically interrelated in a manner which does not require operator decision. This reduces both the need for operator skill and the possibility of operator error. The absence of precision moving parts and adjustments reduces the need for calibration surveillance to areas of wear due to contact with the product samples.

5.3.4.5 Disadvantages of MMC type gages. While MMC type gages adequately meet the requirements of the Government, the inspection principle involves the combined effect of tolerances. This principle does not readily lend itself to analytical inspection. It does not establish a true value for the magnitude and direction of any one particular error. While this information would be helpful to the production contractor, it would also prove quite complicated and expensive. None of the advantages listed for MMC type gages in 5.3.4.4 would no longer be applicable to a gage so designed. Another disadvantage is in the area of recalibration. While calibration surveillance is relatively simple, recalibration due to wear is usually accomplished only by part replacement or rebuild. For this reason, design consideration should be given to ease of recalibration.

5.3.4.6 Design of hole location gages. The example listed in items a through c illustrate the proper designs of MMC type gages relative to a number of variations in the manner of product requirement callout. Most of these variations can be easily explained and illustrated using hole patterns as examples. Such hole patterns can be generally classified as simple, compound, or complex - depending on the relationship between the hole pattern and locating datum surfaces.

a. A simple hole pattern is one in which all holes of the pattern bear an MMC location relationship with one another without involving a locating datum.

b. A compound hole pattern involves an MMC location relationship between a simple hole pattern and a locating datum diameter or its equivalent.

c. A complex hole pattern involves an MMC location relationship between three or more elements, those elements being a simple hole pattern and a locating datum diameter or its equivalent.

In these examples, the method of inspection illustrated consists of basically a flat plate into which precision gaging pins have been mounted. The method of mounting is not of concern for purposes of illustration. In actual practice, they could be press fitted, slip fit removable, or even welded in place. It is important to remember that these gage pins represent the utilization of a particular pin diameter located as closely to the basic positions specified for the product, as is practical. The gage pin diameters are to be regarded as minimum, since only the direction of tolerance is important to this analysis.

5.3.4.6.1 Simple hole patterns. Figures 18 through 20 are examples of simple hole patterns. Figure 18 illustrates a pattern in which all holes are the same diameter and subjected to the same location tolerance. In figure 19, two hole sizes and two location tolerances are involved, but the gage design illustrates that the design method is the same as that used in figure 18. In figure 20, the pattern of figure 18 is repeated and the pattern as a whole is located from the product edges. While these edges are implied datum surfaces, the location tolerance is RFS instead of MMC. The flush pin devices incorporated as part of the gage do not represent MMC gaging. The gage design shown is really a hybrid, using both types of gaging to achieve the goal of checking the location of a simple hole pattern as a composite entity.

5.3.4.6.2 Compound hole patterns. A situation very similar to that shown in figure 20 is shown in figure 21, except that the latter involves a compound hole pattern. The gage shown is designed to check both the hole pattern and its relationship to the related datum diameter "A". Note that the .750 diameter pin is made to the MMC of the hole, while the other gage pins are to the MMC less the location tolerance. In this example, location relative to the edges is not incorporated because these dimensions control the location of only the .750 diameter hole, not the location of the pattern. As such, its location should be inspected separately with an RFS type gage. With minor variation, this situation is repeated in figure 22. In this instance, that minor variation technically changes the hole pattern from compound to complex. However, it does not lend itself to inspection as a complex pattern with a single gage. For inspection purposes, it must be separated into a compound pattern (gage 1) and a simple pattern (gage 2).

5.3.4.6.3 Complex hole patterns. The example of a complex hole pattern in figure 23 is rather basic. Here, both the circle of bolt holes and the outside diameter bear an MMC relationship to the .750 pilot diameter. The .750 diameter is common to both requirements and would be identical on each gage, therefore, it is gaged as a complex hole pattern on the single gage illustrated.

5.4 Test equipment. In this handbook, the category of test equipment designates equipment used in testing a product relative to its functional or performance requirements. Such test equipment may be subcategorized as being commercial standard, test specification controlled, or special detailed designs.

5.4.1 Commercial standard test equipment. The term "commercial standard test equipment" is applied to industry developed multi-usage equipment that is specific to a function rather than to an item. It includes, but is not limited to, hardness testers, tensile strength testers, weighing devices, standard gear testers, electrical meter type devices, hydraulic or pneumatic gages, and oscilloscopes.

5.4.2 Test specification control. Commercial components utilized by the Government are usually defined and described on envelope type drawings. Because proprietary rights are often involved, functional and performance requirements are almost always necessary for proper determination of the component's acceptability. Where practical, test procedures to inspect these requirements are described in QAPs or procurement specifications. These procedures are frequently complex, lengthy, and very detailed making them difficult to specify in written form. In such cases, either a special detailed design or a "Test Equipment Specification Drawing" must be originated. The latter is the preferred solution except under special circumstances, such as described in 5.4.3. Test specification drawings are subdivided into two groups: Type A, which utilizes commercial standard equipment; and Type B, which utilizes the production contractor's specialized equipment.

5.4.2.1 Test equipment specification drawing. A test equipment specification drawing completely defines a test in full detail. It specifies all equipment required, describes the manner in which it is to be used, establishes the necessary characteristics and accuracy of the required equipment, establishes a step-by-step-procedure to be followed, and defines the acceptance criteria for the product. The items listed in a through g should be used as a general guide in the presentation of this information.

a. Name of test - Descriptive (see 5.4.2.1.1).
b. Description of test - If unusual or complex (see 5.4.2.1.2).
c. Purpose of document (see 5.4.2.1.3).
d. Equipment required (see 5.4.2.1.4).
e. Test procedure (see 5.4.2.1.5).
f. Acceptance criteria (see 5.4.2.1.6).
g. Arrangement diagram (see 5.4.2.1.7).

5.4.2.1.1 Name of test. Under this heading, a generally descriptive name of the test is given.

a. This name is also included in the title block such as:

TEST EQUIPMENT SPECIFICATION
LEAKAGE TEST

b. Examples of various tests as they might appear on the drawing are listed in items (1) through (4).

(1) LEAKAGE TEST
(2) ENDURANCE TEST
(3) IMPACT TEST
(4) FRICTION LAG TEST

5.4.2.1.2 Description of test. The names of some tests are not very definitive, particularly if the test is rather unusual or complex. The "Friction Lag Test" is one which is peculiar to the automotive clutch field, therefore, it requires further explanation when placed on the test equipment specification drawing. An example of how it should correctly appear follows.

FRICTION LAG TEST: THE TWO OUTER PLATES OF THE FRICTION DISK ASSEMBLY SANDWICH AND EXERT A SPRING FORCE ON THE HUB TO PRODUCE A DAMPING FRICTION. THE EFFECT OF THIS FRICTION, OR LAG, IS SIMILAR TO HYSTERESIS AND CAN BE MEASURED BY THIS TEST.

5.4.2.1.3 Purpose of document. The purpose of the test equipment specification drawing is to describe a test procedure which will determine product acceptability. Since the possibility of equivalent variations is almost infinite in some instances, these variations should not be excluded and a reasonable amount of control should be maintained by the Government. This is basically expressed by the following example which is shown as it would appear on the drawing.

PURPOSE: THE PURPOSE OF THIS DOCUMENT IS TO DESCRIBE AN ACCEPTABLE ARRANGEMENT OF TEST EQUIPMENT COMPONENTS FOR PERFORMING THE ABOVE TEST. UNLESS OTHERWISE SPECIFIED, THIS ARRANGEMENT MAY BE VARIED TO SUIT THE NEEDS OF THE USER IF THE ACCURACY AND COMPLETENESS OF THE TEST RESULTS ARE NOT ADVERSELY AFFECTED.

5.4.2.1.4 Equipment required. Although variations are permissible when warranted by special circumstances, particularly when dealing with Type B test drawings, the required equipment will be itemized in most instances under three columns titled: Item, Quantity, and Description. Under the term ITEM, a descriptive name will be applied to each piece or type of test equipment used in the test. Each item will be numbered for cross reference with the included arrangement diagrams. Under DESCRIPTION those items whose accuracy, range, capacity, etc. are only important to the operation of the test, but not vital to the accuracy or completeness of the test, may simply be described: TO SUIT. However, any characteristic which affects the accuracy or completeness of the test must be fully defined. Descriptions of accuracy, sensitivity, resolution, regulation, etc. should not be expressed generally as a percentage, but rather as an increment value at a particular range. For example: accuracy and resolution ±0.1 volts at test limits specified, or, accuracy, sensitivity and resolution ±1 psig at test limits specified. In these examples, the phraseology makes it necessary to establish calibration points at test limit values rather than to place reliance on the often misleading claims of accuracy used by instrument manufacturers. The characteristics of the drive motor are more elaborate than could be conveniently contained in tabular listing, therefore a special note has to be added. This same type of note should be added to cover any unusual requirements. A portion of an equipment section as it would appear on a drawing is shown below:

EQUIPMENT REQUIRED:

	ITEM	QUANTITY	DESCRIPTION
1.	AIR PRESSURE SUPPLY	1	TO SUIT.
2.	TUBING & FITTINGS	AS REQ'D	TO SUIT.
3.	PRESSURE REGULATOR	1	RANGE & TYPE TO SUIT. ACCURACY, SENSITIVITY & RESOLUTION ±0.25 psig AT TEST LIMITS SPECIFIED REGULATION ±0.5 psig.
4.	CYCLE TIMER WITH COUNTER	1	RANGE & TYPE TO SUIT-SEE TIMING SEQUENCE CHART. TIMING ACCURACY & SENSITIVITY ±0.1 SECONDS FOR TOTAL CYCLE AND EACH SUBDIVISION.
5.	PRESSURE GAGE	1	RANGE & TYPE TO SUIT. ACCURACY, SENSITIVITY & RESOLUTION: PLUS 0.1 MINUS 0.0 psig AT 18 psig AND PLUS 0.0 MINUS 0.1 psig AT 20 psig.
6.	DRIVE MOTOR	1	TO SUIT-SEE NOTE BELOW.
7.	RECORDING TACHOMETER	1	RANGE & TYPE TO SUIT. RECORDING ACCURACY ±3% OF TRUE SPEED AT DRIVE SPEED SPECIFIED; RECORDING SENSITIVITY 1 RPM AT DRIVE SPEED SPECIFIED.

NOTE: CHARACTERISTICS OF THE DRIVE MOTOR MUST NOT PERMIT A LOSS OF SPEED AT THE INPUT SHAFT OF THE TRANSFER CASE IN EXCESS OF 5 RPM DUE TO A SHIFT TO ANY OF THE THREE POSITIONS POSSIBLE. IT MUST RECOVER FULL SPEED PRIOR TO THE NEXT SHIFT.

5.4.2.1.5 Test procedure. The test procedure must consist of detailed instructions presented in chronological order. It must begin with preparation for the test, i.e., mounting the product sample into a fixture, coupling drive units, attaching control lines or levers, attaching wiring, plugging unused holes, checking lubricant level, checking or adjusting calibration, and whatever else may be considered necessary. This is followed by a description of the test cycle in complete detail, which should include all applicable test values.

5.4.2.1.6 Acceptance criteria. All acceptance criteria must be fully defined in terms of acceptance limits. All such definitions must be clear and precise so as to eliminate, or at least minimize the skill required of the operator.

5.4.2.1.7 Arrangement diagram. A pictorial representation of all test equipment utilized in the test must be included. Balloons should be used to identify each equipment item by cross reference to the required equipment list (see 5.4.2.1.4). Scale will not be applicable to the drawing, but the drawing must exhibit a reasonable attempt to pictorially resemble the items specified. Dimensions will rarely be necessary for holding fixtures other than to show angular mounting positions relative to vertical or horizontal. The method of mounting should be made reasonably apparent, but only detail which is absolutely essential to the test need be shown. The pictorial representation should be supplemented as necessary, or even replaced by schematic plumbing or wiring diagrams, time-sequence charts, etc. Examples of arrangement diagrams are shown in figures 24 and 25.

5.4.2.2 Type A - Commercial standard test equipment. Many functional and performance qualification tests can be performed utilizing commercial standard test equipment. This is particularly true if the product tested is electrical, hydraulic, or pneumatic. In these fields, almost all products manufactured can be tested using commercial standard equipment which is very likely already owned by the production contractor. Emphasis should mainly be placed on calibration accuracy, sensitivity, resolution, and regulation. In the tank-automotive field, experience has shown over 90 percent of the test equipment specification drawings to be Type A.

5.4.2.3 Type B - Contractor's special test equipment. Certain production contractors are normally engaged in the manufacture of components which require a very specialized line of inspection equipment. For example, the manufacturer of automotive friction clutches falls into this category. Basically, all the clutch models produced are subject to the same type of tests, and these tests mostly involve specialized test equipment. The contractor already owns this equipment and has designed it in such a manner as to be readily adaptable to a wide range of product variations. To take advantage of the existence of such equipment and still establish reasonable control, the type B test equipment specification drawing is initiated. As pointed out in 5.4.2.1.2, the test may require additional descriptive notes. The test can sometimes become so involved that much of the basic format must be altered.

5.4.3 Special detailed design. When a situation is encountered in which application of a test equipment specification drawing would be impractical, a special detailed design may become necessary. Justification for such action is partially covered in 5.6.1.

5.5 Standard measuring equipment. Standard measuring equipment is multi-usage equipment used for performing measurements. It includes, but is not restricted to, such items as micrometers, dial indicators, scales, tapes, height gages, sine bars, protractors, and surface plates. Some of these devices or their principles of operation are frequently utilized in the design of special inspection equipment.

5.6 Government inspection equipment. The term Government inspection equipment will apply to special inspection equipment of Government controlled design used by the production contractor to support inspection of Government prescribed product characteristics and/or used by the Government to perform product verification. It also applies to the same type of designs used by the Government for purposes other than to support mission item procurements, such as field and depot operations, R & D testing, or stockpile reliability testing. Special inspection equipment designs are Government controlled designs of inspection equipment not procurable from industry.

5.6.1 Initiation of Government inspection equipment designs. Government inspection equipment designs may be initiated when any one or more of the requirements listed in a through h are satisfied.

a. Where practical measurement of specified performance requirements can only be expressed adequately and completely by characteristics embodied in the inspection equipment design.

b. When a written or schematic description of the inspection equipment would be difficult to understand, when it would be excessive in length, or when it would require a high degree of skill and training to interpret without the aid of a detailed design.

c. When components or assemblies have characteristics classified as "critical".

d. When inspection equipment is necessary for checking important mounting interfaces between a major item of equipment and the weapon system with which it is used.

e. To assure spare parts interchangeability including interchangeability of assemblies.

f. When required for purposes other than to support mission item procurements, such as research and development, the stockpile reliability program, depot maintenance and renovation activities.

g. When the use of such equipment is limited to the production and/or procurement of supplies which are peculiar to the needs of the Government

h. When development cost of the inspection equipment is significant and this cost would represent a recurring cost on each future supply contract of $10,000 or more.

5.6.2 Utilization of government inspection equipment designs. Government inspection equipment designs are used in three ways: (1) as detailed instructions for construction and use of inspection equipment, (2) as a guide for the design of more sophisticated or customized inspection equipment, and (3) as a guide for evaluation of existing or proposed inspection equipment designs.

5.6.3 General drafting practices. Acceptable general drafting practices used in the preparation of Government inspection equipment are illustrated in drawing 7395223 titled "Drawing Procedures for Inspection Equipment Design". Additional information will be found in DOD-STD-100, DOD-D-1000, AMCR 11-26, AMCR 702-2, and TACOM PAM 11-44.

5.6.4 General design practices. Primary design considerations must be based on the fundamental rule of 5.1.2. This rule prohibits the gage, the inspection device, the calibration procedure or the test procedure from being capable of the acceptance of an improper product. Some other factors of consideration, many of which closely relate to the fundamental rule, are listed in items a through d.

a. Minimize the operator skill and effort required (see 5.6.4.1).

b. Consider only low production requirements (see 5.6.4.2).

c. Minimize equipment sophistication (see 5.6.4.3).

d. Provide for necessary calibration (see 5.6.4.4).

5.6.4.1 Minimizing effects of uncontrolled variables. To properly conduct any test or inspection process, all variables which can affect the accuracy of the test results must be controlled. Unfortunately, not all variables can be controlled to the degree necessary for proper testing. Under these conditions, it is the task of the inspection equipment designer to create a design which will minimize the resultant effect of the uncontrolled variable. The operator or user of the inspection equipment must be regarded as just such an uncontrolled variable. For Government designs, the operator's skills and abilities must be regarded as minimal, and the design must be capable of accurate inspection without placing reliance upon the operator's skill. Simplicity of operation and elimination of procedures which require responsible judgements should be considered as primary design requirements.

5.6.4.2 Low production requirements. Another major factor to consider is useful life of the inspection equipment. Where long life is required, much consideration must be given to wear problems which are frequently solved by using better materials, providing adjustments, and designing for ease of replacement for parts thus affected. This increases the cost of both design and construction of the inspection equipment. This increase may be considered wasteful if unwarranted by production requirements. The policy and objectives of this handbook (see forward and 1.4) can best be served by consideration of only low production requirements for reasons listed in items a through c.

a. Most military procurements involve low production rates.

b. Depot maintenance and rebuild programs are all basically classed as low production rates.

c. Since it is intended that the Government inspection equipment designs be used as a guide by the production contractor in the design of his own inspection equipment, and by the Government as a guide in the qualification of the production contractor's inspection equipment; the more basic and simple the Government design, the more readily it will serve these purposes. When low production requirements are considered, the design inherently becomes more basic and simple.

5.6.4.3 Adverse effects of equipment sophistication. The basic goal of Government inspection equipment designs is to reflect the minimum requirements of the inspection equipment necessary to do the job. Sophistication is normally added either to reduce inspection time or for analysis of the error detected. While both reasons may be advantageous to the production contractor, they may also represent an economic disadvantage to the contractor when the contractor must supply and maintain the inspection equipment.

5.6.4.4 Calibration requirements. Established accuracy is a fundamental requirement of all tests, inspections, and inspection equipment. Each inspection equipment design must provide for establishment and verification of the accuracy necessary to accomplish its intended purpose. These calibration requirements will be established in the manner listed in items a through i.

a. Isolate the values of all specified acceptance limits to be tested or inspected.

b. Isolate all variables inherent in the inspection equipment design which can affect the accuracy of the test results.

c. Analyze each variable relative to its effect on the final test results and establish an acceptable tolerance range for each.

d. Ascertain that the design permits achievement and verification of each tolerance limit so established during its initial construction.

e. Based on considerations of wear, fatigue, accidental abuse and/or unauthorized misadjustment, isolate and identify all points which require periodic recalibration during the life of the equipment.

f. Provide for ease of recalibration to a practical degree.

g. Notes should be provided as necessary to adequately explain unusual or complex calibration procedures.

h. Frequency of calibration should have been established in the production contractor's plan of inspection. However, if the design is known to possess an inherent instability which would require an unusually frequent recalibration, this should be prominently noted.

i. Apply the ten-to-one gaging rule, if applicable. The rule is that the gage shall be ten times more accurate than the part being gaged.

5.7 Contractor inspection equipment. This refers to inspection equipment furnished and utilized by the production contractor and approved by the Government.

5.7.1 Utilization of contractor inspection equipment. Contractor inspection equipment will be approved by the Government when it is proven to meet the qualifications established by the applicable documents. This applies to equipment which the production contractor may already possess or have at his disposal, or it may apply to his special design or commercial standard equipment. The only restriction placed on contractor inspection equipment is that it must meet the minimum Government requirements established. Since the production contractor has the responsibility of meeting the production contract requirements, utilization of additional inspection equipment is allowed to assure quality.

5.7.2 Contractor inspection equipment similarities. The contractor inspection equipment must be similar to Government inspection equipment as listed in items a through c.

a. Both must be based on the fundamental rule of 5.1.1.1.

b. Both must minimize the required skill of the operator (see 5.6.4.1).

c. Both must provide for necessary calibration as described in 5.6.4.4.

5.7.3 Differences relative to Government equipment. The contractor inspection equipment may differ from the Government inspection equipment. These differences are listed in items a through d.

a. The contractor's designs are not required to utilize Government drafting standards.

b. The contractor's designs may be tailored to suit the contractor's production requirements, rather than be based strictly on low production.

c. The degree of sophistication incorporated into the contractor's design may vary in respect to the Government design providing that the resultant accuracy of the equipment is not adversely affected.

d. The Government designs must be based on inspection of the completed product so as not to unnecessarily restrict the method of manufacture. In some instances, the contractor may find it advantageous to utilize "in process" inspection to assure the required final result. This can include the substitution of several gage designs used during different stages of production to replace a single gage design used when production is completed. In such instances, the contractor must supply sufficient evidence to the Government that requirements can be satisfied.

5.7.4 Evaluation of contractor equipment designs. Contractor inspection equipment designs must be evaluated. This evaluation will be based on Government documents, such as, product drawings, procurement specifications, QAPs, gage designs, detailed test equipment designs, test equipment, and specification drawings. While these documents will assist in the evaluation, they do not relieve the evaluator from being a properly qualified and competent inspection equipment designer.

6. NOTES

(This section contains information of a general or explanatory nature that may be helpful but not mandatory.)

6.1 Intended use. This handbook is prepared for application to inspection engineering and production contracts for tank automotive materiel. It is intended to avoid duplication of inspection equipment design effort and to prove designs during early phases of an item.

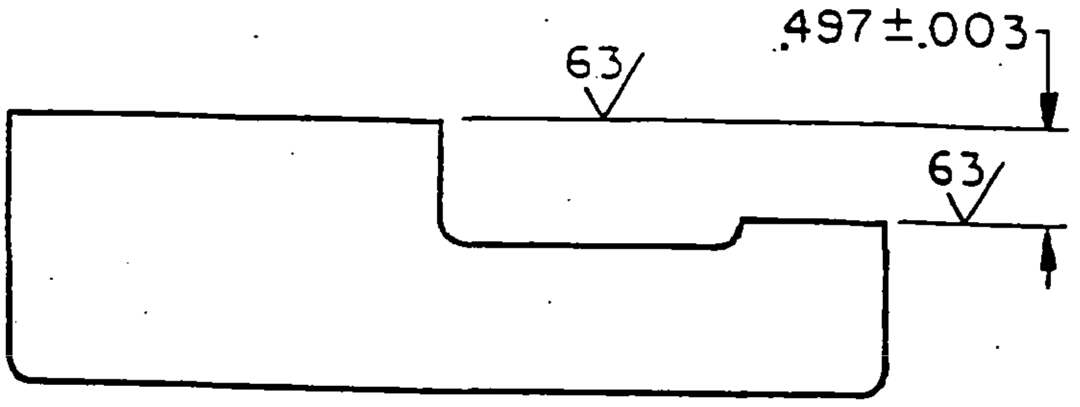
6.2 Issue of DODISS. When this handbook is used in acquisition, the applicable issue of the DODISS must be cited in the solicitation (see 2.1.1 and 2.2).

6.3 Supersession data. This handbook has been prepared from and supersedes TACOM pamphlet DRSTA-RP-702-120, February 1982: Tolerancing, Dimensioning, and Gaging Techniques.

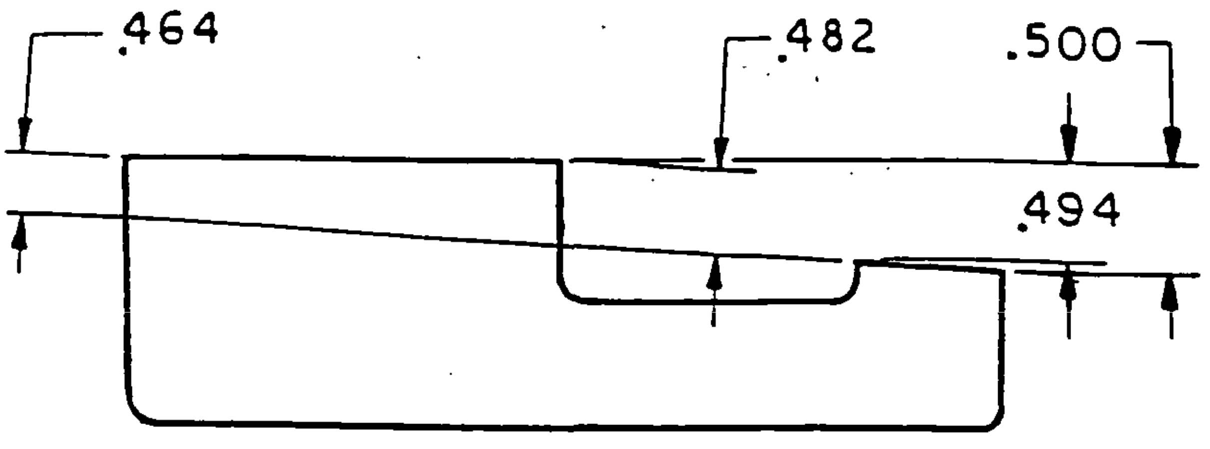
6.4 Subject term (key word) listing.

Acceptance criteria
Commercial standard test equipment
Datum surface
Dimensioning
Fit
Gage design
Inspection equipment designs
Interchangeability
MMC system of dimensioning
Product drawing
Quality assurance provision (QAP)
RFS gages
Standard measuring equipment
Tolerancing
Variables.

6.5 Responsibility. The Government inspection engineering representative assigned to the project should be responsible to provide the necessary technical assistance and guidance regarding the provisions of this handbook and should be responsible for the inspection equipment and associated documentation.



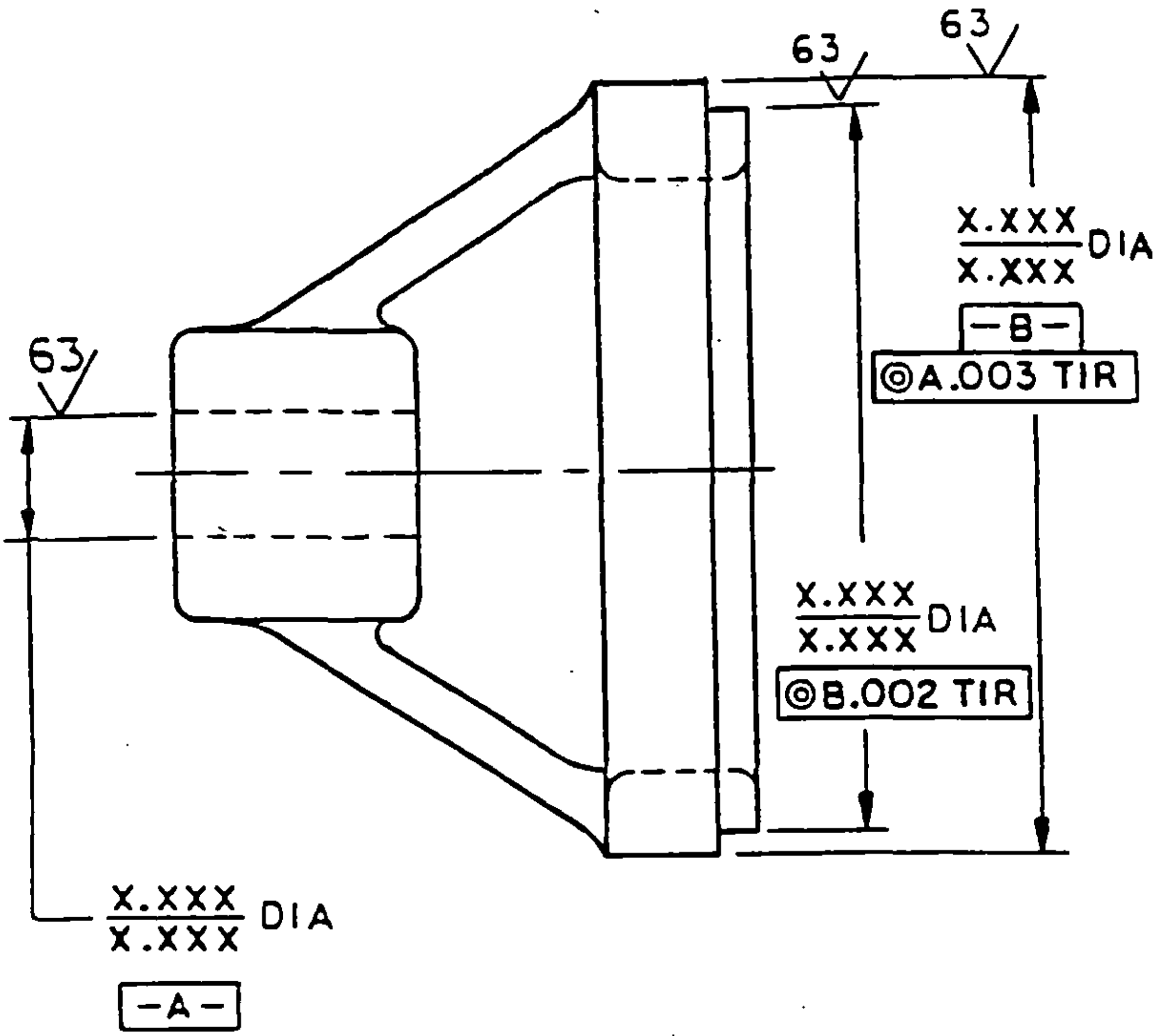
EXAMPLE A



EXAMPLE B

NOTE:
Example A fails to identify the functional machined surface as the locating datum for measurement of the .494/.500 dimension. In example B, the larger and more convenient surface is arbitrarily selected as the locating datum for the inspection equipment The measurement at the right shows all portions of the smaller surface to be located within the specified limits. Using the same part, if the smaller surface is established as the locating datum, the parallelism error between the two surfaces would cause the measured dimension to vary from .464 to .482.

FIGURE 1. Inadequate specification.



QUALITY ASSURANCE PROVISIONS (QAP)	PAGE NO.	NO. OF PAGES	QAP NO.
QAP REVISION LETTER AND DATE: REV. C. 3 FEB. 1982			
CHAR. NO.	CHARACTERISTIC	METHOD OF INSPECTION	
8.	DIA "A" RFS MUST BE CONCENTRIC TO DIA "B" RFS WITHIN .003 T.I.R.	CONCENTRICITY GAGE ORD #D XXXXXXX	

FIGURE 2. Product drawing with related quality assurance provisions (QAPs).

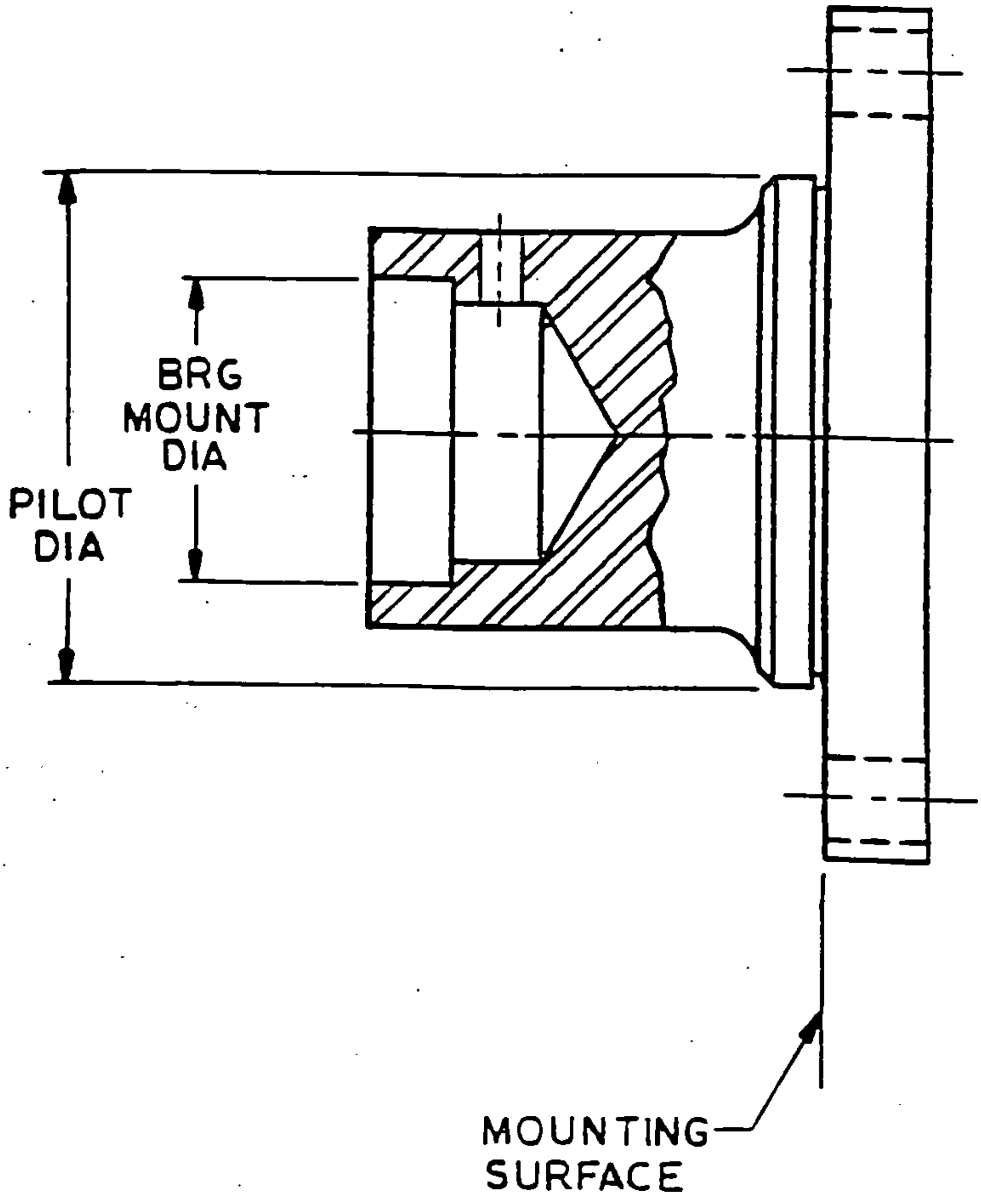


FIGURE 3. Removable bearing mount.

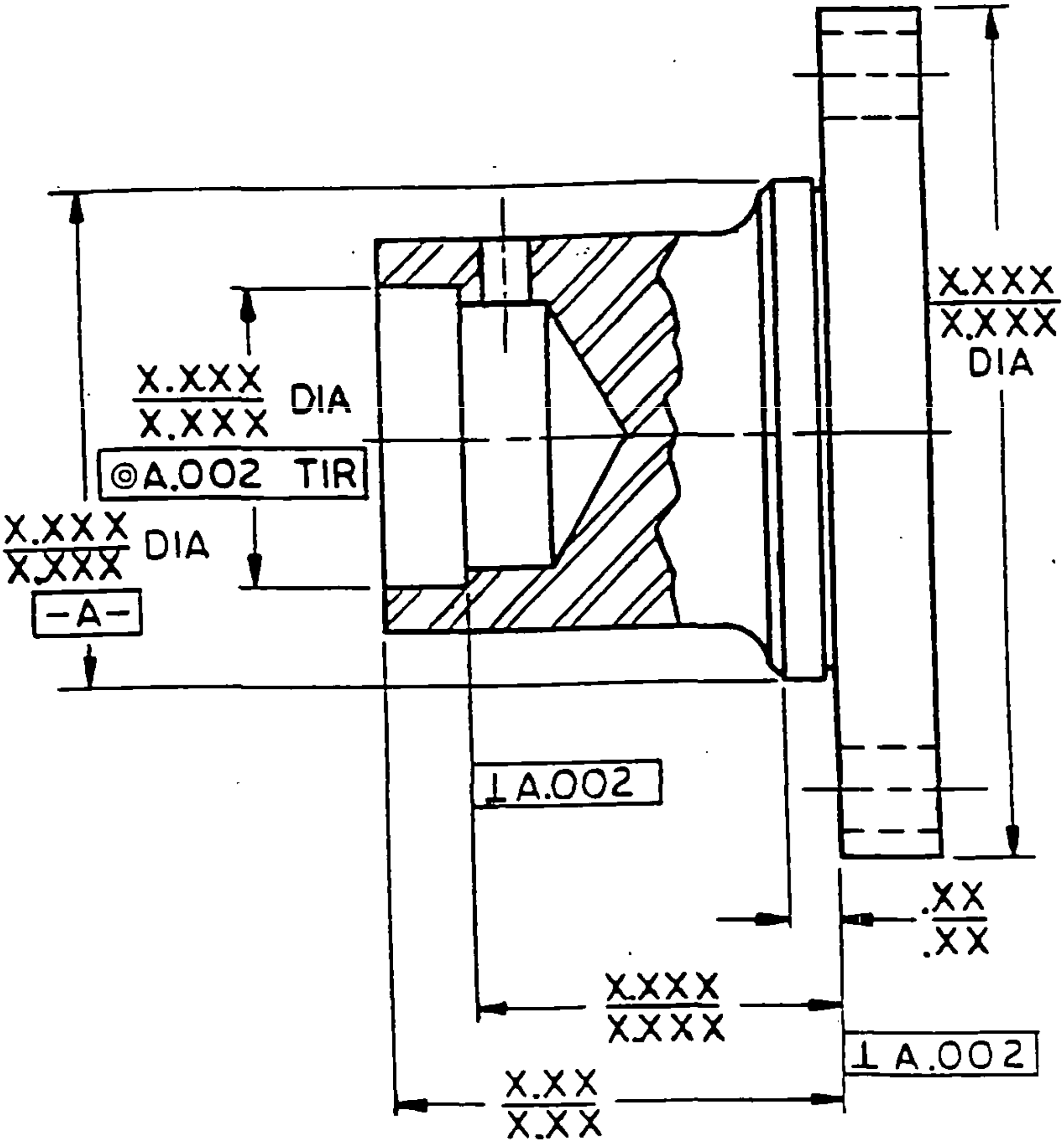


FIGURE 4. Inappropriate dimensioning of removable bearing mount.

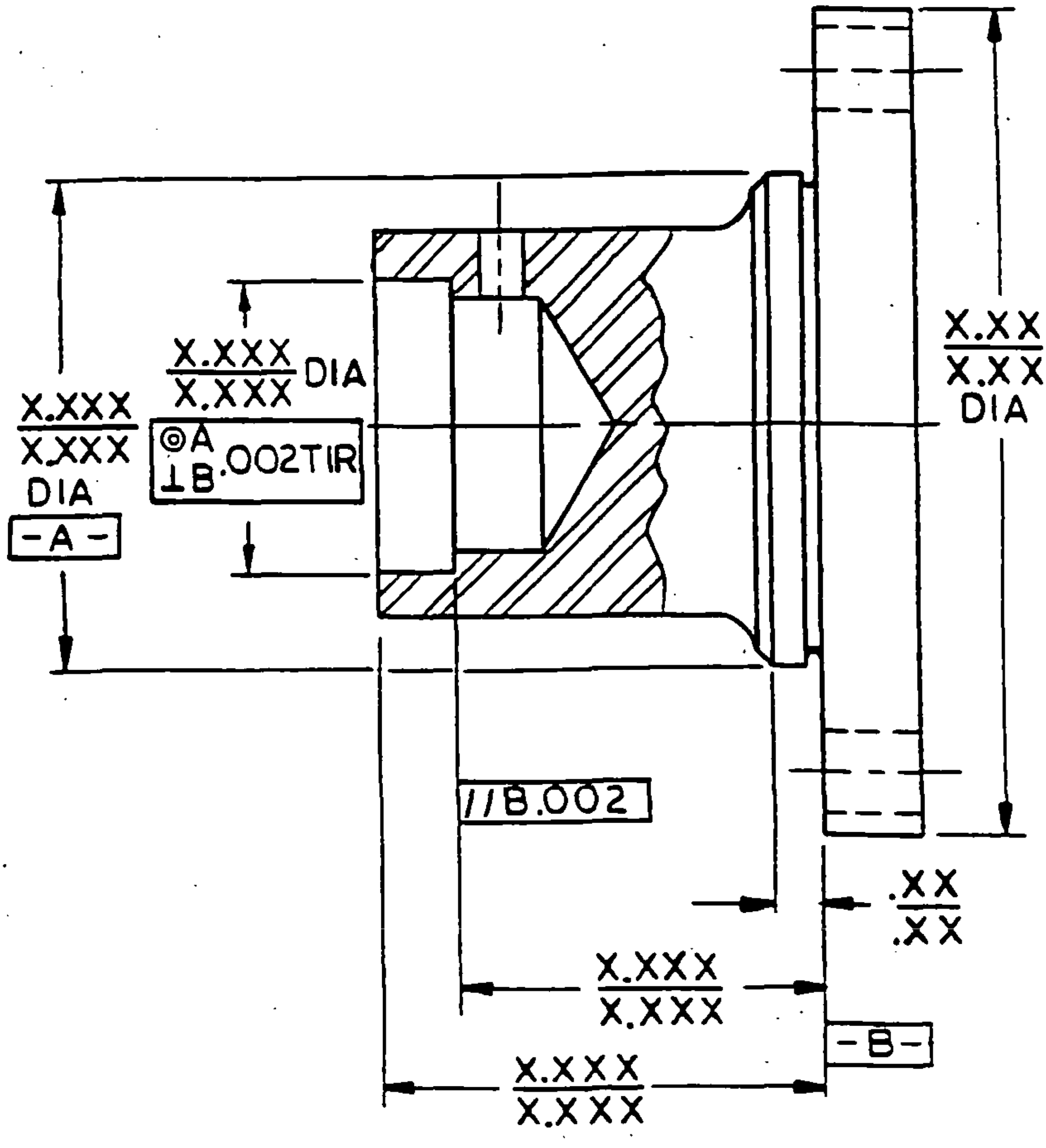


FIGURE 5. Proper dimensioning of removable bearing mount.

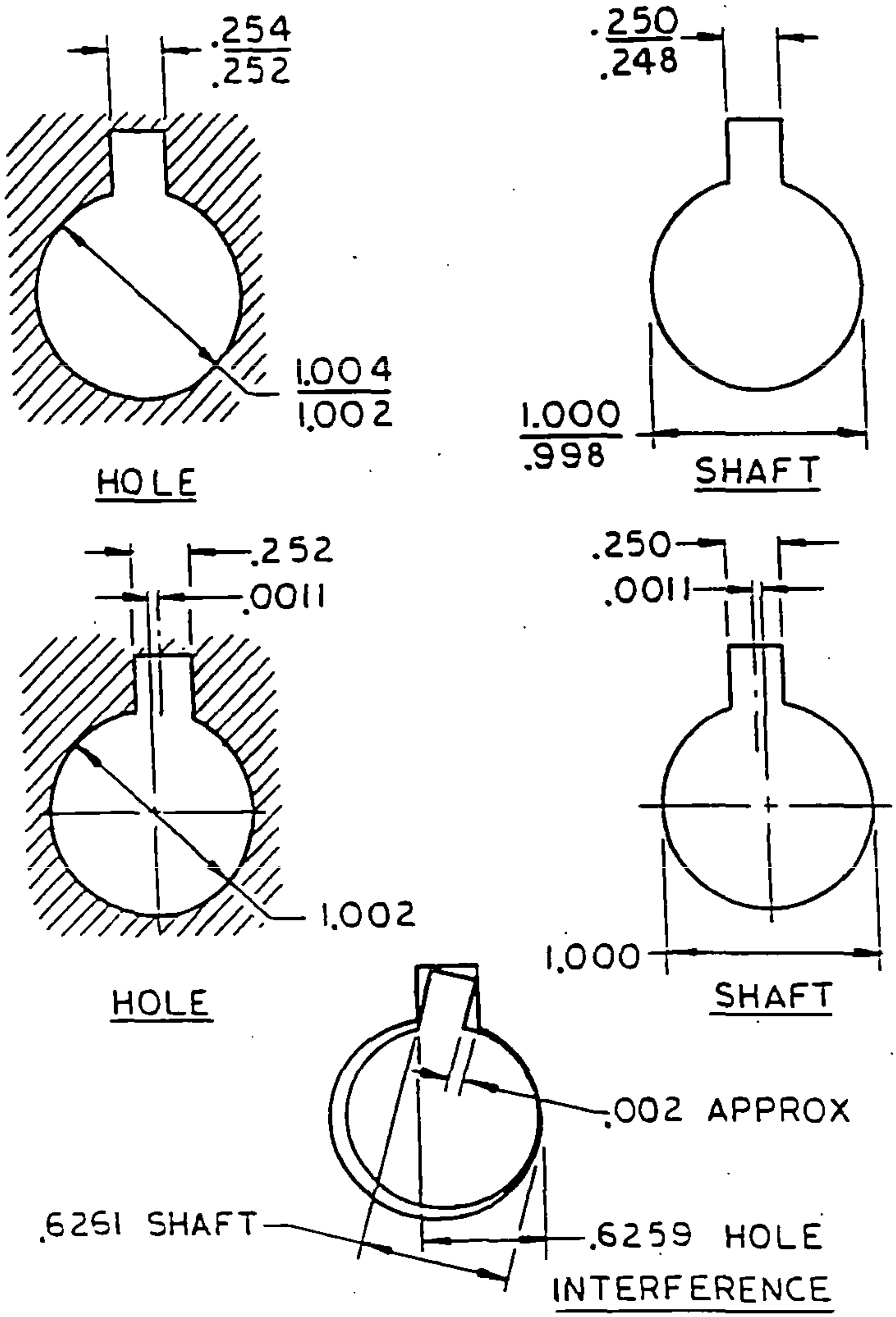


FIGURE 6. Size and positional tolerances of keyed shaft.

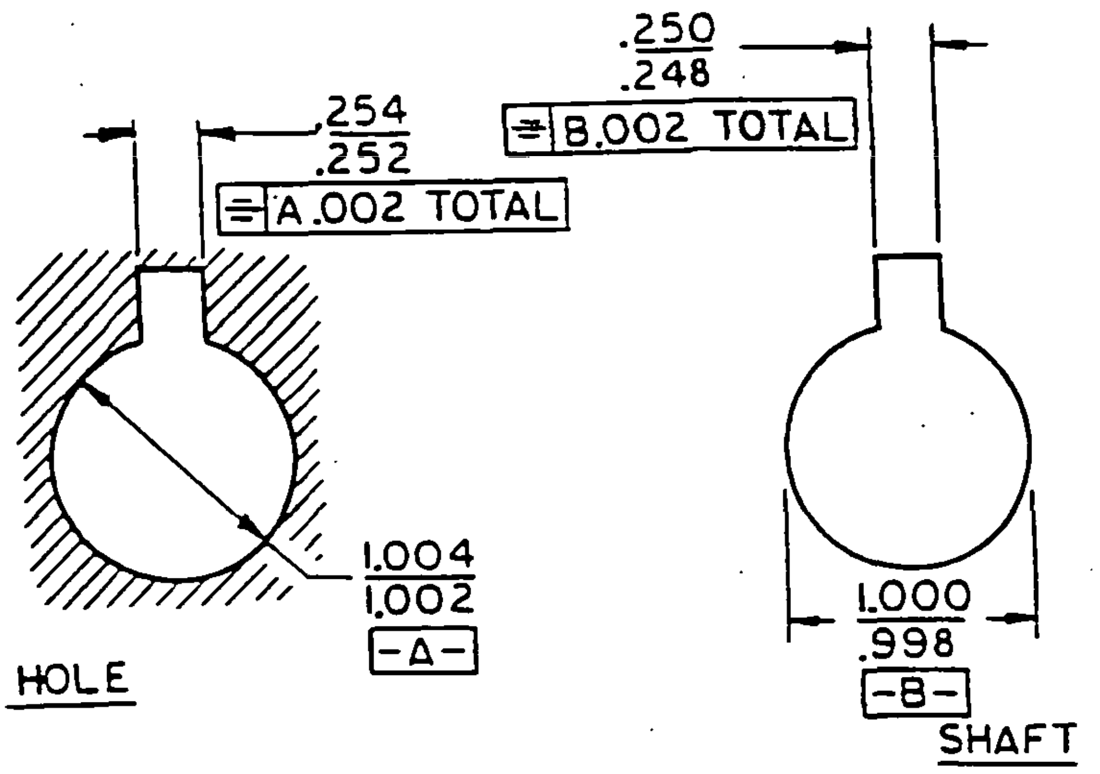


FIGURE 7. Tolerancing of keyed shaft.

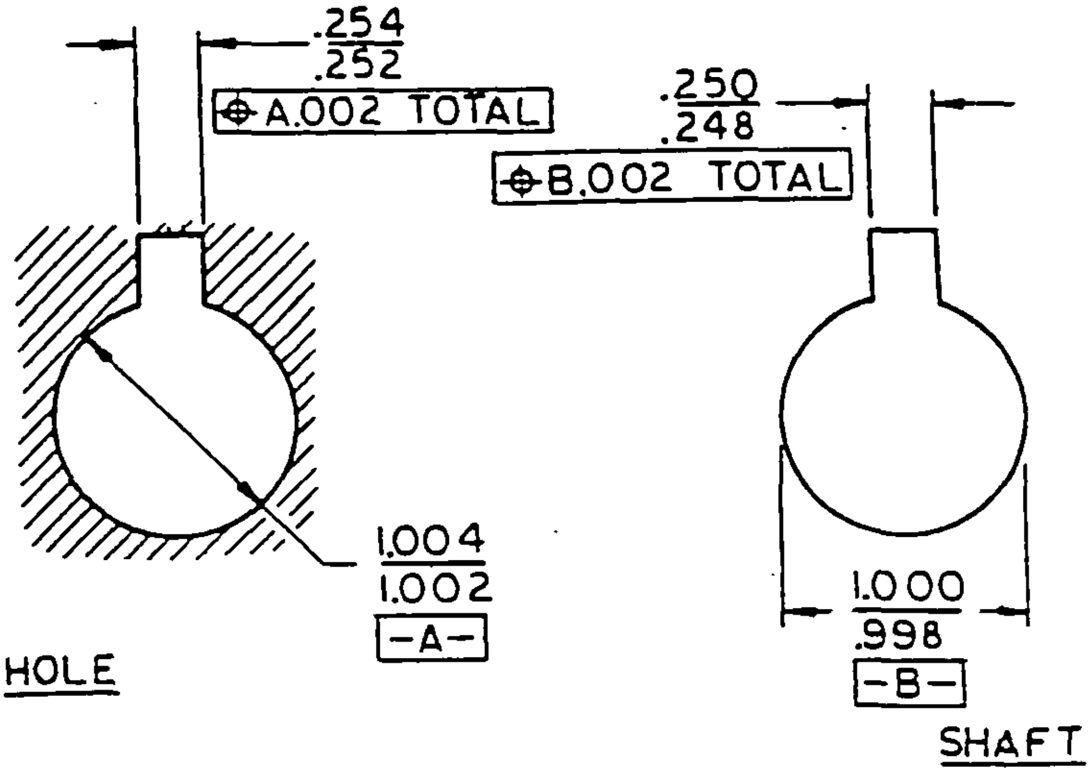


FIGURE 8. Tolerancing of keyed shaft (liberalized).

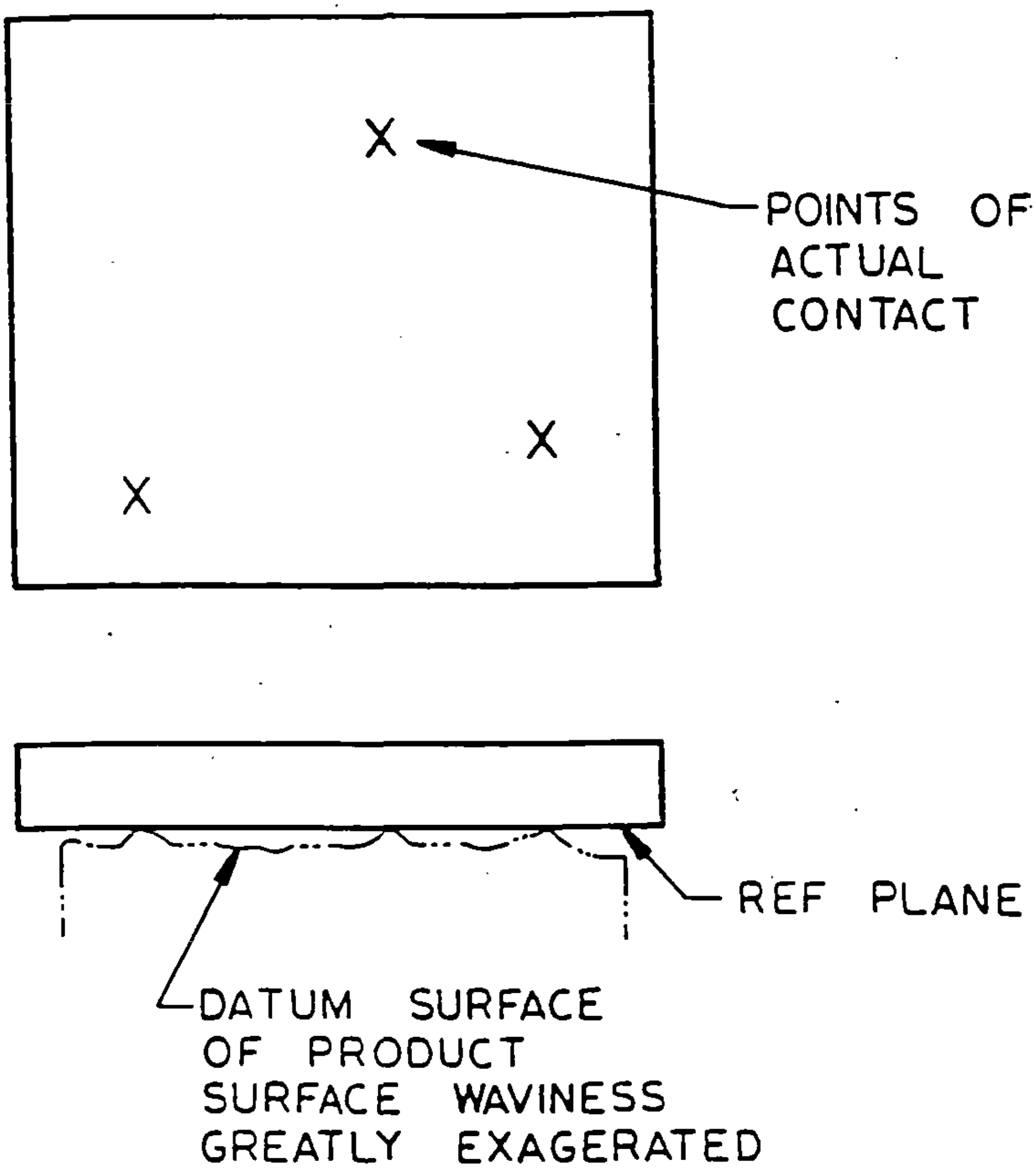


FIGURE 9. Datum surface.

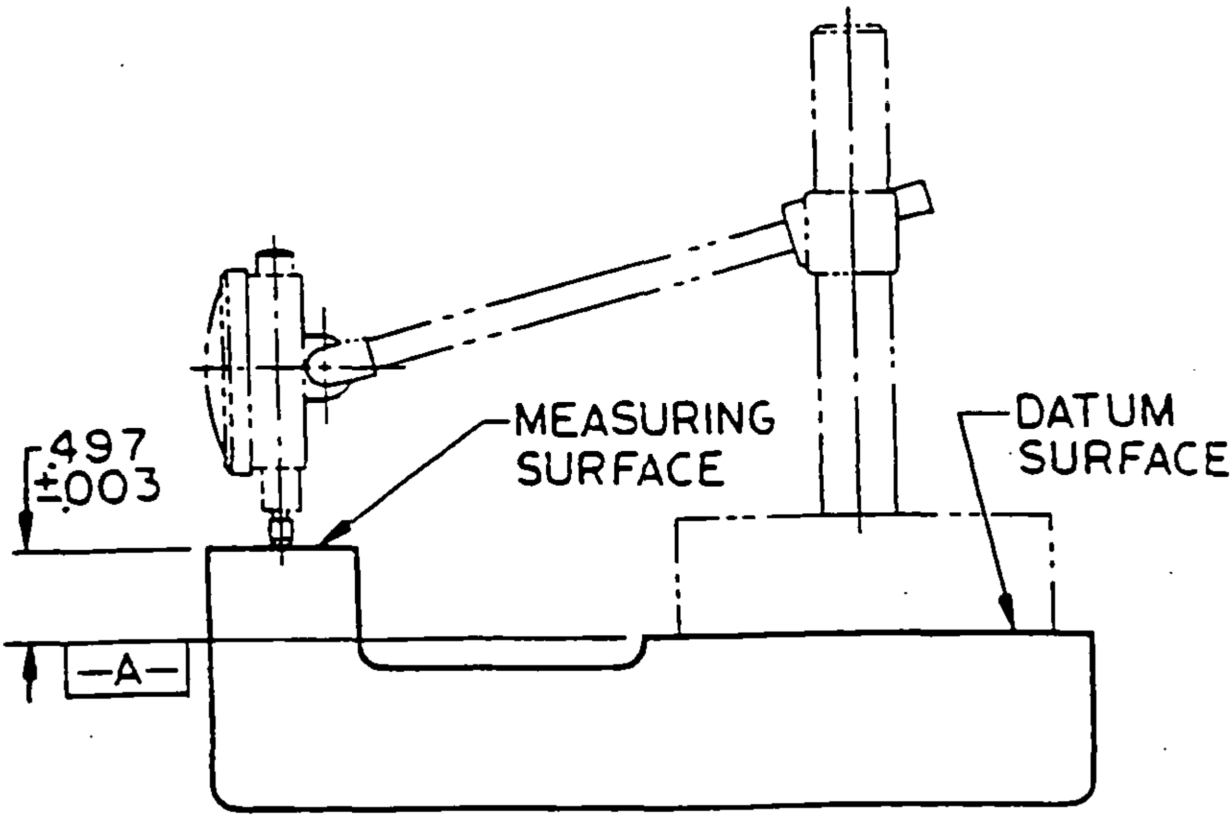


FIGURE 10. Datum and measuring surfaces.

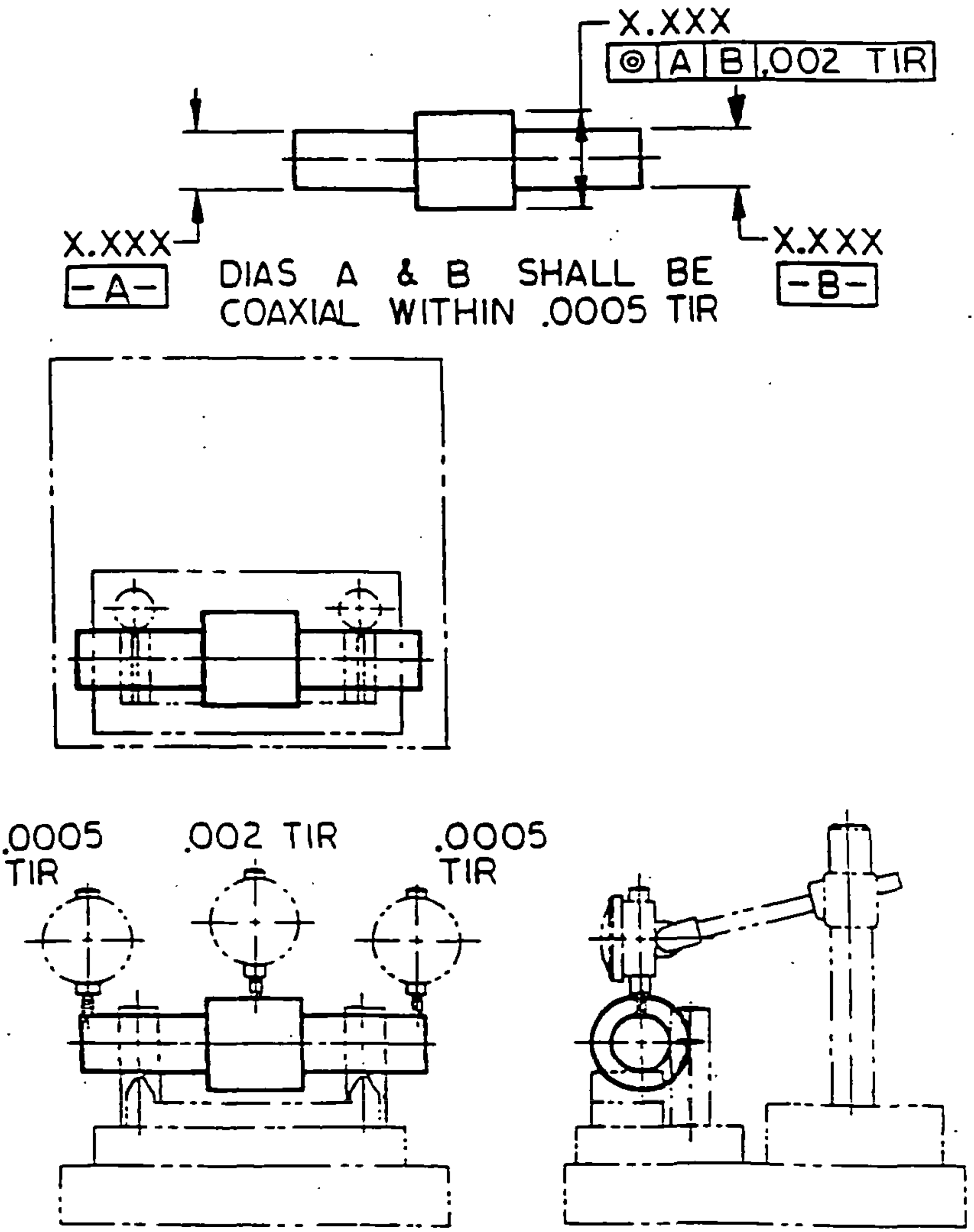


FIGURE 11. RFS type gages.

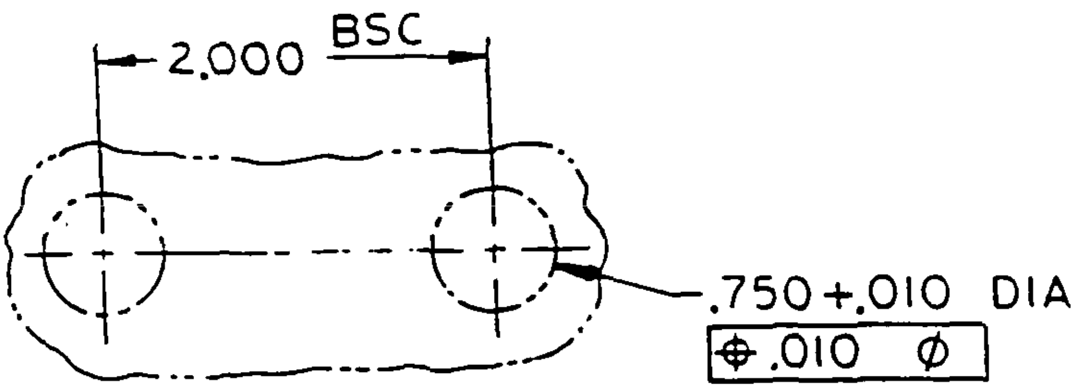


FIGURE 12. Example of product drawing requirement.

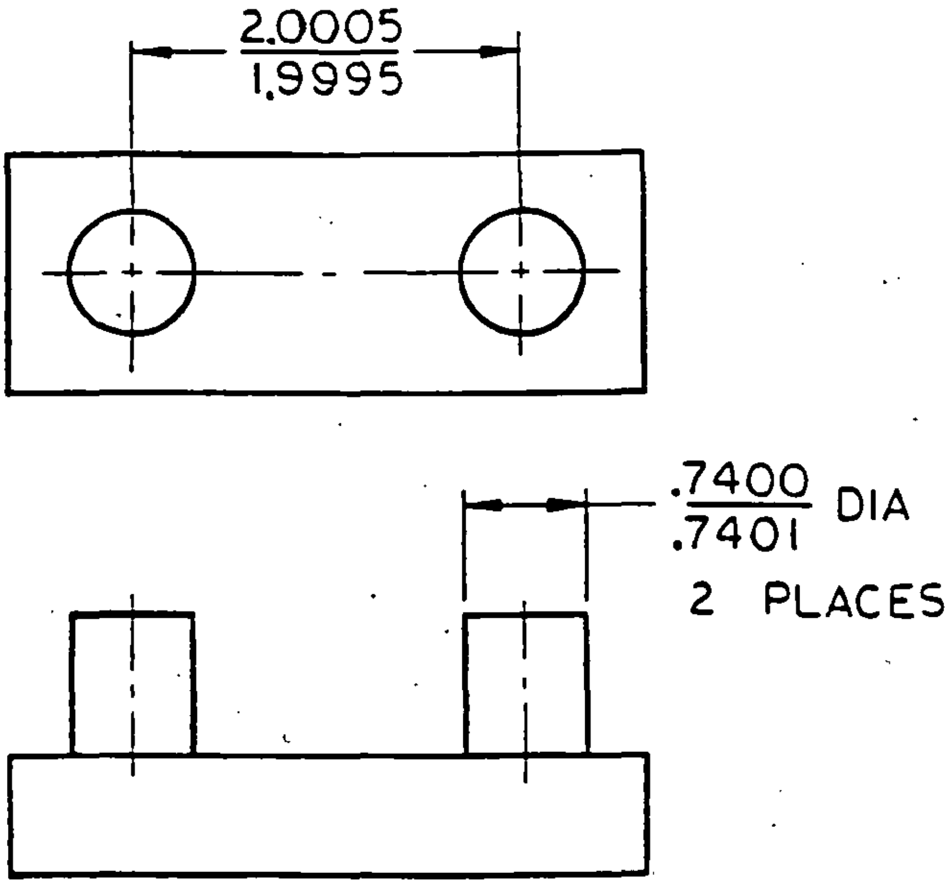


FIGURE 13. Hole location gage.

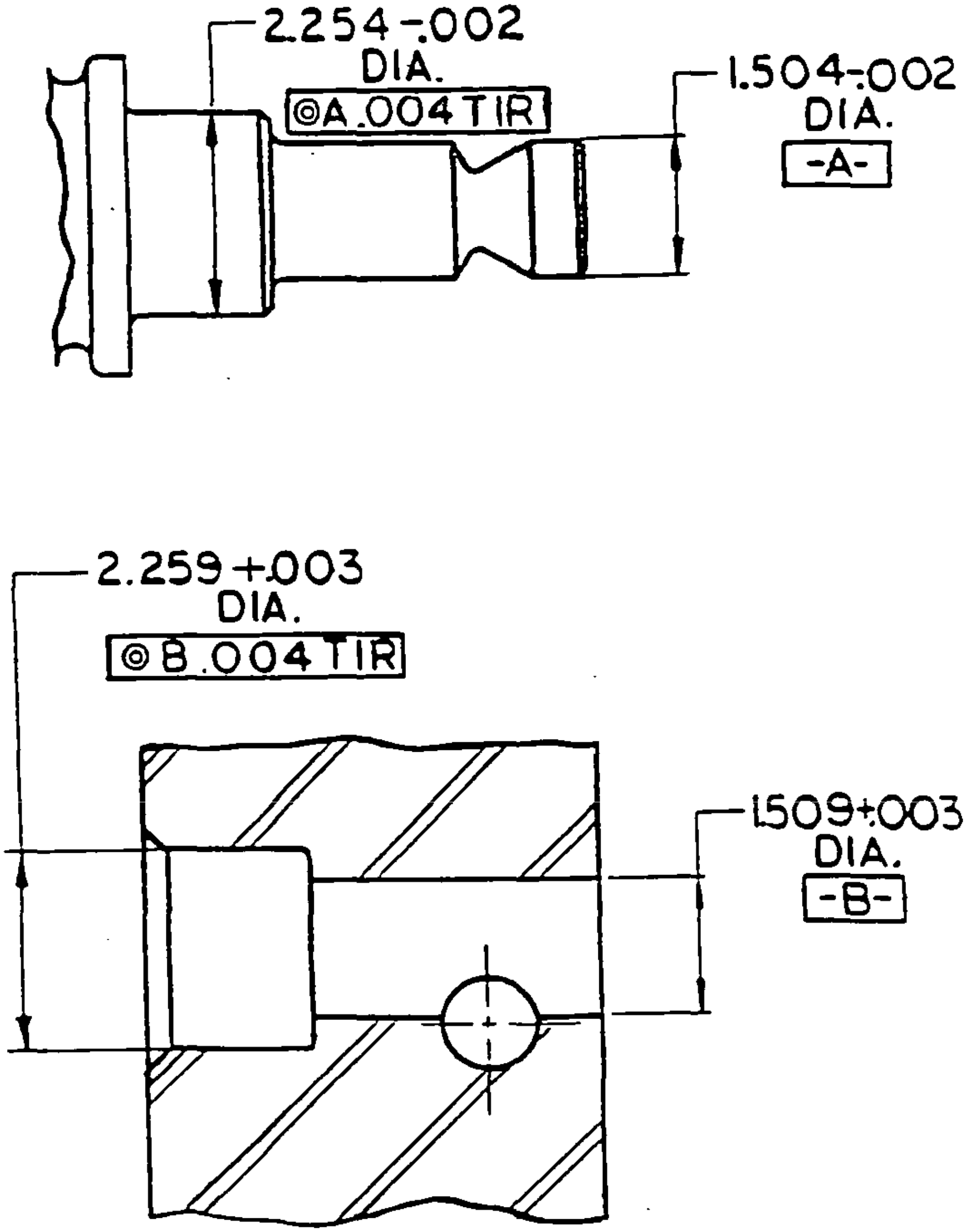


FIGURE 14. Concentricity specified (conventional).

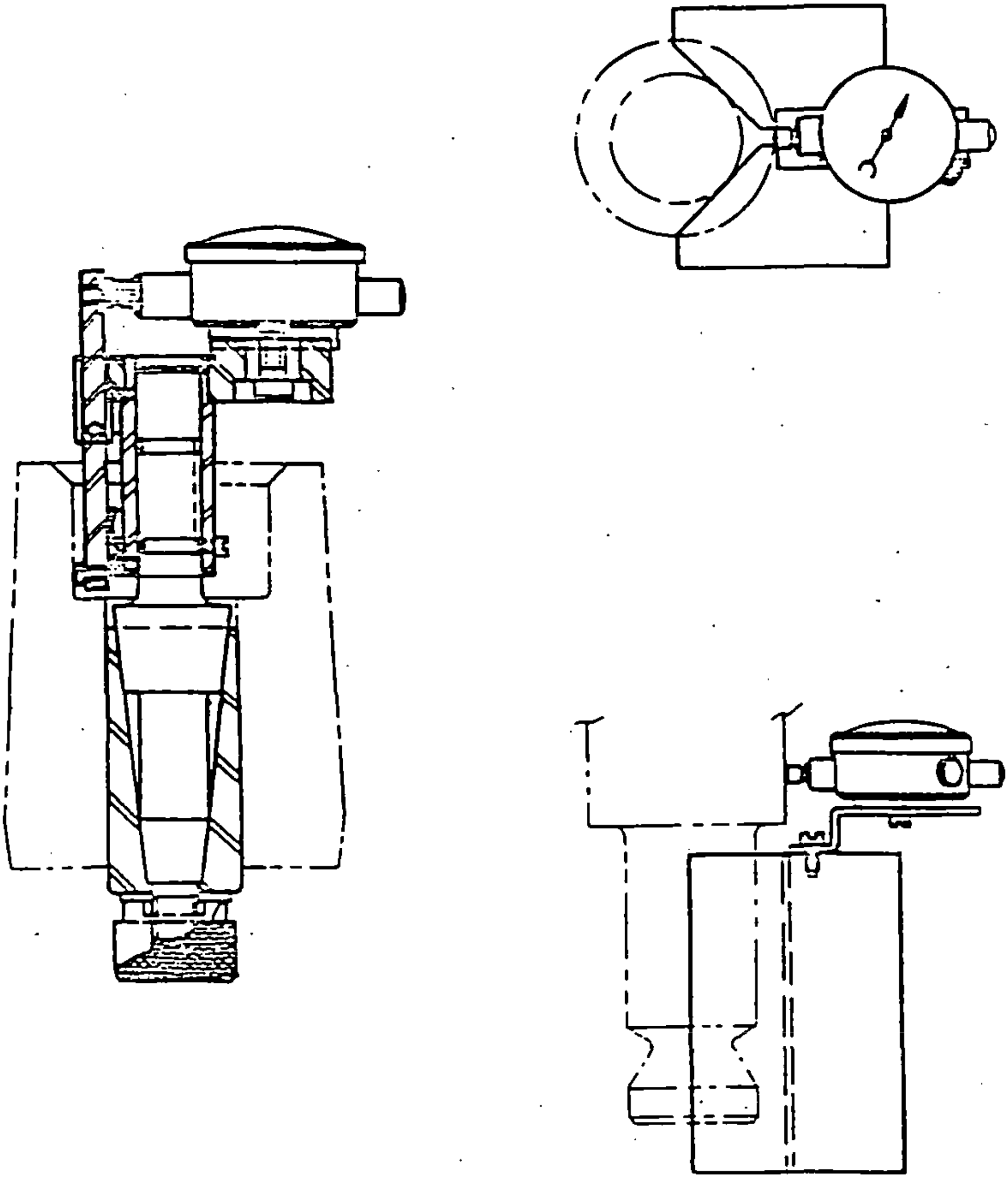


FIGURE 15. Gages used to inspect RFS condition.

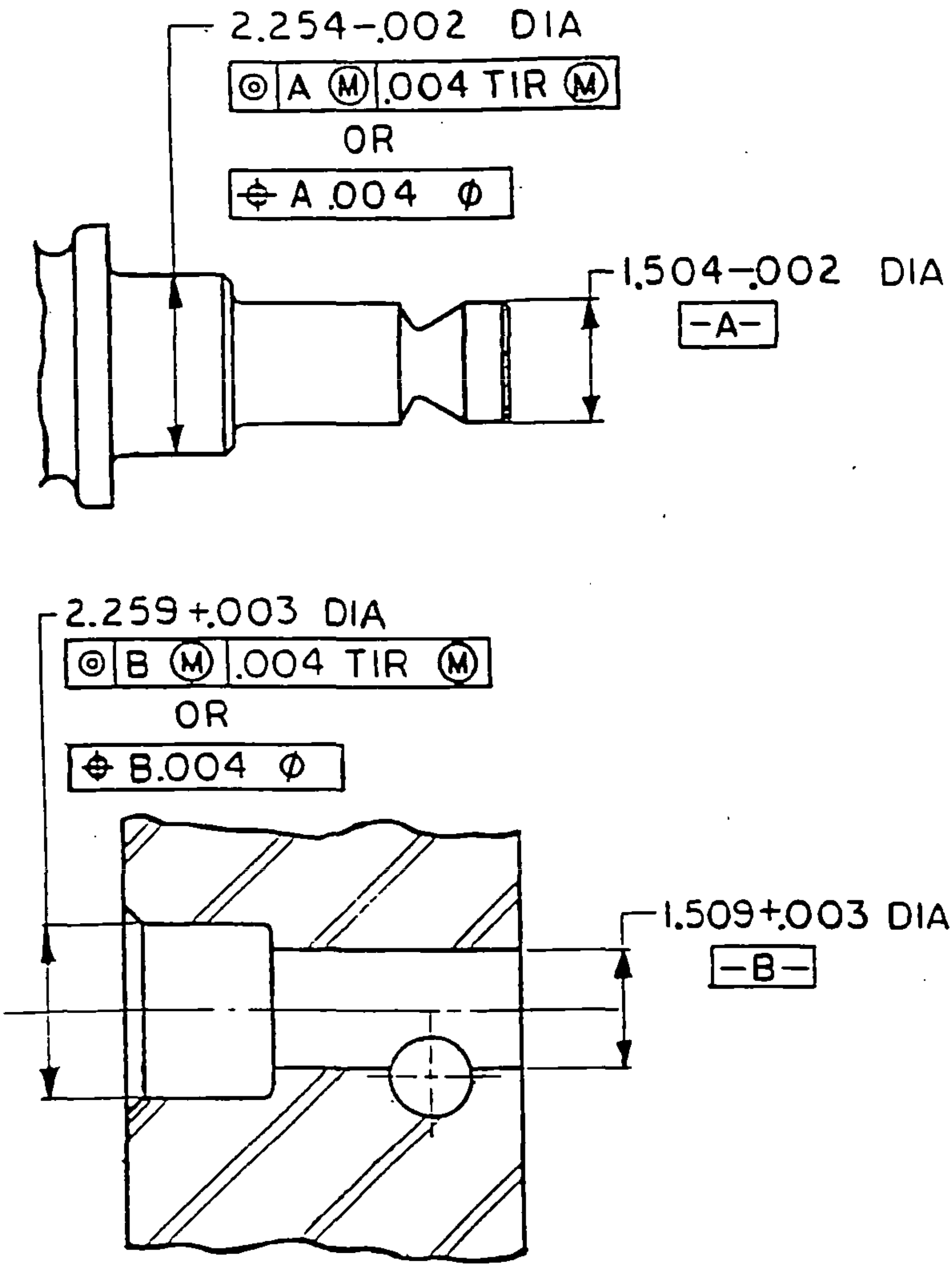


FIGURE 16. Concentricity specified (preferred).

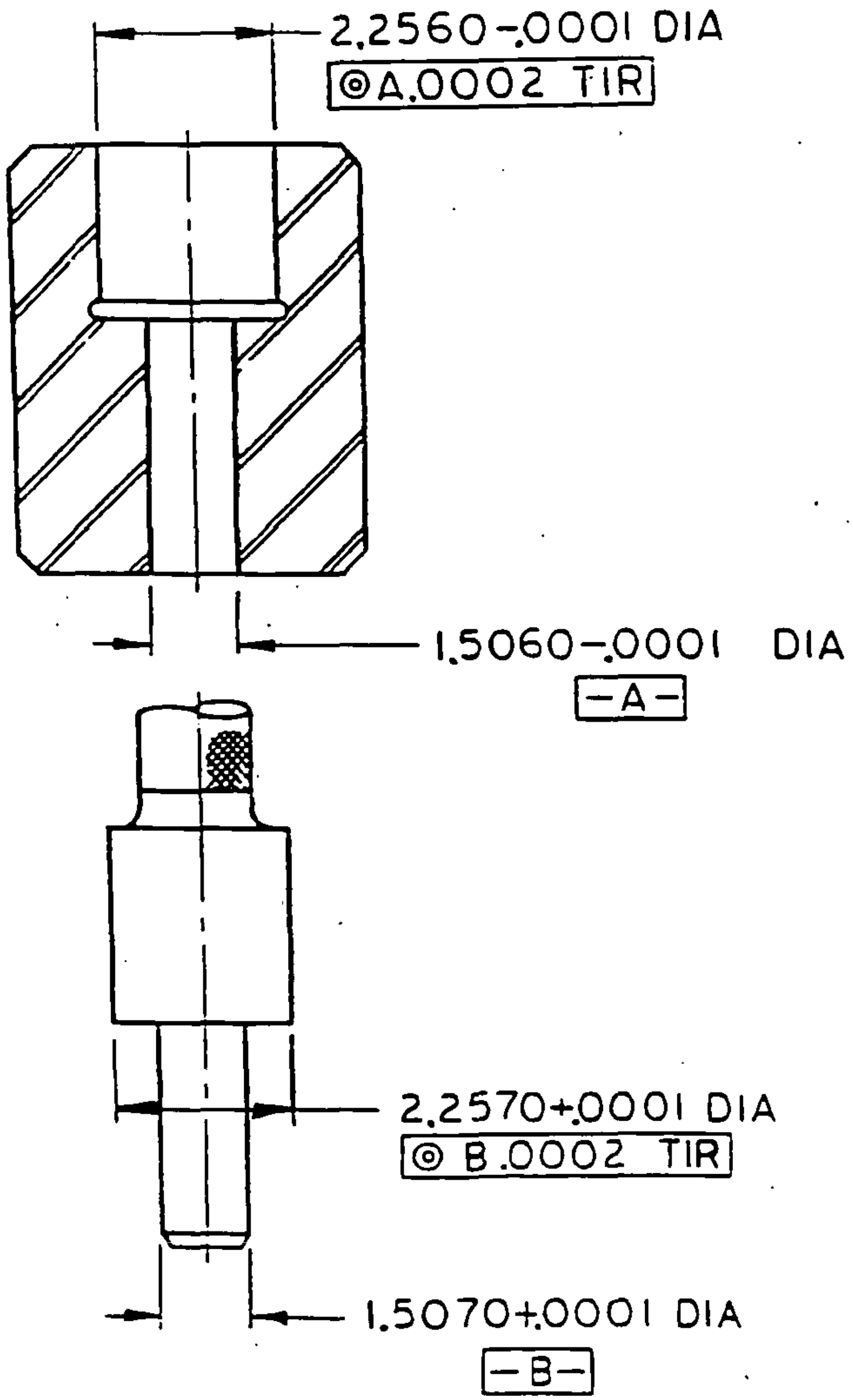


FIGURE 17. MMC gages.

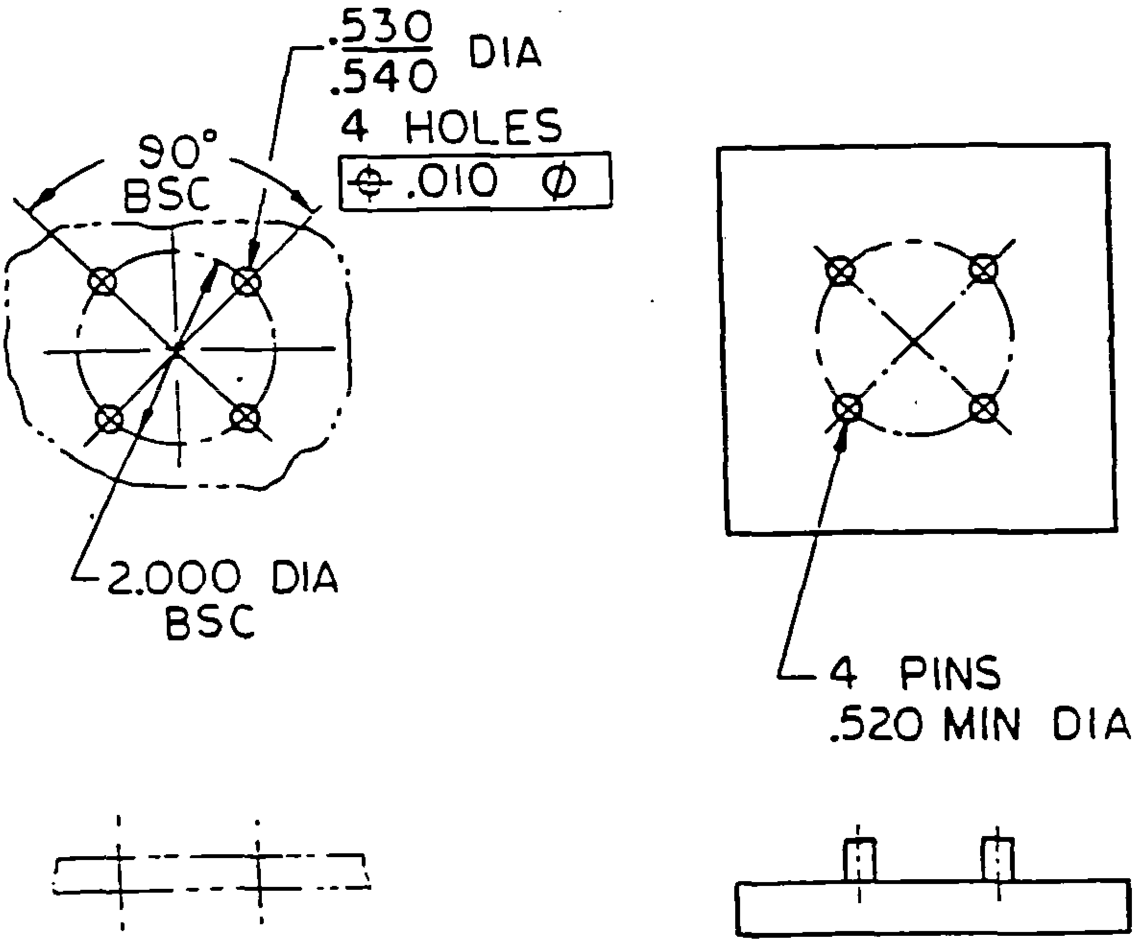


FIGURE 18. Simple hole pattern with identical diameters.

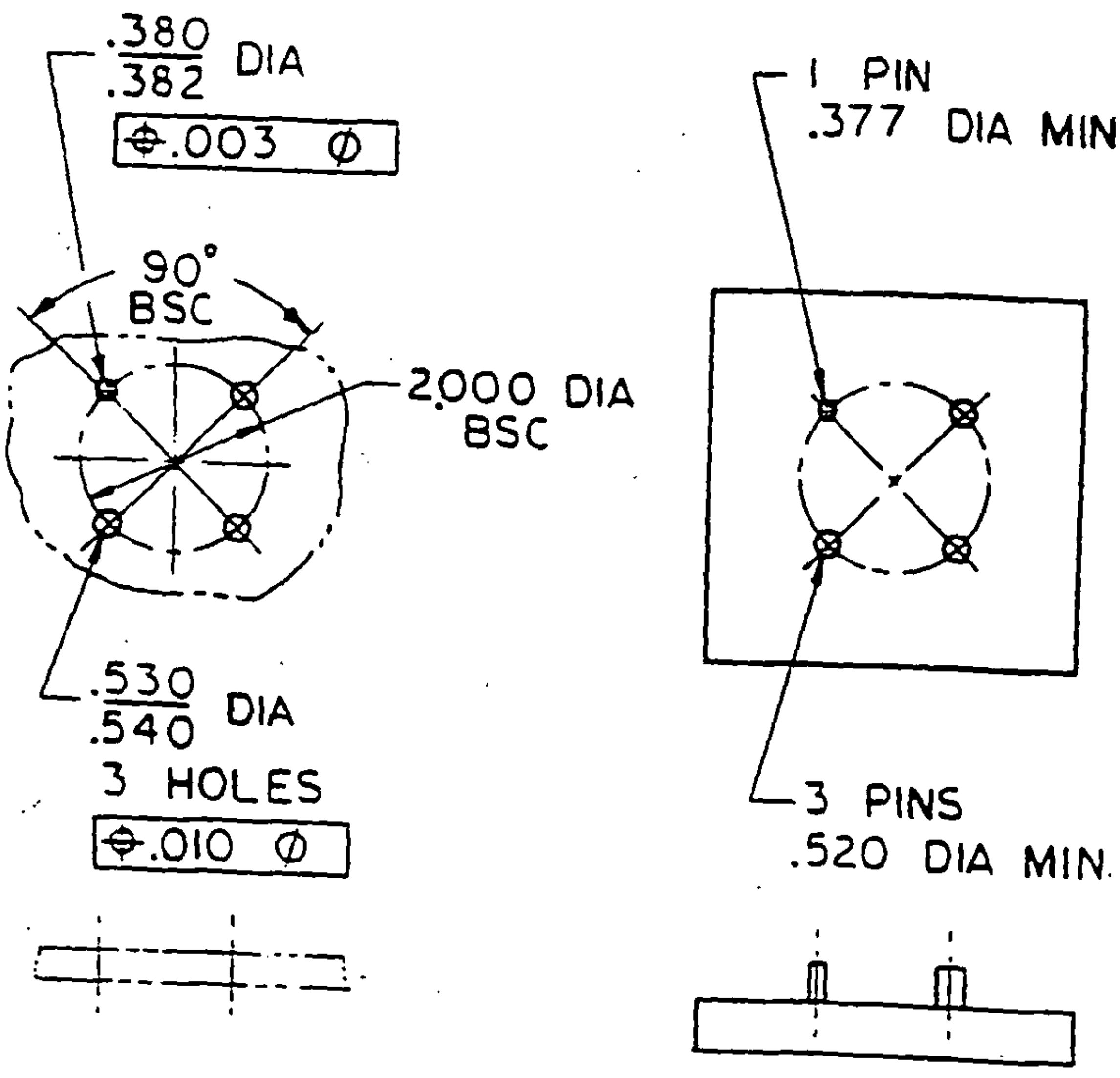


FIGURE 19. Diameter variation in simple hole pattern.

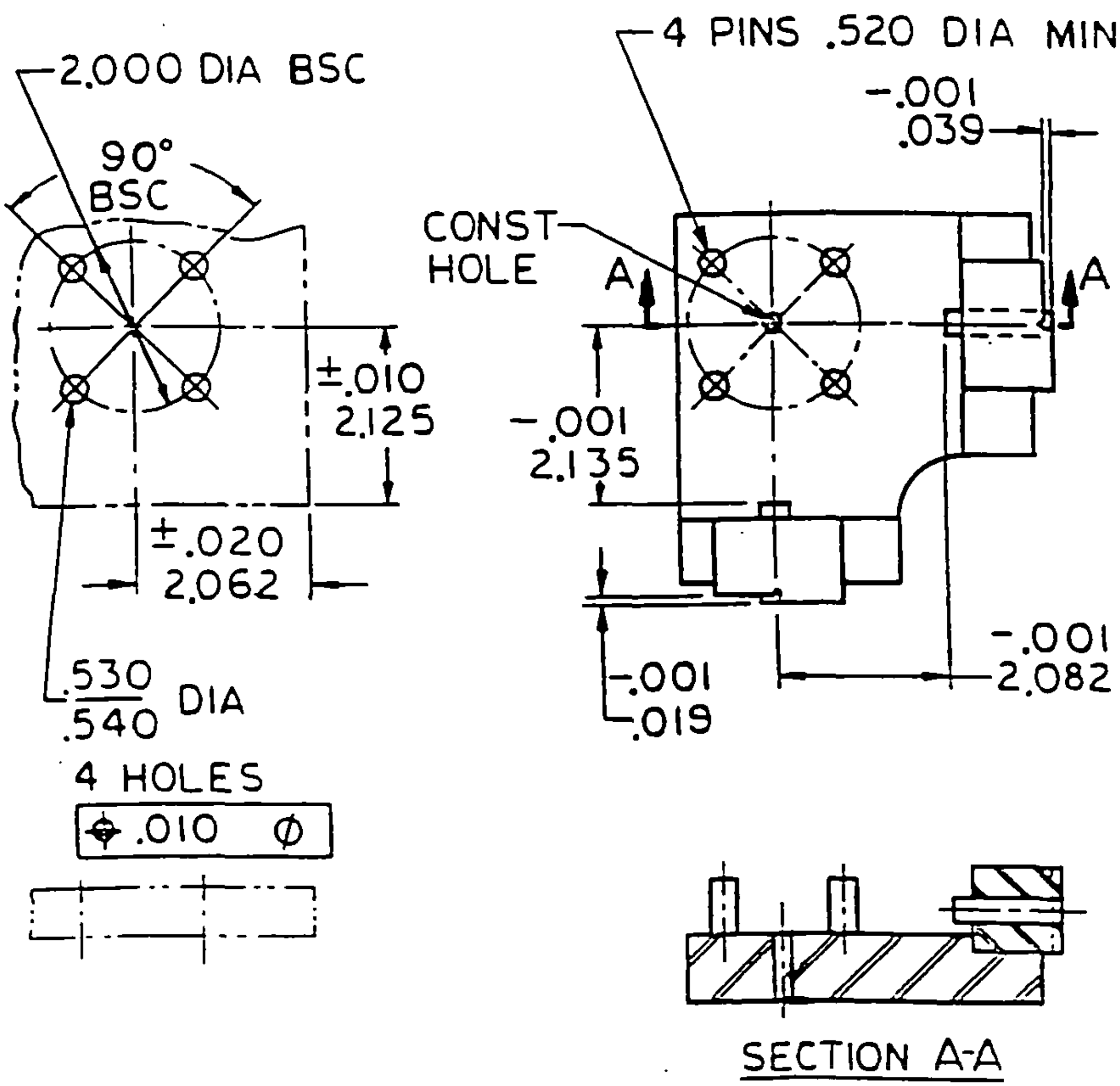


FIGURE 20. RFS location tolerance in simple hole pattern.

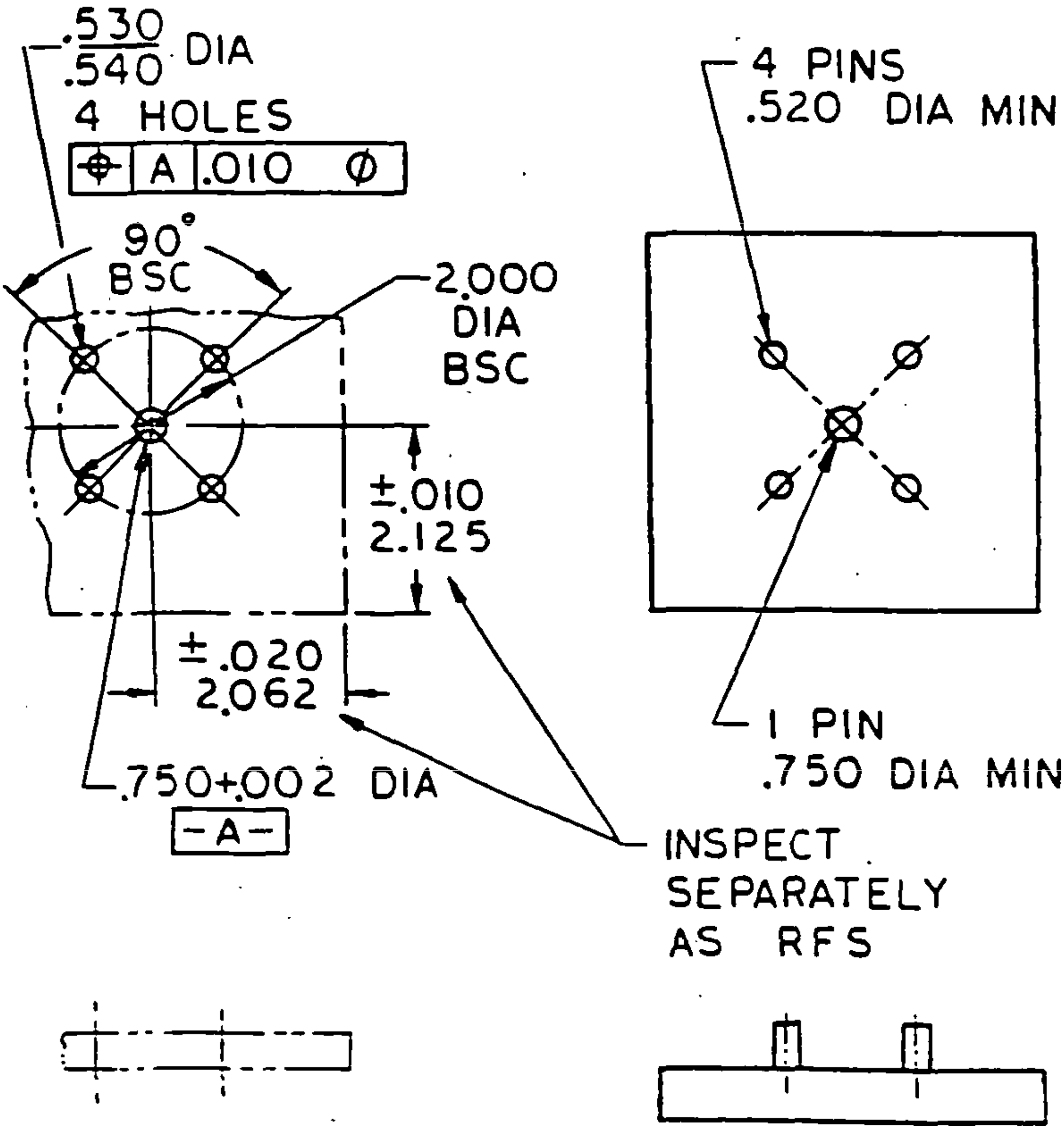


FIGURE 21. Compound hole pattern.

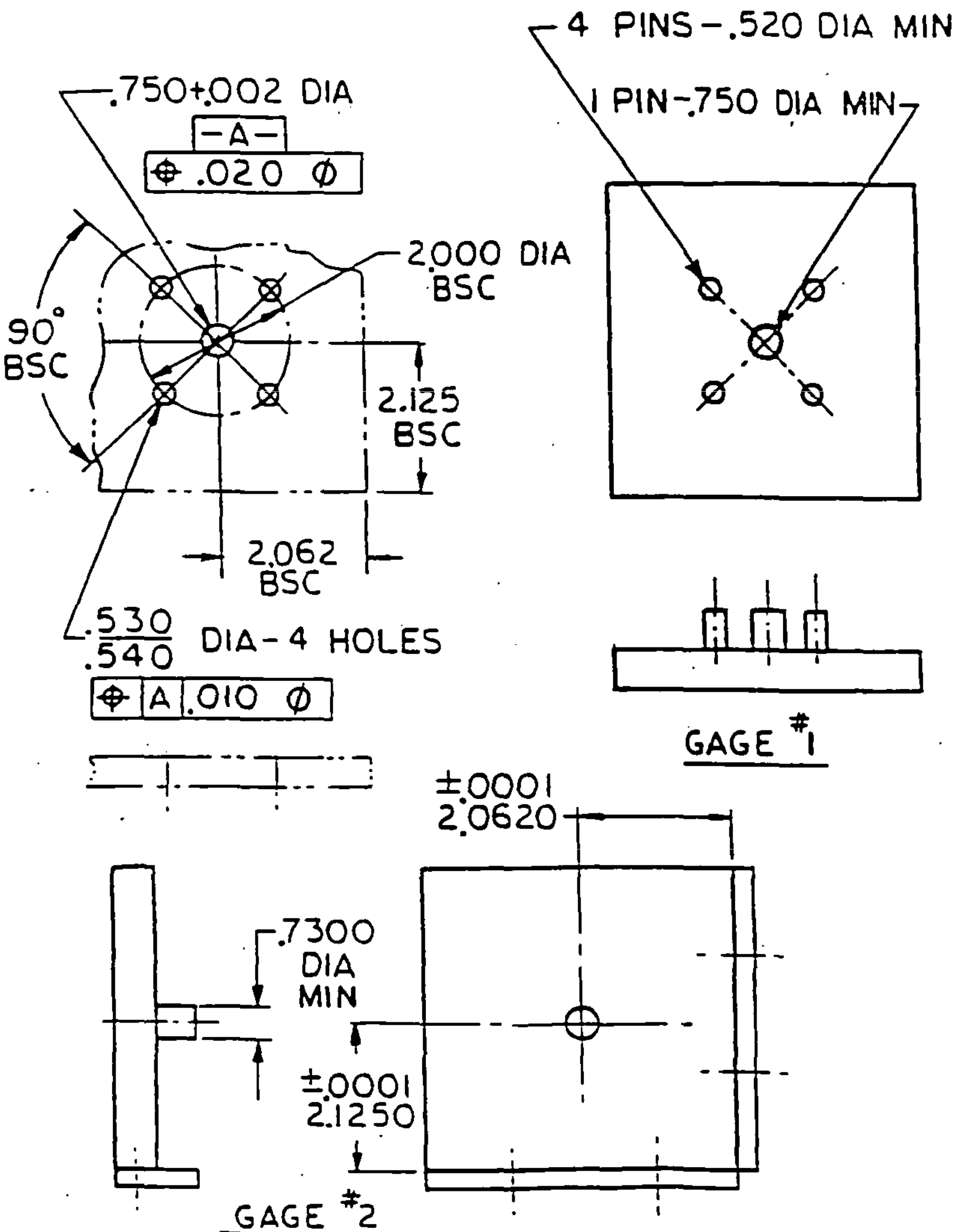


FIGURE 22. Complex hole pattern (inspected as compound and simple pattern).

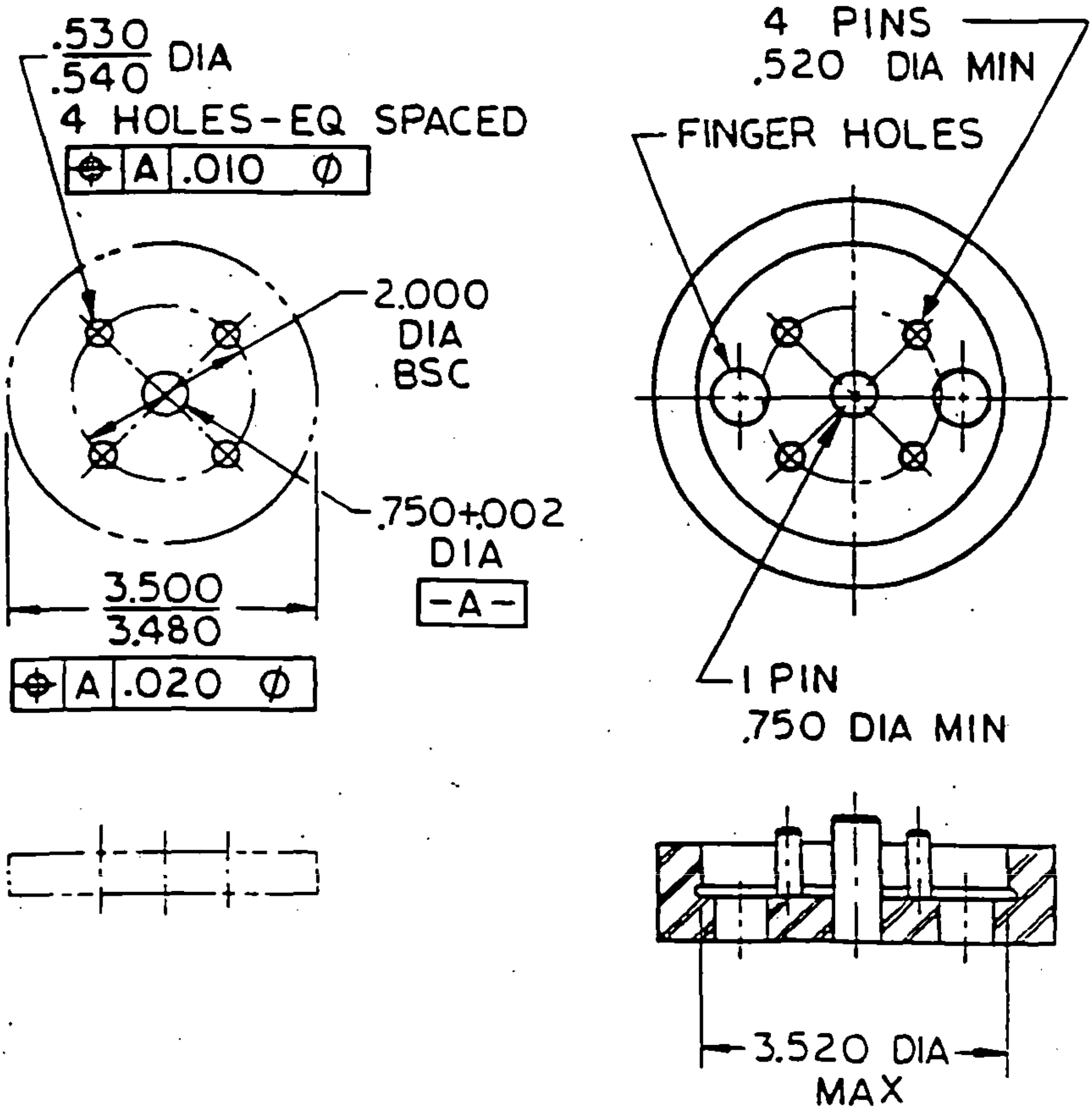


FIGURE 23. Complex hole pattern (basic example).

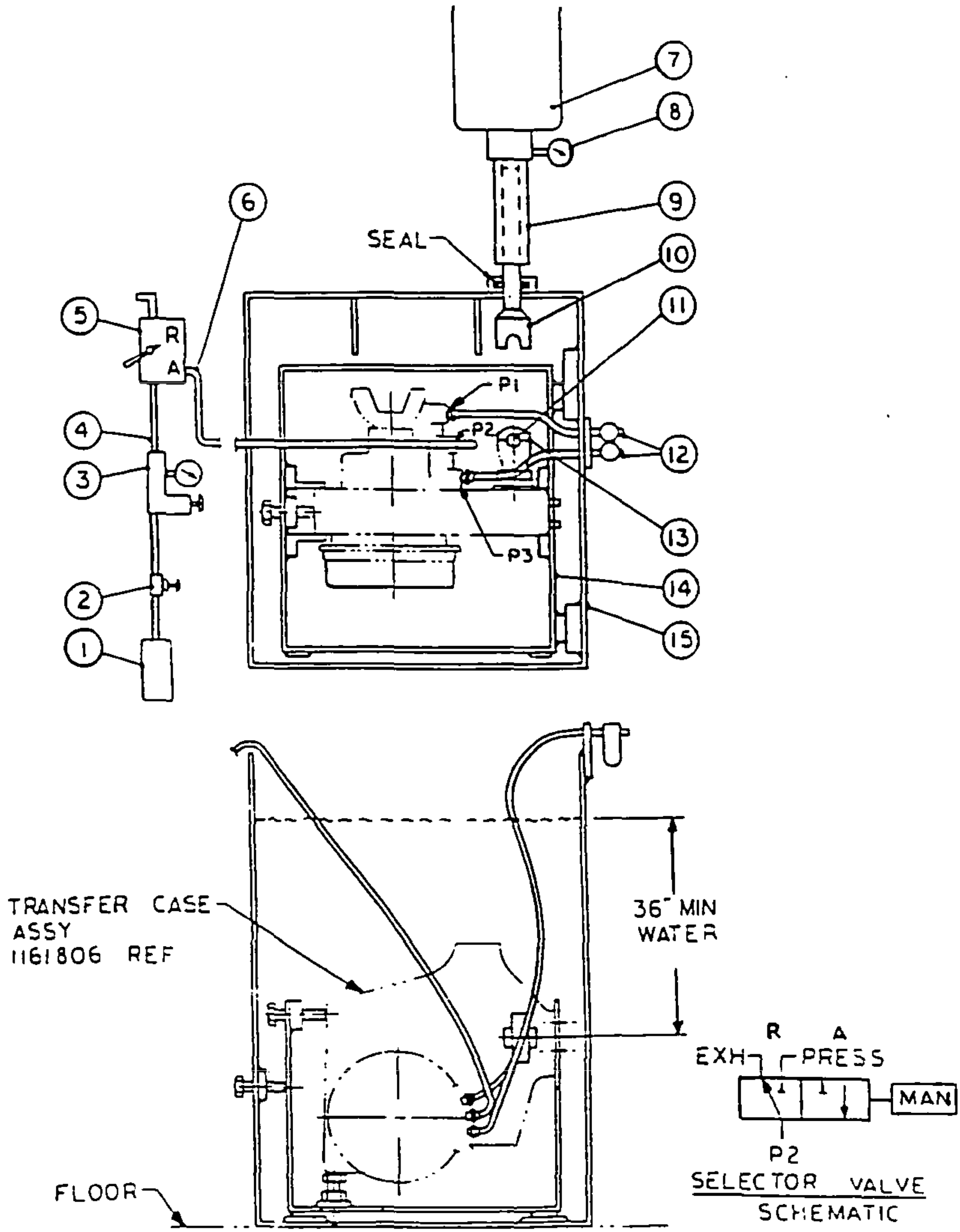


FIGURE 24. Type A arrangement.

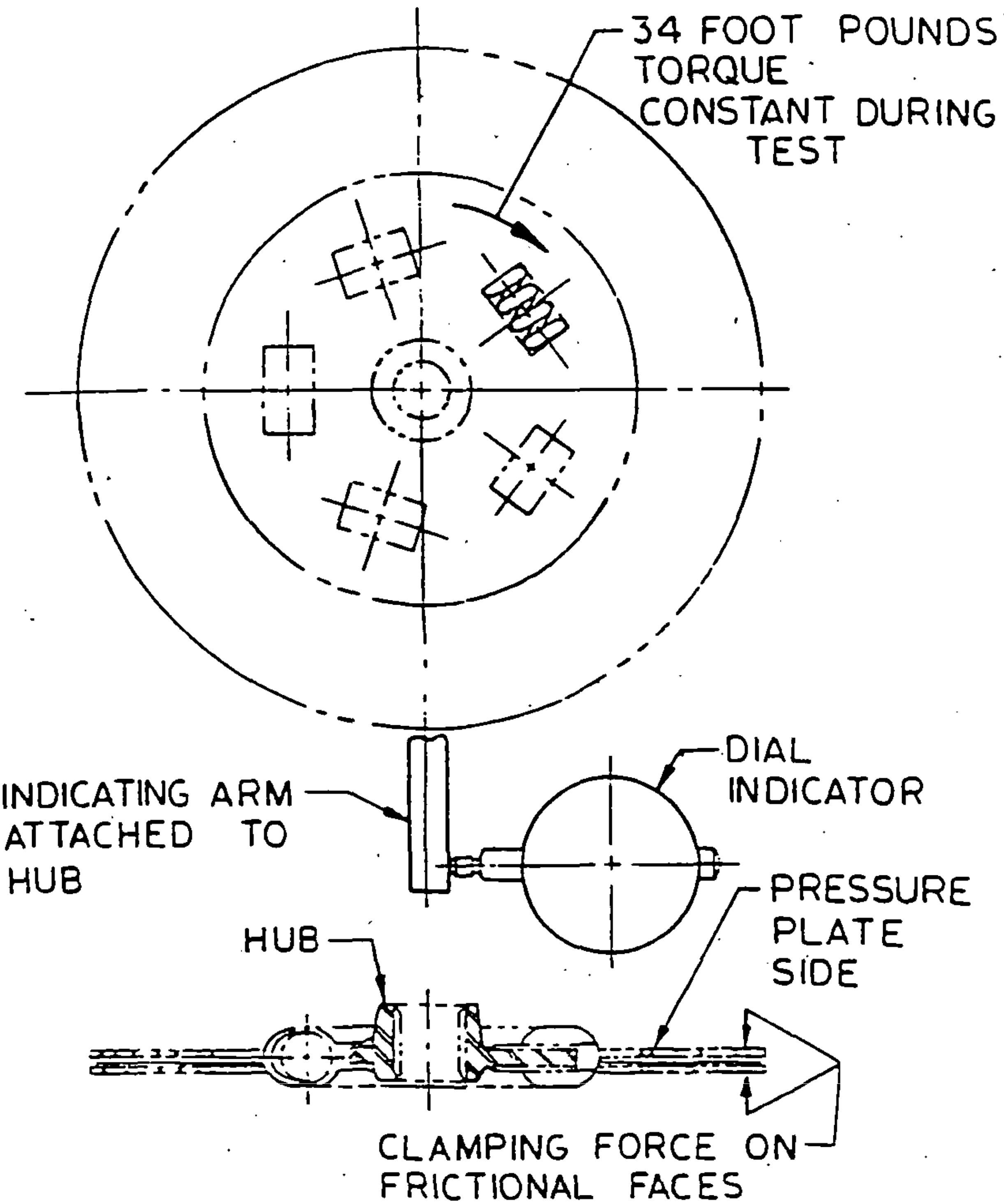


FIGURE 25. Type B arrangement.

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Preparing activity:
Army - AT

(Project QCIC-A133)

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