ASME Y14.43-2011

[Revision of ASME Y14.43-2003 (R2008)]

Dimensioning and Tolerancing Principles for Gages and Fixtures

Engineering Drawing and Related Documentation Practices

AN AMERICAN NATIONAL STANDARD

The American Society of Mechanical Engineers

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AN AMERICAN NATIONAL STANDARD

The American Society of Mechanical Engineers
Three Park Avenue • New York, NY • 10016 USA

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This Standard will be revised when the Society approves the issuance of a new edition.

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The American Society of Mechanical Engineers
Three Park Avenue, New York, NY 10016-5990

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FOREWORD

This Standard contains information showing methods for creating gages and fixtures for features that use principles found in ASME Y14.5, Dimensioning and Tolerancing. It addresses GO gages for measuring maximum material condition (MMC) and NOGO gages for measuring least material condition (LMC). This material was developed from ANSI B4.4-1981, Inspection of workpieces, which has since been retired. This Standard addresses functional gages used for the measurement of geometric tolerances, specifically for the verification of virtual condition boundaries [MMC and maximum material boundary (MMB) concepts]. It also shows examples of functional gages and fixtures used for the measurement of workpiece geometric tolerances referenced at regardless of feature size (RFS) and regardless of material boundary (RMB). GO, NOGO, and functional gages are primarily used for the collection of attribute data. Fixtures are used to properly simulate datum features while an end product is being measured for variable data collection and in certain stages of manufacturing.

This Standard shows the principles and choices available to design, dimension, and tolerance gages and fixtures in compliance with the principles in ASME Y14.5-2009 and previous editions. The gages and fixtures displayed in this Standard represent the physical embodiment of the theory shown in ASME Y14.5 for the simulation of virtual condition (MMC concept) boundaries and proper datum feature simulation.

Gages discussed in this Standard deal with the collection of attribute data only (good versus bad information), while fixtures are to be used in conjunction with variable data collection devices. As illustrated in this Standard, fixtures differ from gages in that gages represent referenced datum features and controlled features, while fixtures represent only the referenced datum features.

The rules and principles in this Standard are consistent with those in ANSI B4.4 and ASME Y14.5. More information and examples of gages and fixtures are presented in this Standard.

The understanding of gages and fixtures is the key to understanding dimensioning and tolerancing of products in accordance with ASME Y14.5.

This Standard is intended to serve the needs of those professionals who are designing gages and fixtures for workpieces dimensioned and toleranced per ASME Y14.5.

Following are the revisions to this edition of ASME Y14.43:

(a) Tables have been added to show definitions, sizes, tolerances, tolerance distribution, and roughness averages for various gage types and classes of fit (ZM, YM, XM, XXM, and XXXM).

(b) The datum feature translation symbol is used and its meaning simulated in gages.

(c) Moveable datum target simulators are shown for the movable datum target symbol.

(d) Oddly configured datum features are simulated in gages with more information on gage element sizes.

(e) More examples of push pin gages are shown.

(f) Threaded holes are shown gaged in improved detail.

(g) Completely disassemblable gages are shown in greater and improved detail.

(h) Curved surfaces as datum features are simulated in gages.

(i) Releasing and invoking spatial degrees of freedom for datum features is demonstrated and gaged.

(j) Radii referenced as datum features are simulated in gages.

(k) Offset slotted datum features are gaged.

(l) The new symbol for unequal or unilateral profile tolerances is shown on gages.

(m) Planar gaging elements referenced at basic locations are shown.

(n) More examples of RFS and RMB datum feature simulators are illustrated.

(o) Planar datum features are simulated at RMB and MMB.

(p) Datum feature patterns are simulated at RMB with expanding gage pins.

(q) More examples of profile of a surface used on oddly configured holes are shown gaged.

(r) Conical datum features are shown fixtured in order to gage radial holes.

(s) Complex datum patterns referenced at RMB and MMB were added.

These revisions are intended to provide the user with more detailed information and a more in-depth understanding of the design, dimensioning, and tolerancing of gages and fixtures than previously presented.

Suggestions for improvement of this Standard are welcome. They should be sent to The American Society of Mechanical Engineers; Attn: Secretary, Y14 Committee; Three Park Avenue; New York, NY 10016.

This Standard was approved by ANSI as an American National Standard on January 28, 2011.

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The Committee welcomes proposals for revisions to this Standard. Such proposals should be as specific as possible, citing the paragraph number(s), the proposed wording, and a detailed description of the reasons for the proposal, including any pertinent documentation.

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Subject:	Cite the applicable paragraph number(s) and the topic of the inquiry.
Edition:	Cite the applicable edition of the Standard for which the interpretation is being requested.
Question:	Phrase the question as a request for an interpretation of a specific requirement suitable for general understanding and use, not as a request for an approval of a proprietary design or situation. The inquirer may also include any plans or drawings, that are necessary to explain the question; however, they should not contain proprietary names or information.

Requests that are not in this format may be rewritten in the appropriate format by the Committee prior to being answered, which may inadvertently change the intent of the original request.

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DIMENSIONING AND TOLERANCING PRINCIPLES FOR GAGES AND FIXTURES

1 GENERAL

1.1 Scope

This Standard presents the design practices for dimensioning and tolerancing of gages and fixtures used for the verification of maximum material condition (MMC) size envelopes and virtual condition boundaries generated by geometric tolerances controlled at MMC, and datum features controlled at maximum material boundary (MMB). Some examples of gages and fixtures used to inspect workpieces using regardless of feature size (RFS) and regardless of material boundary (RMB) are shown in Nonmandatory Appendix C.

Most of these practices focus on the design of receiver-type gages that collect attribute data when used for the verification of workpieces dimensioned and toleranced in accordance with ASME Y14.5-2009. Some examples of fixturing workpieces for the collection of variables data are shown. These practices represent examples of product definitions allowed by ASME Y14.5. Since ASME Y14.5 is not a gaging standard, ASME Y14.43 shows the practical embodiment of the theory displayed in ASME Y14.5 by illustrating how the workpieces can be fixtured and gaged for tolerance verification.

For gaging and fixturing principles and practices, see sections 4 through 8 and Mandatory Appendices I and II.

1.2 Units

The International System of Units (SI) is featured in this Standard as it commonly supersedes U.S. Customary units specified on engineering drawings. U.S. Customary units could equally well have been used without prejudice to the principles established.

1.3 Figures

The figures in this Standard are in accordance with ASME Y14.5-2009. The figures are intended only as illustrations to aid the user in understanding the design principles and methods of gaging and fixturing design described in the text. Figures may show added detail for emphasis or be incomplete by intent. Numerical values of dimensions and tolerances are illustrative only.

1.4 Reference to This Standard

Where drawings are based on this Standard, it shall be noted on the drawing or in a document referenced on the drawing. Reference to this Standard shall state "Prepared in accordance with ASME Y14.43-2011."

2 REFERENCES

The following revisions of American National Standards form a part of this Standard to the extent specified herein. A more recent revision may be used provided there is no conflict with the text of this Standard. In the event of a conflict between the text of this Standard and the references cited herein, the text of this Standard shall take precedence.

ASME B4.2, Preferred Metric Limits and Fits
ASME B46.1, Surface Texture (Surface Roughness, Waviness, and Lay)
ASME B89.6.2, Temperature and Humidity Environment for Dimensional Measurement
ASME B89.7.2, Dimensional Measurement Planning
ASME Y14.36M-1996, Surface Texture Symbols
ASME Y14.5-2009, Dimensioning and Tolerancing
ASME Y14.5M-1994, Dimensioning and Tolerancing
ASME Y14.5.1M-1994, Mathematical Definition of Dimensioning and Tolerancing Principles

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3 DEFINITIONS

3.1 General

The following terms are defined as their use applies in this Standard. Some terms used in this Standard are repeated from ASME Y14.5-2009 or ASME Y14.5M-1994 and are unique to those issues. In other cases, the terms are common to several versions of ASME Y14.5 and no date is shown.

3.2 Gaging

3.2.1 Actual Local Size

actual local size: the measured value of any individual distance at any cross section of a feature of size.

3.2.2 Actual Mating Envelope

3.2.2.1 Actual Mating Envelope (ASME Y14.5-2009)

actual mating envelope: an envelope outside of the material. It is a similar perfect feature(s) counterpart of smallest size that can be contracted about an external feature(s) or largest size that can be expanded within an internal feature(s) so that it coincides with the surface(s) at the highest points. Two types of actual mating envelopes — unrelated (not constrained to datums) and related (constrained to datums) — are described below.

related actual mating envelope: a similar perfect feature counterpart expanded within an internal feature(s) or contracted about an external feature(s) while constrained either in orientation or location or both to the applicable datum(s).

unrelated actual mating envelope: a similar perfect feature(s) counterpart expanded within an internal feature(s) or contracted about an external feature(s), and not constrained to any datum(s).

3.2.2.2 Actual Mating Envelope (ASME Y14.5M-1994)

actual mating envelope: an envelope defined according to the type of feature, as follows:

(a) For an External Feature: A similar perfect feature counterpart of smallest size that can be circumscribed about the feature so that it just contacts the surface at the highest points, for example, a smallest cylinder of perfect form or two parallel planes of perfect form at minimum separation that just contact(s) the highest points of the surface(s). For features controlled by orientation or positional tolerances, the actual mating envelope is oriented relative to the appropriate datum(s), for example, perpendicular to a primary datum plane.

(b) For an Internal Feature: A similar perfect feature counterpart of largest size that can be inscribed within the feature so that it just contacts the surface at the highest points, for example, a largest cylinder of perfect form or two parallel planes of perfect form at maximum separation that just contact(s) the highest points of the surface(s). For features controlled by orientation or positional tolerances, the actual mating envelope is oriented relative to the appropriate datum(s).

3.2.3 Attribute Gage

attribute gage: the family of receiver gages used to collect attributes data, for example, GO and functional gages.

3.2.4 Attributes Data

attributes data: information obtained from an inspection process that indicates only whether a part is acceptable or not acceptable.

3.2.5 Calibration

calibration: the act of inspecting and subsequent adjusting of a gage, where needed, to meet a specific parameter.

3.2.6 Certification

certification: the act of documenting that a gage meets a specific parameter.

3.2.7 Complex Feature (ASME Y14.5-2009)

complex feature: a single surface of compound curvature or a collection of other features that constrains up to six spatial degrees of freedom.

3.2.8 Datum Feature Simulator

NOTE: ASME Y14.5-2009 defines a datum feature simulator as having two definitions: *datum feature simulator (theoretical)* and *datum feature simulator (physical)*. Although in ASME Y14.5-2009 the default meaning of the term is theoretical, in ASME Y14.43 the default meaning of the term is physical.

3.2.8.1 Datum Feature Simulator (ASME Y14.5M-1994)

datum feature simulator: a surface of adequately precise form (such as a surface plate, a gage surface, or a mandrel) contacting the datum feature(s) and used to establish the simulated datum(s).

NOTE: Simulated datum features are used as the practical embodiment of the datums during manufacture and inspection.

3.2.8.2 Datum Feature Simulator (Physical) (ASME Y14.5-2009)

datum feature simulator (physical): the physical boundary used to establish a simulated datum from a specified datum feature.

NOTE: For example, gages, fixture elements, or digital data (such as machine tables, surface plates, a mandrel, or mathematical simulation), although not true planes, are of sufficient quality that the planes derived from them are used to establish simulated datums. Physical datum feature simulators are used as the physical embodiment of the theoretical datum feature simulators during manufacturing and inspection.

3.2.9 Feature of Size, Irregular (ASME Y14.5-2009)

irregular feature of size: the two types of irregular feature of size are as follows:

(a) a directly toleranced feature or collection of features that may contain or be contained by an actual mating envelope that is a sphere, cylinder, or pair of parallel planes

(b) a directly toleranced feature or collection of features that may contain or be contained by an actual mating envelope other than a sphere, cylinder, or pair of parallel planes

3.2.10 Feature of Size, Regular (ASME Y14.5-2009)

regular feature of size: one cylindrical or spherical surface, a circular element, and a set of two opposed parallel elements or opposed parallel surfaces, each of which is associated with a directly toleranced dimension.

3.2.11 Fixed Limit Gage

fixed limit gage: a device of defined geometric form and size used to assess the conformance of a feature(s) of a workpiece to a dimensional specification. Also referred to as a "limit gage."

3.2.12 Fixture

fixture: a device used to hold parts securely in the correct position in a tool or gage during manufacturing, assembly, or inspection.

3.2.13 Functional Fixture

functional fixture: a device having integral gage elements that make physical contact with part datum features. It typically holds parts as they would be held when assembled. The fixture and its gage elements represent simulated datum features from the part and are identified on drawings using techniques found in ASME Y14.5.

3.2.14 Functional Gage

functional gage: a fixed limit gage used to verify virtual condition boundaries (MMC concept) generated by the collective effect of the feature's MMC and the applicable geometric tolerance at the MMC size.

3.2.15 Gage Element

gage element: a physical feature of the gage used in the verification of workpiece compliance to the associated tolerance requirement. These physical features represent datum feature simulators, virtual condition, or datum material boundaries.

3.2.16 GO Gage

GO gage: a fixed limit gage that checks a feature of size for acceptance within MMC perfect form boundary.

3.2.17 Least Material Boundary (LMB) (ASME Y14.5-2009)

least material boundary (LMB): the limit defined by a tolerance or combination of tolerances that exists on or inside the material of a feature(s).

3.2.18 Least Material Condition (LMC)

least material condition (LMC): the condition in which a feature of size contains the least amount of material within the stated limits of size (e.g., maximum hole diameter, minimum shaft diameter).

3.2.19 Maximum Material Boundary (MMB) (ASME Y14.5-2009)

maximum material boundary (MMB): the limit defined by a tolerance or combination of tolerances that exists on or outside the material of a feature(s).

NOTE: To calculate the appropriate MMB for datum feature simulation, see ASME Y14.5-2009, Fig. 4-16 and paras. 4.11.5 and 4.11.6.

3.2.20 Maximum Material Condition (MMC)

maximum material condition (MMC): the condition in which a feature of size contains the maximum amount of material within the stated limits of size (e.g., minimum hole diameter, maximum shaft diameter).

3.2.21 NOGO Gage

NOGO gage: a fixed limit gage that checks a feature of size for violation of the LMC actual local size. This gage is also referred to as a "NOT GO gage."

3.2.22 Regardless of Feature Size (RFS)

regardless of feature size (RFS): indicates that a geometric tolerance applies at any increment of size of the actual mating envelope of the feature of size.

3.2.23 Regardless of Material Boundary (RMB) (ASME Y14.5-2009)

regardless of material boundary (RMB): indicates that a datum feature simulator progresses from MMB toward LMB until it makes maximum contact with the extremities of a feature(s).

3.2.24 Resultant Condition

3.2.24.1 Resultant Condition (ASME Y14.5-2009)

resultant condition: the single worst-case boundary generated by the collective effects of a feature of size's specified MMC or LMC, the geometric tolerance for that material condition, the size tolerance, and the additional geometric tolerance derived from the feature's departure from its specified material condition.

3.2.24.2 Resultant Condition (ASME Y14.5M-1994)

resultant condition: the variable boundary generated by the collective effects of a size feature's specified MMC or LMC, the geometric tolerance for that material condition, the size tolerance, and the additional geometric tolerance derived from the feature's departure from its specified material condition.

3.2.25 Separate Gaging Requirement

separate gaging requirement: the condition in which features or patterns of features that are located from a common datum reference frame do not need to be inspected together (this does not affect the within-pattern requirement). If simultaneous gaging is not required, the abbreviation "SEP REQT" is placed under the feature control frame. See *simultaneous gaging requirement*.

3.2.26 Simultaneous Gaging Requirement

simultaneous gaging requirement: the condition in which all of the features or patterns of features that are located from a common datum reference frame are inspected together as a single pattern relative to that common datum reference frame. The lower segment of a composite feature control frame does not share the requirement unless specified by the abbreviation "SIM REQT."

3.2.27 Variables Data

variables data: information obtained from an inspection process that indicates the level of acceptability of a part by yielding a measured value. Therefore, the level of acceptability is recorded as a numerical value.

3.2.28 Virtual Condition

virtual condition: a constant boundary generated by the collective effects of a considered feature of the size's specified MMC or LMC and the geometric tolerance for that material condition.

3.2.29 Virtual Condition (MMC Concept)

virtual condition (MMC concept): for all internal features of size this is calculated by subtracting the geometric tolerance applicable at MMC from the MMC size of the feature. For all external features of size, this is calculated by adding the geometric tolerance applicable at MMC to the MMC size of the feature. For additional information see *maximum material boundary.*

3.2.30 Workpiece/Part

workpiece/part: the general term denoting a discrete end product, subassembly, or final assembly.

3.2.31 Zero Force

zero force: the theoretical condition of a gage element being brought into conjunction with a workpiece feature without the application of any force. As used within this Standard, zero force is understood as the use of the minimum amount of physical force without distorting or altering the feature or the gage. When the application of physical force distorts or alters the feature or the gage from its free state characteristic, it is considered excessive force.

3.3 Tolerancing

3.3.1 Absolute Tolerance (Pessimistic)

absolute tolerance (pessimistic): the policy of tolerancing gages that ensures complete random assemblability of parts by applying gagemakers' tolerances, workpiece limits of size, and geometric control. See para. 4.3.1.

3.3.2 Gagemakers' Tolerance

gagemakers' tolerance: the manufacturing tolerance allowed a gagemaker that is applied to gages and comparator setting masters.

3.3.3 Measurement Uncertainty

measurement uncertainty: the difference between the corrected measured size and the actual size. In cases where there is adequate information based on a statistical distribution, the estimate may be associated with a specific probability. In other cases, an alternative form of numerical expression of the degree of confidence to be attached to the estimate may be given.

3.3.4 Optimistic Tolerance

optimistic tolerance: the policy of tolerancing gages that ensures all part features within tolerance that are gaged are accepted by the gage. See para. 4.3.2.

3.3.5 Practical Absolute Tolerancing

practical absolute tolerancing: the policy of tolerancing gages that predicts most part features within tolerance will be accepted by the gage, some borderline part features within tolerance will not be accepted by the gage, and a very low probability that some borderline part features not within tolerance will be accepted by the gage. See para. 4.3.4 and Mandatory Appendix II.

3.3.6 Tolerant Tolerance

tolerant tolerance: the policy of tolerancing gages that ensures most part features within tolerance that are gaged are accepted by the gage and most part features not within tolerance that are gaged are rejected by the gage. See para. 4.3.3.

3.3.7 Wear Allowance Tolerance

wear allowance tolerance: an additional amount of size tolerance applied to gage elements that accounts for the wear of the gage over time.

3.3.8 Workpiece/Part Tolerance

workpiece/part tolerance: for tolerancing GO and NOGO gages, this is the difference between the LMC and the MMC. For tolerancing functional gages, this is the difference between the virtual condition (MMC concept) and the LMC (LMC concept).

4 PRINCIPLES

4.1 General

4.1.1 Gage Design Principles. Gages that check envelopes or boundaries are all designed on similar principles whether they inspect MMC or virtual condition (MMC concept). GO gages determine compliance with the MMC envelope that is defined by ASME Y14.5. Functional gages are used to inspect for compliance with the virtual condition boundary created by use of the MMC concept defined by ASME Y14.5. Nonmandatory Appendix B shows examples of functional gages designed, dimensioned, and toleranced to verify workpiece compliance with their applicable virtual condition boundaries. These gages are often limited to attribute data collection (pass/fail). Nonmandatory Appendix C shows examples of functional gages designed, dimensioned, and toleranced to verify workpiece compliance with geometric tolerances specified at RFS and datum features referenced at RMB. Gages that verify workpiece compliance with geometric tolerances referenced at RFS and/or datum features referenced at RMB are often more complex in design and are therefore commonly augmented with expanding or contracting gage elements and probes that are capable of collecting variables data.

4.1.2 Goal of Gaging. While the goal of gaging is to accept all good parts and reject all bad parts, manufacturing of gaging equipment introduces variability making this impossible. Depending upon the tolerancing policy chosen, the size range of gage elements may be larger, smaller, or straddle the boundaries they are inspecting. The tolerance policy chosen will determine whether borderline part features are accepted or rejected. The practice of gage tolerancing requires a gage designed with size tolerances and/or geometric tolerances be as small as economically feasible.

4.1.3 Economic Context. The design and manufacture of gages and fixtures takes place within a specific economic context. The smaller the allowed tolerances for the gage, the more expensive it is to manufacture and the larger the number of parts within specification it will accept when used properly. Alternatively, smaller gage tolerance allows less room for gage wear, therefore shortening the life of the gage. As it wears beyond acceptable limits, it begins to accept technically bad parts. Gages shall be inspected periodically and replaced or repaired before this happens.

Larger toleranced gages will less reliably distinguish in-tolerance parts from out-of-tolerance parts and may reject more in-tolerance parts or accept more out-of-tolerance parts depending on the gage tolerancing policy used. The cost of the gage shall be weighed against the cost of the workpiece accept/reject rate. Therefore, the designer shall give consideration to the break-even point and decide on the correct balance between the gage with prohibitive up-front costs and prohibitive long-range costs caused by rejection of good parts (i.e., parts meeting drawing specification) compared to the acceptance of bad parts.

4.2 Function and Use of Gages

Fixed limit gages, in theory, accept all workpieces dimensionally conforming to specification and reject all workpieces that do not conform. The GO gage and the functional gage shall fully receive the workpiece to be inspected. If used properly, the NOGO gage shall not receive the workpiece in any position.

4.2.1 GO Plug Gages. A GO plug gage shall enter the hole over its full length when applied by hand without using excessive force. If it is not possible to use a full form plug gage or if the rule concerning perfect form at MMC is not in effect, GO segmental gages, if used, are applied to the hole in axial planes uniformly distributed around the circumference. Unless otherwise specified, perfect form is required at MMC for rigid features, necessitating the use of full form MMC sized cylindrical plug gages for holes and full form MMC sized cylindrical ring gages for shafts. When nonrigid workpieces such as thin-walled parts are gaged, zero force must be used, as more than zero force may distort the hole and give a false result. For nonrigid features, perfect form at MMC is not required.

4.2.2 NOGO Gages. The LMC limit of the workpiece is checked with a gage designed to contact the workpiece, if a cylinder, at two diametrically opposed points separated by a distance exactly equal to the LMC size limit. This NOGO gage shall not pass into or over the workpiece at any position. If it is determined that this two-point opposing point type of measurement cannot be used, a NOGO cylindrical or spherical plug gage shall not enter the hole when applied by hand without using excessive force. Excessive force shall be considered force that is sufficient to damage or deform either the workpiece or the gage. The hole shall be checked from both ends, if possible. A NOGO gage with segmental spherical gaging surfaces is introduced into the hole by tilting it, and it shall not be possible to erect the gage in the hole without using excessive force. The inspector is responsible for all cross sections within the hole.

4.2.3 GO Cylindrical Ring Gage. This gage shall encompass the complete length of the shaft when applied by hand using zero measuring force (or any corrected value specified). If a cylindrical ring gage cannot be used because the perfect form at MMC rule has been eliminated for a specific workpiece and a GO snap gage is to be used, the GO snap gage shall

(a) pass over a dimensionally conforming shaft with a horizontal axis under its own weight or the force marked on the gage

(b) pass over a dimensionally conforming shaft with a vertical axis when applied by hand without using excessive force

4.2.4 NOGO Snap Gages. A NOGO snap gage shall

(a) not pass over a dimensionally conforming shaft with a horizontal axis under its own weight or the force marked on the gage

(b) not pass over a dimensionally conforming shaft with a vertical axis when applied by hand without using excessive force

4.2.5 Functional Gages. A functional gage pin shall be able to enter the hole being gaged over the entire depth of the hole without excessive force being applied. A functional gage hole (ring) shall be able to receive the shaft being gaged over the entire length of the shaft without excessive force being applied. If planar datum features are simulated on the gage, the datum features on the workpiece shall contact the datum feature simulators on the gage as appropriate (for example, a minimum of three points of high point contact on a primary planar datum feature, a minimum of two points of high point contact on a secondary planar datum feature, and a minimum of one point of high point contact on a tertiary planar datum feature). To construct a valid datum plane where a datum rocker is an issue, see ASME Y14.5.1M. If restraint is to be applied to the datum features, it shall be specified on the workpiece drawing, or the workpiece shall be restrained so as not to alter the measurement readings of the same part measured in the free state.

(a) When using functional gaging principles, it is recommended that

(1) gages, production tooling, and parts (to include tolerances and allowances) should be designed using a concurrent engineering team

(2) gages be defined using the same geometric characteristics that define the part being gaged

(b) When using functional gaging principles, it is required that

(1) gages simulate datum features as defined by part datum features or datum targets.

(2) functional gages that verify positional requirements have gaging elements located at basic dimensions conforming to feature locations dimensioned on the product drawings.

(3) gages simulate the MMC concept of the controlled features' virtual condition or MMC, as applicable, while datum features of size are simulated at their appropriate MMB or RMB. Simulating datum features at their appropriate LMB, while possible in software programs, has proven impractical in hard gaging.

(4) all functional gage elements go into or over the part features in a single gage where simultaneous requirements are invoked by the product specification.

(c) When using functional gaging principles, it is observed that

(1) specifying one datum reference frame per part will permit one gage to be used for acceptance when there are no separate requirements invoked

(2) any increase in the number of datum reference frames will increase the number of gages or require multiple setups on a gage with multiple datum reference frames and inspection setups

4.3 Gaging Tolerance Policies

Paragraphs 4.3.1 through 4.3.4 explain alternative forms of gage tolerancing policy. A gage or fixture designer may select one of these policies for specific implementation.

This Standard recommends the absolute tolerancing policy for GO gages and the practical absolute tolerancing policy for functional gages. The result is that GO gages designed, dimensioned, and toleranced per ASME Y14.43 accept no parts that have violated their MMC envelope of perfect form, and functional gages, in practicality, accept no parts that have violated their virtual condition boundaries (MMC concept), their MMC, or their MMB, as applicable. A very small statistical possibility exists that the practical absolute gage tolerancing policy will accept parts that are in violation of their geometric tolerances. This is a risk taken to allow more of the borderline but technically in-tolerance parts to be accepted, thereby reducing the long-term cost of the products being gaged. The absolute tolerancing policy is also acceptable for use on functional gages, but if the same amount of tolerance is used that would have been used for a gage toleranced with the practical absolute gage tolerancing policy, a larger part of that tolerance applies in the range that will reject in-tolerance parts. For NOGO gages, this Standard recommends that the gage acts in the spirit of the absolute tolerancing policy, accepting no parts that have violated their LMC. For NOGO gages, this is accomplished by subtracting size tolerance from gage pins, which are designed at LMC, and adding size tolerance to gage holes, which are designed at LMC.

The larger the gage tolerance, the more likely it is that in-tolerance parts are either rejected or accepted, depending on the gage policy chosen from those defined in paras. 4.3.1 through 4.3.4.

4.3.1 Absolute Tolerancing (Pessimistic Tolerancing). Absolute tolerancing (pessimistic tolerancing) is a policy of tolerancing gages that ensures complete random assemblability of parts by applying gagemakers' tolerances, wear allowances, measurement uncertainties, and form controls, all within the workpiece limits of size and geometric control. Gage tolerances add material to the gaging element, beginning at the limit [e.g., MMC or virtual condition (MMC concept) of the feature being gaged]. Gages produced under this policy will accept most part features that are within tolerance, reject all part features not within tolerance, and reject a small percentage of borderline part features that are technically within tolerance. See Mandatory Appendix I, Fig. I-2.

4.3.2 Optimistic Tolerancing. Optimistic tolerancing is the policy of tolerancing gages that ensures all part features within tolerance that are gaged are accepted by the gage. This is accomplished by applying gagemakers' tolerances, wear allowances, measurement uncertainties, and form controls all outside of the workpiece limits of size and geometric control. Gage tolerances subtract material from the gage beginning at the limit [e.g., MMC or virtual condition (MMC concept) of the feature being gaged]. Gages produced in accordance with this policy will accept part features that are within tolerance, reject most features not within tolerance, and accept a small percentage of borderline part features that are technically not within tolerance. See Mandatory Appendix I, Figs. I-3(a) and I-3(b).

4.3.3 Tolerant Tolerancing. Tolerant tolerancing is the policy of tolerancing gages that ensures most part features within tolerance that are gaged are accepted by the gage, and most part features not within tolerance that are gaged are rejected by the gage. This is accomplished by applying gagemakers' tolerances, wear allowances, measurement uncertainties, and form controls in such a way that some of the tolerance on the gage is within the workpiece limits of size and geometric control and some of the tolerance on the gage is outside the workpiece limits of size and geometric control. Gage tolerances both add and subtract material from the gage, beginning at the limit [e.g., MMC or virtual condition (MMC concept) of the feature being gaged]. Gages produced in accordance with this policy will accept most part features that are within tolerance; reject most part features not within tolerance; accept a small percentage of borderline, out-of-tolerance features; and reject a small percentage of borderline, in-tolerance features. See Mandatory Appendix I, Fig. I-4.

4.3.4 Practical Absolute Tolerancing. Practical absolute tolerancing is the policy of tolerancing gages that predicts most part features within tolerance will be accepted by the gage, some borderline part features within tolerance will not be accepted by the gage, and that there is a very low probability that some borderline part features not within tolerance will be accepted by the gage. This is accomplished by applying gagemakers' tolerances, wear allowances, measurement uncertainties, and form controls in such a manner that all of the tolerance on the size of the gage is inside the workpiece limits of size, but allows geometric tolerance a small infringement on the acceptable virtual condition boundary of the workpiece. See Mandatory Appendix II.

4.4 Statistics: Statistical Tolerancing

Statistical tolerancing is a method of assigning tolerances based on the principles of statistics and is typically applied to components of an assembly. Component part tolerances are increased beyond 100% of the arithmetically calculated tolerances from the assembly. The process distribution is considered in determining if the assembled components will produce a usable assembly. Component tolerances are assessed as a population characteristic in place of individual piece part data. Process capability knowledge may be a factor in the production of the components with their increased tolerance. Variables data is needed to establish the population characteristics.

Therefore, it is the recommendation of this Standard that statistically toleranced (ST) features not be verified using hard (attribute) gages. Variables data collectors, such as coordinate measuring machines, are better suited to validating statistical tolerances. Measurement accuracy is improved when using variables data collection processes where fixtures are used to simulate datum features.

4.5 Gage Geometric Tolerances Reflect Part Geometric Tolerances

Each feature of the gage that represents a feature on the workpiece is recommended to receive a tolerance between 5% and 10% of the tolerance assigned to that particular workpiece feature. The selection of a gaging policy, as described in para. 4.3, will associate the gage tolerances to the workpiece tolerances and determine whether they are contained within or additive.

NOTE: This Standard recommends that the gage designer consider 5% of the part tolerance used as gage tolerance with an additional 5% considered for wear allowance. These are intended as guidelines from which to begin the gage design. Gage tolerance selection shall take part function, safety, and economic ramifications into consideration. Caution shall be used in consideration of accumulated (tolerance stack-up) error with the gage components.

4.5.1 Effects of Tolerance Stack-Up. Gages are to be dimensioned in the same manner as the parts that they gage, using from 5% to 10% of the tolerance assigned to the features being gaged. It is recommended that basic dimensions be used to reduce tolerance stack-up. If 5% to 10% of the tolerance on all features being gaged is represented in the gage, consideration should be given to the entire gage tolerance that has accumulated. It is recommended that this tolerance not exceed 50% of the tolerance for the specific workpiece feature being gaged. For example, if a pattern of holes is being gaged for a position tolerance and the maximum position tolerance for the holes is 0.3 (which includes any possible bonus tolerance drawn from the size limits of the holes), then the gage that inspects that hole pattern (which may include the gage flatness tolerance on the primary datum feature simulator, the size tolerance and the perpendicularity tolerance on the secondary datum feature simulator, the size tolerance and the position tolerance on the tertiary datum feature simulator, and the gage pins size tolerance and position tolerance for the hole pattern), when added, should not exceed 50% of the 0.3 part tolerance on the holes. In this example, the accumulation of all pertinent gage tolerances that simulate the part's datum features and represent the gage pins that inspect the hole pattern on the part should not exceed a tolerance of 0.15.

4.6 Gage Design Requirements

All workpieces being gaged shall be adequately dimensioned and toleranced to enable a gage to be created and used to check features on the workpiece.

4.6.1 Gage Design Criteria. It is the goal of each gage is to ensure the compliance of each feature being gaged. Gages shall be designed to reflect the workpiece specification. Therefore, the workpiece shall be fully dimensioned and toleranced so that the functional requirements are clear to manufacturing and inspection. An incomplete part specification can result in a situation wherein a gage can not be designed, dimensioned, and toleranced.

4.6.2 Completeness. All gages shall be fully dimensioned and toleranced.

4.7 Principles of Gage Size and Full Engagement of Features

4.7.1 Principle of GO and NOGO Gaging. MMC and LMC are separately verifiable size requirements.

(a) The MMC limit of the feature being gaged is checked using a plug gage or ring gage with a length equal to the maximum length of the feature or the maximum length of engagement of the workpiece to its mating part, and a diameter equal to the MMC of the workpiece feature. This GO gage should fully pass into or over an in-tolerance workpiece feature with zero force.

(b) The LMC limit of the workpiece is checked with a gage designed to contact the workpiece at two diametrically opposite points separated by a distance equal to the LMC limit of the workpiece. This NOGO gage should not pass into or over an in-tolerance workpiece feature at any position.

(c) Functional gaging of virtual condition boundaries (MMC concept) is a separately verifiable requirement from size limits, unless the MMC and virtual condition boundary are the same (as is the case with zero tolerancing at MMC), wherein both the MMC envelope and the virtual condition boundary may be verified with the functional gage. The virtual condition boundary of the feature or pattern of features being gaged is checked with a plug gage or ring gage of a diameter equal to the virtual condition (MMC concept) and of length equal to the maximum length of the feature(s), or the maximum length of engagement of the feature to its mating part (as indicated by feature length, partial feature control, or projected tolerance zone, as applicable). These functional gage elements should be able to fully pass into or over an in-tolerance workpiece feature with zero force. Datum features are simulated by gage elements that are the geometric inverse of the part features. Datum features of size are simulated at their appropriate MMB or RMB. Datum features of size that must be simulated at their LMB are best simulated in software by computer-assisted measurement machines rather than hard (physical) gages.

4.7.2 Departure from Principles

(a) Some examples of considerations of departure from the principles given in paras. 4.7.1(a) and (c) [gaging MMC and virtual condition (MMC concept)] are

(1) The length of a GO or functional gage plug or ring 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 or orientation (as applicable) of the hole or shaft or other feature of size 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 gage blanks.

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

(3) A GO or functional cylindrical ring gage is often inconvenient for gaging shafts and may be replaced by a snap-type gage if it is known that, with the manufacturing process used, the errors of roundness 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 that have small diameters should be checked separately.

(b) Some examples of considerations of departure from the principles given in para. 4.7.1(b) (gaging LMC) are given below. Gaging the LMC with a two-point checking device is not always necessary or used if

(1) point contacts are subject to rapid wear, and in most cases may be replaced, where appropriate, by small planar, cylindrical, or spherical surfaces.

(2) for gaging very small holes, a two-point checking device is difficult to design and manufacture. A NOGO plug gage of full cylindrical form may have to be used, but the user shall be aware that there is a possibility of accepting workpieces having diameters outside the NOGO limit.

(3) nonrigid workpieces may be deformed to an oval by a two-point mechanical contact device operated under a finite contact force. If it is not possible to reduce the contact force to almost zero, then it will be necessary to use a NOGO ring or plug gage of full cylindrical form.

NOTE: A dedicated NOGO gage to check LMC at every set of two opposing points may often be simulated sufficiently by simple inspection tools such as micrometers with appropriate measurement tips, vernier calipers, or even small hole gages.

4.8 Distortion of a Workpiece During Gaging

A gage may distort a workpiece if used without proper care. This shall be avoided by proper handling during the gaging process. Distortion of either the part or the gage during use will impair the correctness of the gaging operation and can lead to acceptance of nonconforming parts or rejection of conforming parts.

4.8.1 All Measurements Free State. The workpiece shall not be distorted to obtain compliant measurement results. Unless otherwise specified, all workpieces are to be inspected in the free state. [See ASME Y14.5-2009, paras. 1.4(m) and 5.5.]

4.8.2 Restraint. If a workpiece is to be inspected in a restrained state (see ASME Y14.5-2009, para. 5.5.2), it shall be so noted on the design drawing and on the dimensional measurement plan (see ASME B89.7.2) for the workpiece or the feature being inspected. These notes shall be as complete as necessary to ensure that the workpiece will be inspected as it will actually function.

4.8.3 Flexible Parts. Unless otherwise specified, all flexible parts are to be inspected in the free state [see ASME Y14.5-2009, para. 1.4(m)]. If restrained state inspection is desired, it shall be noted on the workpiece drawing and accompanying inspection methods plan.

4.9 Size Controls Form Principle (Envelope Principle)

(a) For Holes. The diameter of the largest perfect imaginary cylinder that can be inscribed within the hole so that it just contacts the high points of the surface shall be no smaller than the MMC limit of size. The maximum diameter at any position in the hole shall not exceed the LMC limit of size at any two diametrically opposed points.

(b) For Shafts. The diameter of the smallest perfect imaginary cylinder that can be circumscribed about the shaft so that it just contacts the high points of the surface shall be no larger than the MMC limit of size. The minimum diameter at any position on the shaft shall not be less than the LMC limit of size at any two diametrically opposed points.

(c) The above interpretations require that if the workpiece is everywhere at its maximum material limit, the workpiece shall be perfectly round and straight (i.e., a perfect cylinder). Size limits control the surface form for all features of size such as cylinders, spheres, and any two parallel opposed planar surfaces, such that if the feature of size is produced uniformly at its MMC, it shall have perfect form. Unless otherwise specified, and subject to the above requirements, departures from perfect form for all features of size may reach the full value of the size tolerance specified when the feature of size is produced at its LMC.

(d) In cases where the maximum errors of form permitted by the size tolerances are too large to allow satisfactory functioning of the assembled parts, separate tolerances of form should be specified (e.g., flatness, straightness, circularity, and cylindricity). In other cases, where the maximum errors of form permitted by the size tolerances are too small, the perfect form at MMC rule may be eliminated or relaxed using one of the following methods:

(1) using the independency symbol on a feature of size (see ASME Y14.5-2009)

(2) an average dimension may be shown denoting that the feature's size only has to average within the size tolerance

(3) using a control such as straightness of the derived median line or flatness of the derived median plane

(4) a drawing note such as "Perfect form at MMC is not required"

(e) The above rules about perfect form being required at MMC do not apply to

(1) nonrigid features.

(2) features of stock size in the as-purchased condition.

(3) features geometrically controlled by feature control frames that use an LMC symbol after the specified geometric tolerance. Such features controlled at LMC, when measured for size violations, shall conform to perfect form at LMC and for MMC violations at every two diametrically opposed points (for example, on a diameter).

4.9.1 Cross Section Versus Two Point Versus Envelope. Unless otherwise specified, all rigid regular features of size are inspected for an envelope of perfect form at MMC violation with a full form GO gage or a simulation thereof. Unless otherwise specified, LMC is inspected with a two-point opposed point inspection tool approximating a NOGO gage. If a two-point opposed point NOGO gage is not available, LMC violations may be approximated through the use of a gage that measures feature cross sections, such as a small hole gage.

4.10 Functional Gages Verify Assemblability

The common usage of a functional gage is to verify a workpiece's ability to assemble. This shall be accomplished through inspection of the size and geometric characteristics of the workpiece feature or features under consideration.

4.11 Gaging Temperatures

Gages shall be calibrated at 20°C (68°F). See para. 7.2.1.

4.12 Economics

When a GO or functional gage is not economically feasible, suitable simulations may be constructed using other inspection tools. For example, a computer-controlled coordinate measurement machine may be used to acquire a digital data set. The points may then be used to model actual values and compare these with a worst-case computer design model of the feature under test to determine violations of the boundaries normally inspected with a hard (physical) GO or functional gage. These computer-generated GO and functional gages simulate the function of hard gages. The simulated soft gage will verify or reject only the points probed, which are not necessarily representative of all points on the workpiece being gaged. Also, it is recommended for features being gaged for interrelationships to datums that these workpieces be fixtured whenever possible to give a better simulation of the high-point planes and axes than may be possible through the use of probes directly on the datum features. Fixtures shall be produced at a sufficient level of accuracy to ensure acceptable uncertainty.

4.12.1 Initial Cost Justification. Fixed limit functional gages and fixtures may be used for inspection of workpieces when

(a) the ease of use serves the purpose of inspection

(b) the number of workpieces to be checked is great enough to justify the cost of manufacturing the gages

(c) plain limit gages may be designed to match the shape of the workpiece

(d) a large number of workpieces are to be verified for attribute data, whereas variables data will be collected on a smaller number of sample parts

(e) flexible parts are being inspected that will require restraint

4.12.2 Speed and Capability: Hard Versus Soft Gage. When considering the initial cost of investment of GO and functional gages, the speed at which such a gage will verify or reject part features should be considered. These gages will normally inspect complex feature geometry at a much greater speed than many other inspection tools. However, unless a computer-generated soft gage is used, only attribute data is collected by hard GO and functional gages. Whereas variables data is not normally associated with hard GO and hard functional gage use, variables data is commonly collected by soft GO and functional gages.

5 GAGE DESIGN

5.1 GO/NOGO Gages

5.1.1 Plug Gages

(a) Full Form Cylindrical Plug Gages (Recommended). A full form cylindrical plug gage has a gaging surface in the form of an external cylinder. The method of attaching the gage to the handle shall not affect the size and form of the gage by producing an undesirable stress.

(b) Modified Full Form Cylindrical Plug Gages (Not Recommended). A small circumferential groove near the leading end of the gage and a slight reduction in diameter of the remaining short cylindrical surface at the end may be used to serve as a pilot to facilitate the insertion of the gage into the workpiece hole. This Standard does not recommend this practice. However, if used, the actual end gaging diameter shall remain as sharp as possible. For safety purposes, it is recommended that the corner be broken with a 10% or 0.25 maximum chamfer, whichever is less. A chamfer larger than this will act as a lead and may damage the gage and/or the workpiece.

(c) Segmented Cylindrical Plug Gage [Not Recommended by This Standard for Features Being Gaged for Violations of the MMC Envelope or the Virtual Condition Boundary (MMC Concept)]. A segmented cylindrical plug gage has a gaging surface in the form of an external cylinder from which two axial segments are either relieved or removed.

(d) Segmented Spherical Plug Gage [Not Recommended by This Standard for Features Being Gaged for Violations of the MMC Envelope or the Virtual Condition Boundary (MMC Concept)]. A segmented spherical plug gage is similar to a full form spherical plug gage but has two equal segments cut off by planes normal to the axis of the handle. In the transverse plane, the diameter shall everywhere conform to the limiting dimensions of the gage.

(e) Segmented Cylindrical Plug Gage with Reduced Measuring Faces [Not Recommended by This Standard for Features Being Gaged for Violations of the MMC Envelope or the Virtual Condition Boundary (MMC Concept)]. Segmented cylindrical plug gages with reduced measuring faces are similar to segmented cylindrical plug gages but have reduced measuring faces in a plane parallel to the axis of the handle. In the transverse plane, the diameter shall everywhere conform to the limiting dimensions for the gage.

5.1.2 Spherical Ended Rod Gages [Not Recommended by This Standard for Features Being Gaged for Violations of the MMC Envelope or the Virtual Condition Boundary (MMC Concept)]. For spherical and gaging faces, the contact radius shall not be greater than 50% of the minimum workpiece dimension. The gage shall be sufficiently rigid so as not to flex significantly in use. Rod gages may be either fixed or adjustable (e.g., telescoping gage). Spherical-ended rod gages are recommended by this Standard for features being gaged for violations of the applicable actual local size limit(s).

5.1.3 Full Form Cylindrical Ring Gage (Recommended). A full form cylindrical ring gage has a gaging surface in the form of an internal cylinder. The wall of the ring gage shall be sufficiently thick to avoid deformation under normal conditions of use.

5.1.4 Snap Gage. A snap gage has, for its working size, flat and parallel gaging surfaces. The GO and NOGO gaps should lie on the same side of the snap gage. The snap gage should be either fixed or adjustable.

5.1.5 Setting Master Disc. A setting master disc has a gaging surface in the form of an external cylinder.

5.1.6 Setting Master Ring. A setting master ring has a gaging surface in the form of an internal cylinder.

5.1.7 Differentiation. GO and NOGO gages shall be easily distinguishable. This may be achieved by using different shapes or lengths of gaging elements, such as a short NOGO gage as compared to a long GO gage. Alternately, a colored marker, preferably green for GO and red for NOGO, or a groove should be used to indicate NOGO. Either way, the gages should also be marked in a manner that will not wear off with normal usage (e.g., stamping into a nonfunctional area on the gage).

5.2 Functional Gage Configuration

A functional gage takes its physical and functional configuration from the product description of the component that is to be gaged.

5.2.1 Gaging of Detail Parts to Achieve Assembly or Functional Requirements. Each feature(s) to be gaged is to be inspected to ensure features meet the detail part requirements that were derived from assembly requirements. If the functional criteria are something other than assembly, the gage shall ensure the detail part requirements derived from functional requirements.

5.2.2 Datum Feature Simulator. In designing gages, simulated datums are established by the interaction of workpiece datum features and datum feature simulators contained on the gage. These simulators shall be of adequate precision and governed by the following shape, size, orientation, and location descriptions:

(a) Planar Feature

(1) Shape. A planar datum feature shall be simulated by a flat surface. This surface shall be of sufficient area to allow contact with the entire datum feature. If another configuration is chosen, the risk of accepting an out-of-tolerance part or rejecting an in-tolerance part must be considered.

(2) Orientation. A gage surface intended for the simulation of a primary datum feature needs no specific orientation since it establishes the orientation of other gage elements. A gage surface intended for the simulation of a secondary or tertiary datum feature shall be oriented at the specified or implied basic angle to the datum(s) of higher precedence.

(b) Cylindrical Hole

(1) Shape. A hole used as a primary or secondary datum feature shall be simulated by an external cylindrical surface (pin) of sufficient length to allow engagement with the entire datum feature. If the hole is a tertiary datum feature, it shall be simulated by a cylindrical surface. If another configuration is chosen, the risk of accepting an out-of-tolerance part or rejecting an in-tolerance part must be considered.

(2) Orientation. A gage surface intended for the simulation of a primary datum feature needs no specific orientation since it establishes the orientation of other gage elements. A gage surface intended for the simulation of a secondary or tertiary datum feature shall be oriented at the specified or implied basic angle to the datum(s) of higher precedence.

(3) Size. For a single hole referenced on an MMB basis, the gage pin will be of fixed size. The pin size for the simulation of a primary datum feature will be the MMC size of the feature if the feature's axis is not controlled by a straightness tolerance. If the datum feature's axis is controlled by a straightness tolerance, the simulator shall be the virtual condition size (MMB). The pin size for the simulation of a secondary and/or tertiary datum feature shall be the MMB size. For a single hole referenced as a datum feature on an RMB basis, the gage pin shall be capable, as a minimum, of simulating the range of sizes from the inner boundary to the LMC. That is, rather than a fixed-size pin, a series of graduated-size pins or an expandable device shall be used. This simulator shall center the datum feature regardless of the feature's size while maintaining its basic orientation and location to the datums of higher precedence.

(4) Location. A gage pin intended for the simulation of a primary datum feature has no specific location since it establishes the location of other gage elements. Secondary and tertiary simulators shall be located with respect to the simulators of higher precedence.

(c) Cylindrical Shaft

(1) Shape. A shaft that is a primary or secondary datum feature shall be simulated by an internal cylindrical surface (hole) of sufficient length to allow engagement with the entire datum feature. If the shaft is a tertiary datum feature, it shall be simulated by an internal cylindrical surface. If another configuration is chosen, the risk of accepting an out-of-tolerance part or rejecting an in-tolerance part must be considered.

(2) Orientation. A gage surface intended for the simulation of a primary datum feature needs no specific orientation since it establishes the orientation of other gage elements. A gage surface intended for the simulation of a secondary or tertiary datum feature shall be oriented at the specified or implied basic angle to the datum(s) of higher precedence.

(3) Size. For a shaft referenced on an MMB basis, the gage hole shall be of fixed size. The gage hole size for the simulation of a primary datum feature will be the MMC size of the feature if the feature's axis is not controlled by a straightness tolerance. If the datum feature's axis is controlled by a straightness tolerance, the simulator shall be the virtual condition size (MMB). The hole size for the simulation of a secondary and/or tertiary datum feature shall be the MMB size. For a shaft referenced on an RMB basis, the gage hole shall be capable, as a minimum, of simulating the range of sizes from the inner boundary to the LMC. That is, rather than a fixed-size hole, a contractible device shall be used. This simulator shall center the datum feature regardless of the material boundary's size while maintaining its basic orientation and location to the datums of higher precedence.

(4) Location. A gage hole intended for the simulation of a primary datum feature has no specific location since it establishes the location of other gage elements. Secondary and tertiary simulators shall be located with respect to the simulators of higher precedence.

(d) Slot Widths

(1) Shape. A slot width shall be simulated by a pair of parallel external opposed planar surfaces (block) that are of sufficient area to allow association with the entire datum feature.

(2) Orientation. Gage surfaces intended for the simulation of a primary slot width have no specific orientation since they establish the orientation of other gage

elements. Gage surfaces intended for the simulation of secondary and/or tertiary slot widths shall be oriented at the specified or implied basic angle to the datum(s) of higher precedence.

(3) Size. For a slot width referenced on an MMB basis, the gage surfaces will be at a fixed separation. The fixed separation used for the simulation of a primary datum feature shall be the MMC size of the feature if the feature's center plane is not controlled by a flatness tolerance. If the datum feature's center plane is controlled by a flatness tolerance, the simulator shall be the virtual condition size (MMB). The fixed separation for the simulation of secondary and/or tertiary datum features shall be the virtual condition size (MMB) of the feature. For a slot width referenced on an RMB basis, the gage surfaces shall be capable, as a minimum, of simulating the range of sizes from the inner boundary to the LMC. That is, rather than a fixed-size block, a series of graduated-size blocks or an expandable device shall be used. This simulator shall center the datum feature regardless of the material boundary's size while maintaining its basic orientation and location to the datum or datums of higher precedence.

(4) Location. Gage surfaces intended for the simulation of a primary datum feature have no specific location since they establish the location of other gage elements. Secondary and tertiary simulators shall be located with respect to the simulators of higher precedence.

(e) Tab

(1) Shape. A tab shall be simulated by a pair of internal opposed planar surfaces (gap) that are of sufficient area to allow engagement with the entire datum feature.

(2) Orientation. Gage surfaces intended for the simulation of primary datum features have no specific orientation since they establish the orientation of other gage elements. Gage surfaces intended for the simulation of secondary and/or tertiary datum features shall be oriented at the specified or implied basic angle to the datum(s) of higher precedence.

(3) Location. Gage surfaces intended for the simulation of a primary datum feature have no specific location since they establish the location of other gage elements. Secondary and tertiary simulators shall be located with respect to the simulators of higher precedence.

(4) Size. For a tab referenced on an MMB basis, the gage surfaces shall be at a fixed separation. The fixed separation used for the simulation of a primary datum feature will be the MMC size of the feature if the feature's center plane is not controlled by a flatness tolerance. If the datum feature's center plane is controlled by a flatness tolerance, the simulator shall be the virtual condition size (MMB). The fixed separation for the simulation of secondary and/or tertiary datum features shall be the virtual condition size (MMB) of the feature. For a tab referenced on an RMB basis, the gage surfaces shall be capable, as a minimum, of simulating the range of sizes from the inner boundary to the LMC. That is, rather than a fixed-size slot width, a contractible device shall be used. This simulator shall center the datum feature regardless of the material boundary's size while maintaining its basic orientation and location to the datum or datums of higher precedence.

(f) Contoured and Mathematically Defined Surfaces. If a curved or contoured surface is used as a datum feature, it shall be represented by a datum feature simulator meant to simulate the appropriate boundary condition.

(g) Special Condition Datum Simulators

(1) Cylindrical datum features of size are simulated for purposes of location and angular orientation by cylindrical gaging elements that are fixed at their basic location. However, if a translation symbol is used after the datum feature reference in the feature control frame on the workpiece, the gaging element shall be capable of a sliding motion. This movement shall be allowed in a direction that shall contain the part's remaining functional degrees of freedom.

(2) Width datum features of size are simulated for purposes of location and angular orientation by width gaging elements that are fixed at their basic location. However, if a translation symbol is used after the datum feature reference in the feature control frame on the workpiece, the gaging element shall be capable of a sliding motion. This movement shall be allowed in a direction that shall contain the part's remaining functional degrees of freedom.

(3) Datum features are referenced in feature control frames to eliminate spatial degrees of freedom (x, y, z, u, v, and w) for part features. The spatial degrees of freedom that each datum feature eliminates may also be specified next to the datum feature reference in brackets. This overrides the natural ability of the datum features to stem certain degrees of spatial freedom in favor of subsequently referenced datum features in that feature control frame. In these instances, the gage elements that simulate the datum features shall be representative of the workpiece's specified design requirements. See Fig. B-24.

5.2.3 Gage Element Configuration

(a) Fixed Versus Removable Elements. Fixed elements are used as datum feature simulators for simple parts and when small quantities are to be gaged/fixtured where element wear is minimal. Fixed elements may also be used in machining fixtures where rigidity during clamping is required. Removable elements may be used for datum feature simulators for complex parts when loading/unloading or indexing cannot be accomplished with fixed elements. Removable elements may also be used when large quantities of parts are to be gaged/fixtured where ease of replacement of elements, such as gage pins, due to wear is required. In designing a gage with removable elements, consideration shall be given

to the effect of the removable gaging element fit on measurement uncertainty.

(b) Movable/Rotational Elements. Elements that swing away or rotate to allow clearance or access for part loading require an indexing feature to provide repeatability. In designing a gage with rotational elements, consideration should be given to the effect of the rotational gaging element fit on measurement uncertainty.

5.2.4 Datum Target Configuration

(a) Datum Target Point Simulator. Spherical or hemispherical pins are used to represent datum target point simulators. The center of the spherical simulator shall be located offset normal to the nominal part surface by an amount equal to the spherical radius. Datum target point simulators are fixed in location by default. Where the moveable datum target symbol is applied or where datum targets establish a center point, axis, or center plane on an RMB basis, a moveable datum target simulator is used. In these instances, the surface configuration on the workpiece at the point of contact may dictate the use of a conical pin. If the target point to be contacted is on a radius or other curved surface, the cone tip may stabilize the part and contact the target point better than a sphere. The tip of the pin is to be set at any specified basic dimensions, but may move in the direction at the basic angle implied normal or as dimensioned on the part drawing. Datum target simulators shall contact the workpiece surfaces normal to the desired geometry of the surface unless otherwise specified. Therefore, moveable datum target simulators shall be capable of movement that brings them into contact with the workpiece surface as defined on the workpiece drawing at the specified point of contact.

(b) Datum Target Line Simulator. The use of the side of a cylindrical pin to represent datum target lines is preferred in most instances. Datum target line simulators are fixed in location by default. Where the moveable datum target symbol is applied or where datum targets establish a center point, axis, or center plane on an RMB basis, a moveable datum target simulator is used. The simulator is to be set at the specified basic dimensions and may move in the direction at the basic angle implied normal or as dimensioned on the part drawing. Datum target simulators shall contact the workpiece surfaces normal to the desired geometry of the surface unless otherwise specified. Therefore, moveable datum target simulators shall be capable of movement that brings them into contact with the workpiece surface as defined on the workpiece drawing at the specified line of contact.

(c) Datum Target Area Simulator. The use of a datum target area simulator that is representative of the area with which it is making contact is recommended. For example, if datum target areas are planar, datum target area simulators shall be planar. Ideally, planar area simulators require full area contact with the workpiece feature. Surface irregularities will limit the contact to appropriate high points. The part is placed on the target simulator in an unrestrained condition, unless restrained contact is specified in a drawing note. Full area contact is attempted, but irregularities in the part surface will relegate the fixture to contacting high points within the target area or areas. If multiple areas are used to construct the same datum, then all areas are treated as though they were one continuous surface seeking to establish high point contact appropriate to the datum. If multiple areas are used to establish a datum reference frame, precedence shall be given to the order of the datum and appropriate contact made on that basis. If the datum target area is implied or designated as a moveable datum target area, the same rules apply to the gage or fixture datum target simulators as stated in paras. 5.2.4(a) and (b).

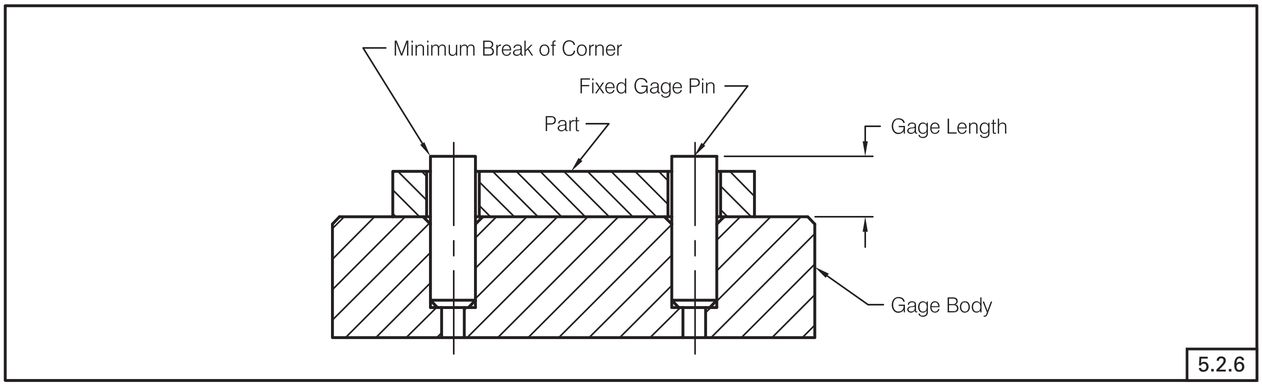
5.2.5 Material Condition and Boundary Modifiers. Material condition symbols and material boundary symbols, also known as modifiers, are used in geometric controls on gaging elements that represent datum features of size. Gaging elements that are features of size may be specified at MMC, LMC, or RFS. If referenced on the gage as datum features, they may be referenced at MMB, LMB, or RMB. Each material condition symbol used has an effect on the cost of the gage and the number of workpieces that will be accepted by the gage. As with the tolerancing of workpieces, the tolerancing of gages will rely on the engineering team to determine the most appropriate use of material condition symbols.

Referencing gage datum features of size at either MMB or LMB allows the controlled gaging elements to shift as a pattern as the datum feature(s) depart from their applicable MMB or LMB. This allows the gage to be less accurate in determining an in-tolerance workpiece from an out-of-tolerance workpiece. It may allow the gage to accept a workpiece with features that have shifted beyond their tolerance in the same direction as the gage elements. However, it is more likely that the gage pattern shift will not be in the same direction as the workpiece pattern shift. This may cause the gage to reject in-tolerance workpieces due to the inaccuracies allowed by the pattern shift.

This Standard therefore recommends the use of the RMB concept when referencing gage datum features of size. This concept allows no pattern shift on the gage as the datum features change size or become more geometrically perfect. The use of the RMB concept on datum features may cause the initial cost of the manufacture of the gage to increase. This initial increase should be offset over time by the benefits of a more accurate, reliable gage.

For a discussion of the ramifications of material condition symbol selection and examples of each, see Mandatory Appendix II and Nonmandatory Appendix A.

Fig. 5-1 Fixed Pin Construction



5.2.6 Controlled Feature Influence on Gage. Controlled features of the workpiece are to be represented by the gage elements at their virtual condition size for all features using the MMC concept. If the controlled feature is a shaft, it is represented with a gage hole, such as a full form ring gage. If the controlled feature is a hole, it is represented with a full form gage pin. Whatever the controlled feature configuration, it is represented with a gage element that is the natural inverse of the configuration being gaged.

(a) Fixed Pins. When inspecting internal features of size for orientation or location, fixed pin gages may be used, however, it may be difficult to determine if datum features are making appropriate contact with their representative gaging elements.

Fixed gage pins are designed to be assembled and remain fixed to their respective gage base or body during the use of the gage. See Fig. 5-1. For through holes, the minimum gage length of the gage pin is the maximum length of the feature being gaged. For blind holes, the gage length of the gage pin is the minimum length of the feature being gaged. The functional corners of the gage pins shall remain as sharp as possible without being a safety concern to prevent the workpiece from leading onto the gage, accepting a bad part, and/or possibly damaging the workpiece or the gage. The pilot end of the gage pin should be chamfered to aid in assembling the gage pin into the gage base or body.

(b) Push Pins. To facilitate loading and unloading the workpiece, push pin gage design may often be more desirable than the fixed pin concept. The push pin concept allows the part to seat appropriately in its datum reference frame before an attempt is made to insert the gage pins into the gage and the part being gaged.

An additional application of the push pin gage design is to inspect multiple patterns of features that allow separate gaging requirements. This can reduce the total number of gages required.

If the push pin gage design is employed, the part tolerance shall be divided between the gage pin size limits and its counterpart gage hole's positional tolerance. Consideration shall also be given to the fit between the gage pin and its counterpart gage hole. Caution shall be used in the design of push pin gages to ensure that tolerances given to the gage holes and the pins that are used in them provide for a pin that can be easily inserted and extracted from its gage hole, yet with a minimum of clearance.

With the absolute gage tolerancing and practical absolute gage tolerancing methods, the tolerance on the gage pin size is to be all plus and no minus. The gage hole receiving the pin shall have tolerance as well. Its size shall be at least as large as the gage pin's MMC if the gage pin is always to enter its gage hole.

It is recommended that projected tolerance be used on these types of gage holes, since the gage hole gives orientation to the gage pin. The amount of tolerance used can increase the virtual size of the gage pin (MMC concept virtual condition), consequently infringing on the controlled hole's virtual condition boundary (MMC concept). This creates a gage pin virtual condition larger than the virtual condition of the hole it checks. The more tolerance given to the projected tolerance zone of the gage hole, the greater the probability of rejecting controlled part holes theoretically acceptable in accordance with the engineering drawing. Size tolerances given to the gage pin shall be kept to a minimum. See ASME B4.2 for sliding fits.

Push pins are designed to be moveable or removable depending upon the application. The two types of push pins will be referred to as Type 1 and Type 2.

(1) Type 1 push pins are designed to be removed from the gage base or body while loading and unloading the workpiece being inspected. See Fig. 5-2. The pilot is the portion of the push pin that guides the pin into the gage body, positioning the gage pin in the proper location and orientation. The engagement length of the pilot is the interface between the pilot and the gage body before the gage diameter reaches the workpiece. Engagement length is recommended to be 2.5 to 3 times

Fig. 5-2 Push Pin Construction — Type 1

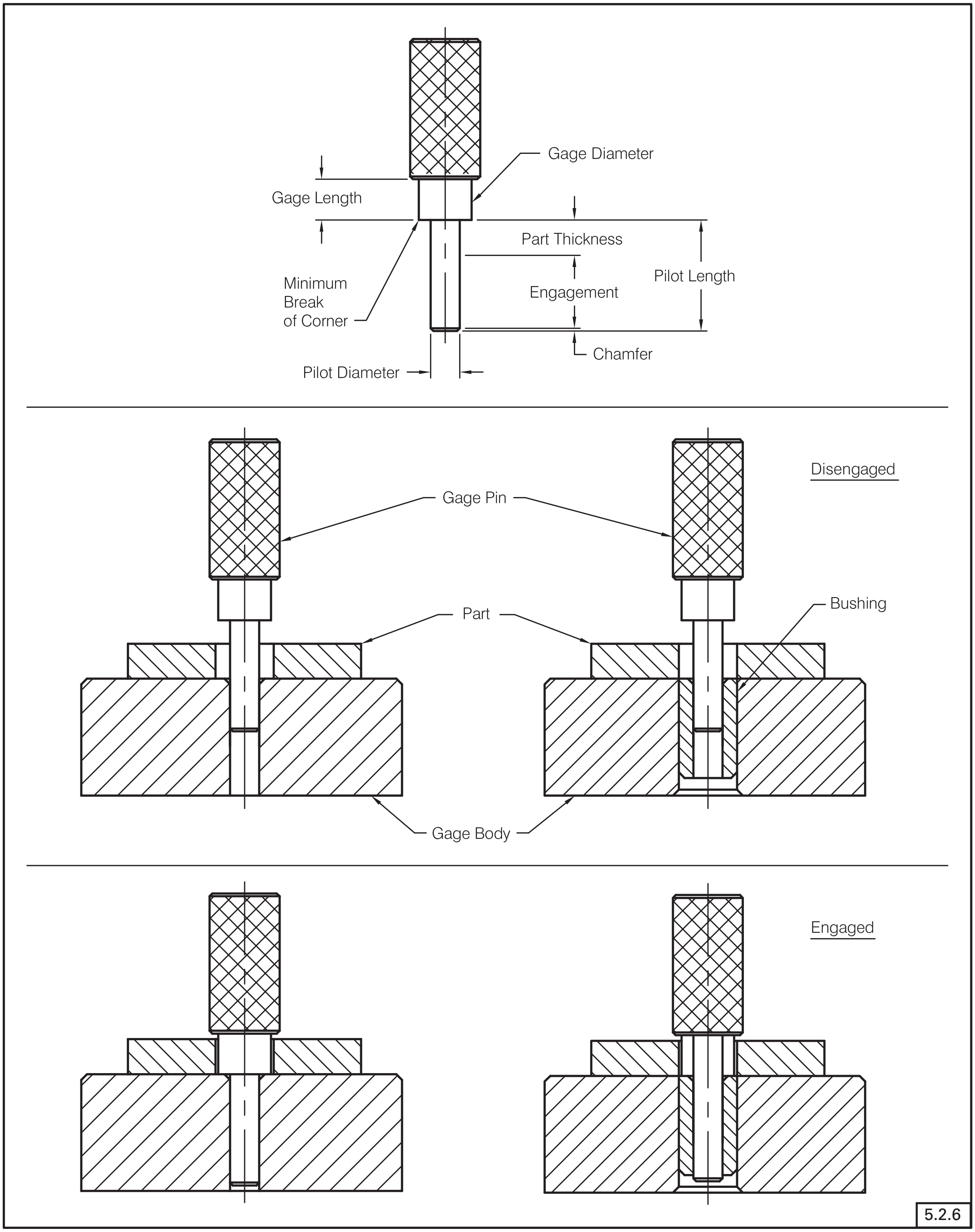
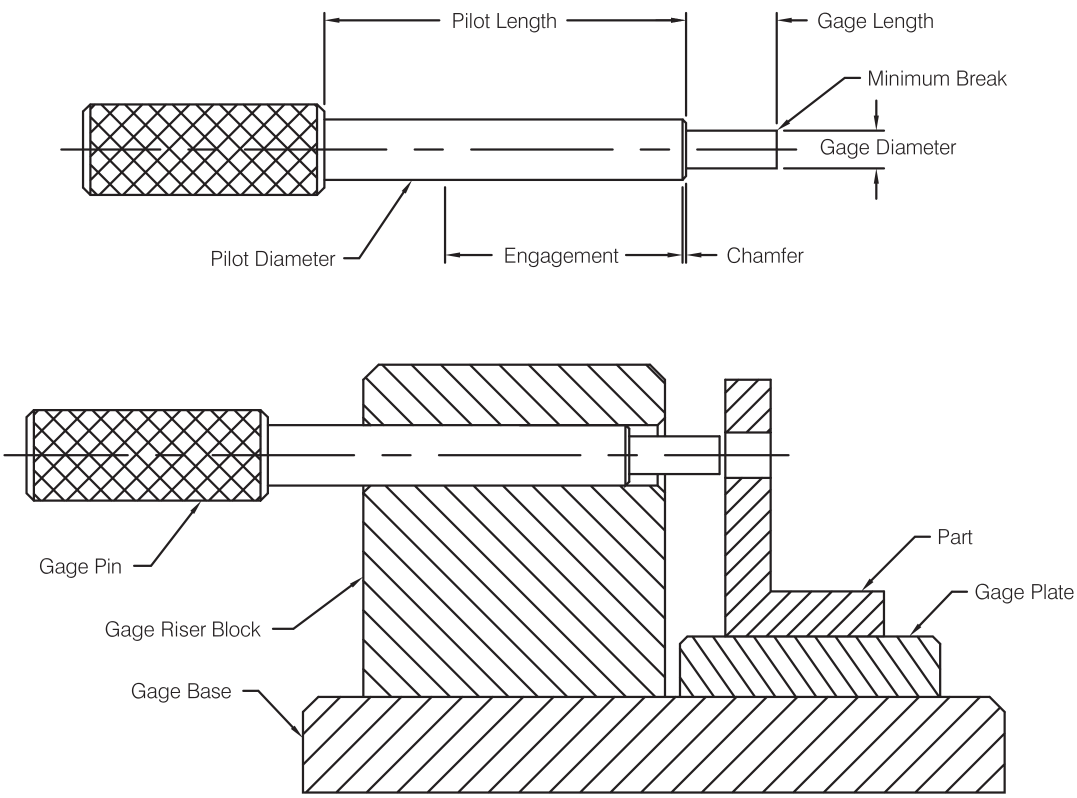


Fig. 5-3 Push Pin Construction — Type 2



the diameter of the pilot to ensure the gage pin is fully positioned and oriented before the gage diameter reaches the workpiece. The gage diameter is the actual gaging element of the gage pin. The length of the gage diameter shall be, at a minimum, the maximum length of the feature being gaged. The functional corners of the gage diameter shall remain as sharp as possible without being a safety concern.

(2) Type 2 push pins are designed to remain assembled with the gage block or body, but are retracted to facilitate loading and unloading the workpiece. See Fig. 5-3. The engagement length of the pilot is the interface between the pilot and the gage body before the gage diameter reaches the workpiece. The engagement length is recommended to be at least four times the diameter of the pilot to ensure stable positioning of the push pin. The pilot is the portion of the push pin that engages the gage body, giving the push pin proper location and orientation. The pilot length shall be, at a minimum, the sum of the width of the gage body and any distance between the gage body and the workpiece. The pilot diameter should be of a standard size, approximately 30% larger than the gage diameter. Gage diameter is the actual gaging element of the push pin. The minimum gage length is the maximum length of the feature being gaged. The functional corners of the gage diameter shall remain as sharp as possible without being a safety concern.

(c) Boundary Concept. The boundary concept is used when tolerance zones are to be verified by gaging the MMC concept generated. Originally explained in previous editions of ASME Y14.5 for elongated holes and shafts, the concept was expanded in ASME Y14.5M-1994 to include the more unusually shaped features not considered features of size in prior editions of ASME Y14.5. Still, the concept is the same for a common cylindrical feature being oriented or positioned as it is for an oddly configured feature. If a virtual condition boundary can be calculated for the controlled feature, a gage can be constructed to gage that boundary. When the boundary is to be gaged specifically in lieu of a tolerance zone, the word "BOUNDARY" may be noted beneath the controlled feature's feature control frame as an option.

(d) Simultaneous Versus Separate Requirements. The simultaneous gaging principle is invoked when the same datums in the same order of precedence are used for location in controls on feature patterns, and use the same material boundary modifiers after any datum features

referenced. Multiple patterns of features that fall under the simultaneous gaging requirement rule shall be inspected with the same gage simultaneously. This is more restrictive than a separate requirement. Separate gaging requirements use a separate gage for each pattern and for many reasons (such as rocking on datum features and patterns shifting in different directions) are less restrictive than a simultaneous requirement. In concept, separate gaging requirements accept a greater number of workpieces gaged. Such gaging methods do not ensure the multiple patterns of features gaged with separate gages will assemble with one part that contains mating features for all patterns simultaneously.

One main purpose of using a simultaneous gaging requirement is to ensure that multiple patterns of features will function as though they were one pattern, for example, all simultaneously mating with multiple patterns of features that are also simultaneously gaged on the mating parts in the assembly. To clarify that patterns are to be simultaneously gaged, a note (as allowed by ASME Y14.5) such as SIM REQT may be placed on the product drawing next to or beneath the feature control frames of all features that are part of the simultaneous gaging requirement. To clarify that patterns may be separately gaged, a note such as SEP REQT may be placed on the product drawing next to or beneath the feature control frames of all features that may be otherwise considered or confused as a simultaneous gaging requirement.

The simultaneous gaging requirement rule does not automatically apply to the lowest segment of a composite feature control frame. If such a requirement exists, a note such as SIM REQT shall be placed on the product drawing to the right of the lowest level of the composite feature control frame.

5.3 Design Constraints

As with any measurement tool, consideration shall be given to the advantages and disadvantages of gages as they pertain to the design, manufacture, use, and maintenance of the gage.

5.3.1 Useful Life. Gages wear as they are used. Eventually the gage will wear beyond acceptable limits and begin to accept parts that are not within tolerance. Therefore, gages shall be closely monitored for wear to determine when it is appropriate to replace or refurbish the gage. Where possible, the original gage design should facilitate both the monitoring and maintenance.

5.3.2 Availability of Commercial Components. When it is possible to purchase off-the-shelf components for gages, they should be considered for use. This practice has the potential to reduce the original and refurbishment cost of the gages.

5.3.3 Size and Weight. Whenever possible, gages should be made at a physical size and weight that allows the gage to be easily handled for optimal use. A gage that is unnecessarily heavy may be difficult to maneuver and use. If difficult to handle, damage may be caused to the workpiece or the gage while inspecting the workpiece.

5.3.4 Physical Properties. The material used for gages shall be selected with consideration to stability, durability, and rigidity.

(a) *Material.* Gaging elements shall normally be manufactured from a high-quality tool steel suitably selected to provide a high degree of wear resistance after heat treatment. Other wear-resistant materials, for example, tungsten carbide, may be used, provided that their wear qualities are not less than those of the tool steel specified above.

Hard chromium plating may also be applied to gaging surfaces, but the thickness of deposit shall at least accommodate the normal wear of the gage.

There may be specific applications where uses of special materials, (e.g., glass) are necessitated by the nature of the workpiece or the manufacturing environment. In such applications, care shall be taken to establish gage calibration procedures at sufficient frequency such that wear of the gages is adequately controlled.

(b) *Hardness.* The hardness of the gaging surface shall be at least 700HV (Vickers Hardness scale)/ RHC60 (Rockwell C Hardness).

(c) *Stabilization.* The gage manufacturer shall ensure that the gages are adequately stabilized by a method appropriate to the material, shape, and size.

(d) *Surface Texture.* The surface texture shall be consistent with the accuracy of the gage desired. The maximum roughness values are expressed in roughness average values, R_a, for the preferred classes as follows:

Gagemakers' Tolerance Class	Roughness Average (R_a)	
	ISO-1302, micrometers	ASME Y14.36M, microinches
ZM	0.2	8
YM	0.1	4
XM	0.1	4
XXM	0.05	2
XXXM	0.05	2

See ASME B4.2 and ASME B46.1. Consideration should be given to specifying additional surface texture parameters that provide greater control of surface topography than the R_a specification and may allow greater likelihood of conforming to the design criteria listed in section 5.

5.3.5 Marking. Each gage and fixture and its associated hardware shall be legibly and permanently marked with the following:

(a) the workpiece limits or, alternatively, the value of the basic size and the symbol designating the tolerance zone of the workpiece

(b) GO or NOGO as applicable
(c) the manufacturer's name or trademark
(d) serial or part number (optional)
The marking shall be on other than gaging surfaces and shall not affect the accuracy of the gages.

NOTE: For plug gages with renewable ends, marking shall appear on the handle and on the renewable ends.

5.3.6 Ergonomic Requirements. A gage shall be designed that considers ease of use. Size and weight are to be considered, as well as configuration. Where appropriate, handling features such as gripping features and lift rings should be designed into the gage. Gage tables or other similar types of handling devices may be included as part of the design.

(a) Safety Considerations. Consideration shall be given to safety. Whenever possible, sharp corners should be removed, weight should be minimized, and size and configuration optimized for handleability and safety.

(b) Process Aids. To ensure the correct use of the gaging device, consideration shall be given to providing process aids such as picture panels or process pictures that will aid in the performance of the gaging operation.

(c) Separate Gage Details. Where the gage design includes separate details that comprise the gage device, provision shall be made to store the loose components of the gage assembly and ensure proper use of the gage assembly. Examples include push pins, setting blocks, and calibration artifacts.

5.3.7 Environment

(a) Storage Environment. Gages shall be stored in an environment that is conducive to optimal preservation. Whenever possible, gages shall be repackaged between uses. It is recommended that the gage be coated with a corrosion-preventive substance (e.g., light machine oil or its equivalent). Caution shall be used with oil and plastic parts. Compatibility shall be investigated.

(b) Use Environment. In designing the gage, consideration shall be given to environmental factors that may have a detrimental influence on use or maintenance of the gage. Some of these factors may include oil, chips, water, atmosphere, contaminants, and vibration.

5.4 Coefficient of Expansion

Coefficient of expansion is the value that represents the amount that a material expands or contracts relative to a change in temperature, resulting in thermal expansion. See ASME B89.6.2

(a) Gages With Components of the Same Material. Where practical, some components of the gage may be fabricated of the same material as the parts being gaged in order to minimize the effects of thermal expansion (e.g., an aluminum base for a gage checking an aluminum part). However, the datum feature simulators and the gaging elements shall meet the requirements of para. 5.3.4(b).

(b) Gages With Components of Different Materials. When gages have components of different material than the part being gaged, such as a steel gage base for an aluminum part, the effect of thermal expansion shall be analyzed for its affect on the gaging process. However, inspecting the parts at 20°C (68°F) will control the effects of thermal expansion.

5.5 Gaging of Flexible Parts

The design of gages that are intended to be used with flexible parts shall recognize the restraint requirements as defined on the engineering drawing and simulate these requirements as prescribed. It is assumed that the engineering drawing shall describe the restraint requirements sufficiently to duplicate the expected functional conditions. The gage can then be designed to reproduce these requirements and minimize the gaging error. The process tooling (e.g., tooling fixtures) may include additional supports used for machining purposes that may not appear on the gage.

5.6 Repeatability

Gages are designed to produce optimum repeatability of measurements taken. Repeatability is greatly affected by the form and orientation controls given to gage elements. The tighter the form and orientation controls, the easier it is to seat and orient the part on the gage in the same manner each time the gage is used. Inspectors will vary in their handling of gages. This also may affect the repeatability of the gaging results.

Environmental stability is a major factor in repeatability. An unstable environment will cause gaging results to vary. Therefore, the environment should be as carefully controlled as possible.

6 DIMENSIONING AND TOLERANCING

6.1 General

Gages shall be dimensioned and toleranced in a manner that is reflective of the dimensioning and tolerancing method used on the workpieces being gaged. When practical, tolerances are assigned to be 10 to 20 times tighter than the features being gaged.

6.2 Tolerance Calculation

6.2.1 GO Gages. GO gages are made to the MMC size of the feature(s) they gage. GO gages check perfect form at MMC by gaging the MMC size for an envelope violation.

6.2.2 Functional Gages. Functional gages are made relative to the virtual condition (MMC concept) of the feature(s) they gage. Functional gages check for a violation of the virtual condition boundary (MMC concept). See dimensioning and tolerancing options in Nonmandatory Appendix A.

6.2.3 Gage Tolerance. It is recommended that 5% of the workpiece tolerance be used as gagemakers' tolerance with an additional 5% considered for wear allowance. Combined, they make up the total gage tolerance (5% to 10%) that is applied to the MMC size limit for a GO gage or to the virtual condition (MMC concept) limit for a functional gage. See para. 6.4.

6.2.4 Workpiece Tolerance. Workpiece tolerance for a GO gage is the difference between the MMC and LMC size of the feature being gaged.

Workpiece tolerance for a functional gage is the difference between the virtual condition (MMC concept) and the LMC size of the feature being gaged.

6.2.5 Virtual Condition (MMC Concept). Virtual condition (MMC concept) for all internal features of size is calculated by subtracting the geometric tolerance applicable at MMC from the MMC size of the feature. Virtual condition (MMC concept) for all external features of size is calculated by adding the geometric tolerance applicable at MMC to the MMC size of the feature.

6.2.6 Datum Target Tolerances. All geometric characteristics of datum target simulators may be toleranced. This includes form, size, orientation, location, and, for lines and areas, extents.

6.2.6.1 Datum Target Basic Dimensions. When datum targets are defined with basic dimensions, ASME Y14.5 states that tooling or gaging tolerances apply. This method benefits greatly from a company's internal process standard (or other general or local tolerance specifications) to provide the applicable tolerances to the basic dimensions. When such documentation exists, it is recommended that it be referenced on the workpiece drawing or in a document referenced thereon.

However, when there is no company documentation or workpiece definition, and basic dimensions are shown (or implied) to define the form, size, orientation, or location of datum target simulators, and no tolerance is given, this Standard defines default tolerances for use on the basic dimensions for the datum target simulators as follows:

(a) For Form: 10% or less of the largest tolerance that controls form given to the surfaces on which the datum targets reside.

(b) For Orientation: 10% or less of the largest tolerance that controls orientation between the surfaces on which the datum targets reside. This control is typically used with target line and area simulators.

(c) For Location: 10% or less of the largest tolerance that controls location between the datum targets and the part features located (usually by position or profile) from them.

(d) For Size: 10% or less of the largest tolerance that controls size given to the feature on which the datum targets reside. If no size tolerance for the workpiece feature is given, then 10% or less of the largest tolerance that controls form shall be used.

NOTE: ASME Y14.5-2009 indicates the use of this Standard for information on datum feature simulator tolerances and toleranced relationships between the simulators. Reference on a workpiece drawing to this Standard is only required when the workpiece drawing is based on using the defaults contained herein. Where it is desired to invoke the defaults of this Standard, the workpiece drawing shall contain a note such as "Default datum target tolerances per ASME Y14.43."

6.2.6.2 Datum Target Toleranced Dimensions. When datum targets are defined with toleranced dimensions, this Standard recommends that a note be added to the workpiece drawing or in a document referenced thereon indicating if 100% of the tolerances specified with the datum target are for use in the tooling and gaging processes or if some other interpretation is intended.

Considerations for the development of datum target tolerances should include the following:

(a) Using 10% of the datum feature form, size, orientation, or location tolerance to shape or to relate datum targets to each other.

(b) In some instances, it is necessary to define the dimension and tolerances of the target simulator, such as the spherical diameter of a simulator. Due to flaws in the part surface, these dimensions and tolerances will determine how effectively the simulator touches the point(s) on the part surface.

6.2.6.3 Dimensional Interpretation. The following conditions exist for the interpretation of dimensions related to the upper portion of the datum target symbol. See Fig. 6-1. It should be understood, since ASME Y14.5 makes no interpretation of the value used with the datum target symbol (either inside or outside), as to being either basic or toleranced. Coordination with the preparer of the workpiece drawing is necessary to ensure full understanding of all requirements. The following information applies when this Standard is listed on the gage or fixture drawing:

(a) The value contained in the upper portion of the symbol defaults to a basic dimension. No box around the dimension is required. See Fig. 6-1(a).

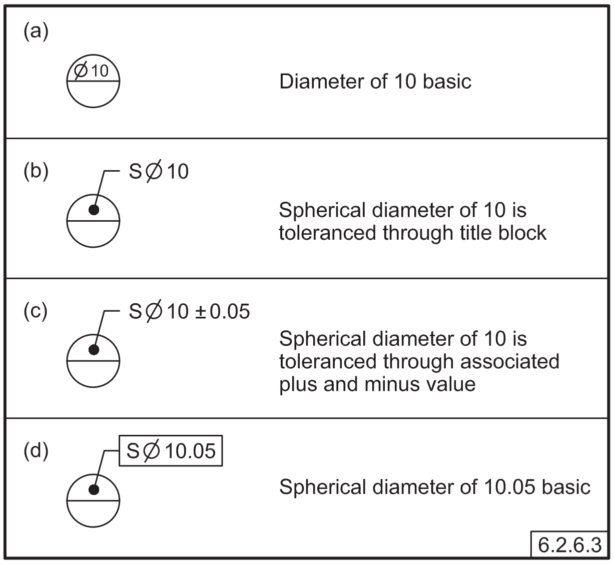
(b) The use of a nonbasic dimension without a tolerance applied to the symbol with a leader line indicates the title block tolerance applies. See Fig. 6-1(b).

(c) The use of a limit dimension or a plus and minus toleranced dimension applied to the symbol with a leader line indicates the allowable tolerance. See Fig. 6-1(c).

(d) The use of a basic dimension placed outside the symbol with a leader, the dimension shall be enclosed in a box. See Fig. 6-1(d).

NOTE: When using either method (b) or (c), the total tolerance specified represents the full tooling tolerance requirement.

Fig. 6-1 Datum Target Symbol



Figures 6-1 through 6-4 demonstrate the techniques described in para. 6.2.6.3.

6.3 TOLERANCE DISTRIBUTION

6.3.1 Size and Geometric Tolerances. The distribution of gage tolerances between size and geometric controls should optimize the manufacture of the gage and the acceptance of all gages within the extremes of the range of total gage tolerance. At times, this may call for geometric tolerances assigned to the gage to be zero tolerance at MMC or LMC. However, if some of the gage tolerance appears in the feature control frame as well as in the size limits, the RFS concept may be employed. For push pin gages, guide holes in the base of the gage rarely use zero tolerance at MMC or LMC due to the extremely tight size tolerance dictated by ASME B4.2 for sliding fits.

6.3.2 Application of Tolerances. Under the absolute gaging policy, all gagemakers' tolerances, wear allowances, and measurement uncertainties shall be held within the workpiece/part size limits.

6.3.3 Tolerance Effects. Under the recommended practice of this Standard, for GO gages (absolute tolerancing), all gage tolerances must be applied within the size or, for functional gages if absolute tolerancing is used, within the virtual condition limits (see Fig. 6-2). Either the absolute or the practical absolute tolerancing methods are the recommended practices of this Standard for functional gages. Any tolerances given to the gage using these methods will effectively reduce the workpiece tolerance that is actually useable.

The gagemakers' tolerance used with these gage tolerancing methods is meant to prevent the acceptance of parts that violate their size or geometric tolerances, while also creating the possibility of rejecting a small percentage of borderline, marginally acceptable parts. The practical absolute gage tolerancing practice also allows, in theory, the acceptance of a small percentage of borderline, marginally out-of-tolerance parts, with a very small mathematical probability of this happening in reality. The practical absolute gage tolerancing policy is recommended so that an equal amount of tolerance can be used on the gage as is allowed by the absolute gage tolerancing policy, but with only half as much of that tolerance going toward the rejection of out-of-tolerance workpieces.

Wear allowance will extend the useful life of the gage and should be used in applications where gage wear is critical. However, this additional wear allowance may increase the percentage of what would otherwise be marginally acceptable parts that will be rejected as in violation of their size or geometric tolerance.

6.4 Tolerance Tables

This section describes gages to be used for the inspection of size for workpieces in the tolerance range of 0.006 mm (IT6) to 0.4 mm (IT11). It covers size ranges up to 500 mm for internal (hole) gages and for external (shaft) gages, and is presented as applicable for cylindrical features. However, the same principles may also be used for other geometric shapes and similar tables can be developed for functional gage tolerancing applications. The information presented here is based on ASME B4.2.

Figure 6-3 gives descriptions of standard gagemakers' tolerance classifications and the applicable gagemakers' tolerances (rounded to 5%) for those classes given in Fig. 6-4. Tables 6-1 through 6-4 provide calculated GO

Fig. 6-2 Absolute Tolerancing Method

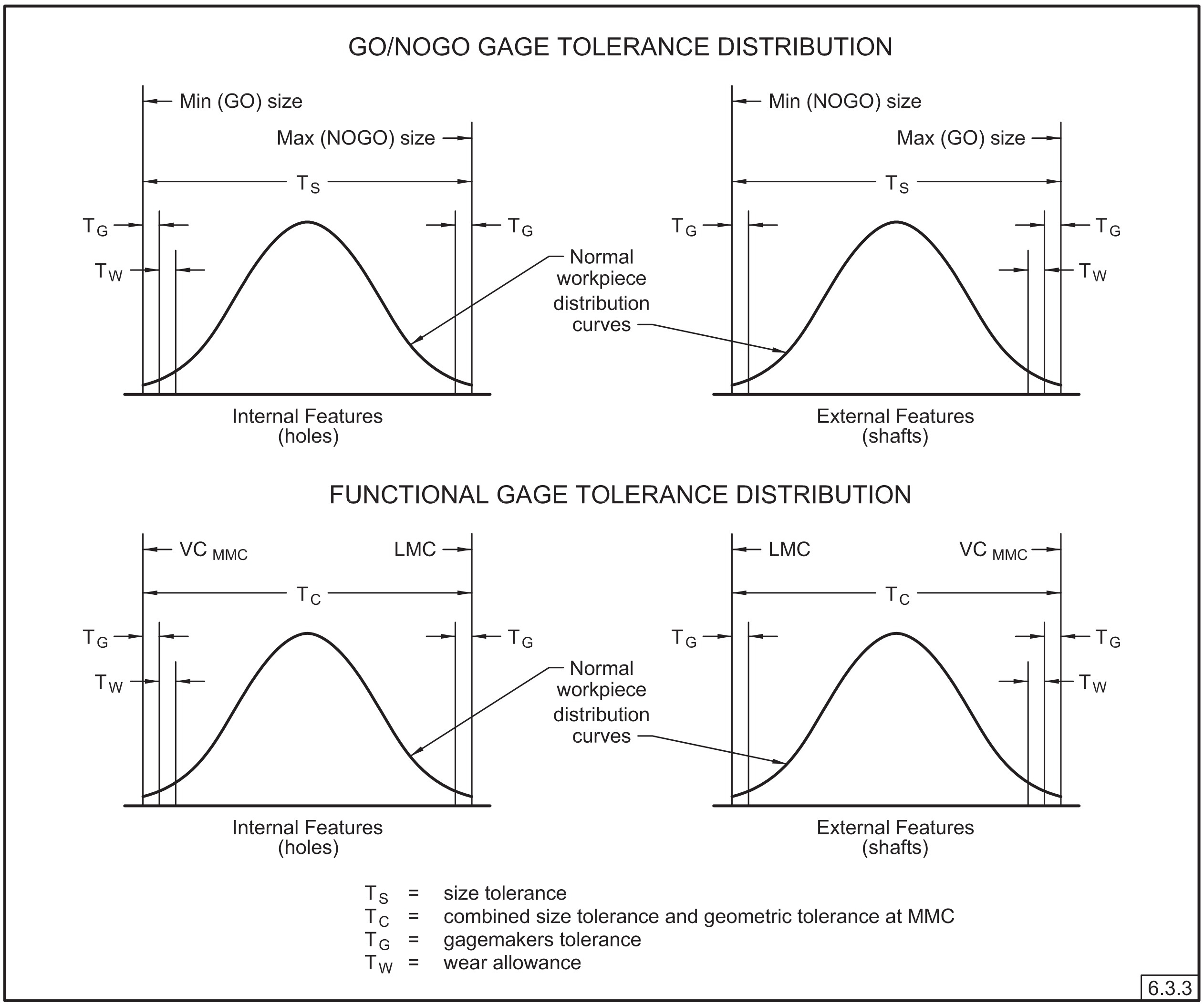


Fig. 6-3 Gagemakers' Tolerance Classes

	Gagemakers' Tolerance			Workpiece Tolerance
	Class	ISO Symbol [Note (1)]	IT Grade	Recommended Usage
Rejection of good parts increase ↑	ZM	0.05IT11	IT11	Low-precision gages recommended used to inspect workpieces held to internal (hole) tolerances C11 and H11 (see Table 6-1) and to external (shaft) tolerances c11 and h11 (see Table 6-3)
	YM	0.05IT9	IT9	Gages recommended used to inspect workpieces held to internal (hole) tolerances C9 and H9 (see Table 6-1) and to external (shaft) tolerances c9 and h9 (see Table 6-3).
	XM	0.05IT8	IT8	Precision gages recommended used to inspect workpieces held to internal (hole) tolerances F8 and H8 (see Table 6-1).
	XXM	0.05IT7	IT7	Recommended used for gages to inspect workpieces held to internal (hole) tolerances G7, H7, K7, N7, P7, S7, and U7 (see Table 6-2) and to external (shaft) tolerances f7 and h7 (see Table 6-3).
Gage cost increase ↓	XXXM	0.05IT6	IT6	High-precision gages recommended used to inspect workpieces held to external (shaft) tolerances g6, h6, k6, n6, p6, s6, and u6 (see Table 6-4).

GENERAL NOTE: For closer gagemakers' tolerance classes than Class XXXM, specify 5% of IT5, IT4, or IT3 (see ANSI B4.2, Table BI) and use the designation 0.05 IT5, 0.05 IT4, etc.

NOTE:

(1) Gagemakers' tolerance is equal to 5% of workpiece tolerance or 5% of applicable IT grade value (see Fig. 6-4).

Fig. 6-4 Gagemakers' Tolerance Chart

Basic Size Over	Basic Size To	Class ZM (0.05IT11)	Class YM (0.05IT9)	Class XM (0.05IT8)	Class XXM (0.05IT7)	Class XXXM (0.05IT6)
0	3	0.0030	0.0012	0.0007	0.0005	0.0003
3	6	0.0037	0.0015	0.0009	0.0006	0.0004
6	10	0.0045	0.0018	0.0011	0.0007	0.0005
10	18	0.0055	0.0021	0.0013	0.0009	0.0006
18	30	0.0065	0.0026	0.0016	0.0010	0.0007
30	50	0.0080	0.0031	0.0019	0.0012	0.0008
50	80	0.0090	0.0037	0.0023	0.0015	0.0010
80	120	0.0110	0.0043	0.0027	0.0017	0.0011
120	180	0.0125	0.0050	0.0031	0.0020	0.0013
180	250	0.0145	0.0057	0.0036	0.0023	0.0015
250	315	0.0160	0.0065	0.0040	0.0026	0.0016
315	400	0.0180	0.0070	0.0044	0.0028	0.0018
400	500	0.0200	0.0077	0.0048	0.0031	0.0020

Table 6-1 Plug Gage Limit Dimensions — Classes ZM, YM, and XM

		Class ZM (0.05IT11) [Note (1)]				Class YM (0.05IT9)				Class XM (0.05IT8)			
		C11 [Note (2)]		H11		D9		H9		F8		H8	
Basic Size		GO	NOGO	GO	NOGO	GO	NOGO	GO	NOGO	GO	NOGO	GO	NOGO
1	Max.	1.0630	1.1200	1.0030	1.0600	1.0212	1.0450	1.0012	1.0250	1.0067	1.0200	1.0007	1.0140
	Min.	1.0600	1.1170	1.0000	1.0570	1.0200	1.0438	1.0000	1.0238	1.0060	1.0193	1.0000	1.0133
1.2	Max.	1.2630	1.3200	1.2030	1.2600	1.2212	1.2450	1.2067	1.2250	1.2067	1.2200	1.2007	1.2140
	Min.	1.2600	1.3170	1.2000	1.2570	1.2200	1.2438	1.2000	1.2238	1.2060	1.2193	1.2000	1.2133
1.6	Max.	1.6630	1.7200	1.6030	1.6600	1.6212	1.6450	1.6012	1.6250	1.6067	1.6200	1.6007	1.6140
	Min.	1.6600	1.7170	1.6000	1.6570	1.6200	1.6438	1.6000	1.6238	1.6060	1.6193	1.6000	1.6133
2	Max.	2.0630	2.1200	2.0030	2.0600	2.0212	2.0450	2.0012	2.0250	2.0067	2.0200	2.0007	2.0140
	Min.	2.0600	2.1170	2.0000	2.0570	2.0200	2.0438	2.0000	2.0238	2.0060	2.0193	2.0000	2.0133
2.5	Max.	2.5630	2.6200	2.5030	2.5600	2.5212	2.5450	2.5012	2.5250	2.5067	2.5200	2.5007	2.5140
	Min.	2.5600	2.6170	2.5000	2.5570	2.5200	2.5438	2.5000	2.5238	2.5060	2.5193	2.5000	2.5133
3	Max.	3.0630	3.1200	3.0030	3.0600	3.0212	3.0450	3.0012	3.0250	3.0067	3.0200	3.0007	3.0140
	Min.	3.0600	3.1170	3.0000	3.0570	3.0200	3.0438	3.0000	3.0238	3.0060	3.0193	3.0000	3.0133
4	Max.	4.0737	4.1450	4.0037	4.0750	4.0315	4.0600	4.0015	4.0300	4.0109	4.0280	4.0009	4.0180
	Min.	4.0700	4.1413	4.0000	4.0713	4.0300	4.0585	4.0000	4.0285	4.0100	4.0271	4.0000	4.0171
5	Max.	5.0737	5.1450	5.0037	5.0750	5.0315	5.0600	5.0015	5.0300	5.0109	5.0280	5.0009	5.0180
	Min.	5.0700	5.1413	5.0000	5.0713	5.0300	5.0585	5.0000	5.0285	5.0100	5.0271	5.0000	5.0171
6	Max.	6.0737	6.1450	6.0037	6.0750	6.0315	6.0600	6.0015	6.0300	6.0109	6.0280	6.0009	6.0180
	Min.	6.0700	6.1413	6.0000	6.0713	6.0300	6.0585	6.0000	6.0285	6.0100	6.0271	6.0000	6.0171
8	Max.	8.0845	8.1700	8.0045	8.0900	8.0418	8.0760	8.0018	8.0360	8.0141	8.0350	8.0011	8.0220
	Min.	8.0800	8.1655	8.0000	8.0855	8.0400	8.0742	8.0000	8.0342	8.0130	8.0339	8.0000	8.0209
10	Max.	10.0845	10.1700	10.0045	10.0900	10.0418	10.0760	10.0018	10.0360	10.0141	10.0350	10.0011	10.0220
	Min.	10.0800	10.1655	10.0000	10.0855	10.0400	10.0742	10.0000	10.0342	10.0130	10.0339	10.0000	10.0209
12	Max.	12.1005	12.2050	12.0055	12.1100	12.0521	12.0930	12.0021	12.0430	12.0173	12.0430	12.0013	12.0270
	Min.	12.0950	12.1995	12.0000	12.1045	12.0500	12.0909	12.0000	12.0409	12.0160	12.0417	12.0000	12.0257
16	Max.	16.1005	16.2050	16.0055	16.1100	16.0521	16.0930	16.0021	16.0430	16.0173	16.0430	16.0013	16.0270
	Min.	16.0950	16.1995	16.0000	16.1045	16.0500	16.0909	16.0000	16.0409	16.0160	16.0417	16.0000	16.0257
20	Max.	20.1165	20.2400	20.0065	20.1300	20.0676	20.1170	20.0026	20.0520	20.0216	20.0530	20.0016	20.0330
	Min.	20.1100	20.2335	20.0000	20.1235	20.0650	20.1144	20.0000	20.0494	20.0200	20.0514	20.0000	20.0314
25	Max.	25.1165	25.2400	25.0065	25.1300	25.0676	25.1170	25.0026	25.0520	25.0216	25.0530	25.0016	25.0330
	Min.	25.1100	25.2335	25.0000	25.1235	25.0650	25.1144	25.0000	25.0494	25.0200	25.0514	25.0000	25.0314
30	Max.	30.1165	30.2400	30.0065	30.1300	30.0676	30.1170	30.0026	30.0520	30.0216	30.0530	30.0016	30.0330
	Min.	30.1100	30.2335	30.0000	30.1235	30.0650	30.1144	30.0000	30.0494	30.0200	30.0514	30.0000	30.0314
40	Max.	40.1280	40.2800	40.0080	40.1600	40.0831	40.1420	40.0031	40.0620	40.0269	40.0640	40.0019	40.0390
	Min.	40.1200	40.2720	40.0000	40.1520	40.0800	40.1389	40.0000	40.0589	40.0250	40.0621	40.0000	40.0371
50	Max.	50.1380	50.2900	50.0080	50.1600	50.0831	50.1420	50.0031	50.0620	50.0269	50.0640	50.0019	50.0390
	Min.	50.1300	50.2820	50.0000	50.1520	50.0800	50.1389	50.0000	50.0589	50.0250	50.0621	50.0000	50.0371
60	Max.	60.1495	60.3300	60.0095	60.1900	60.1037	60.1740	60.0037	60.0740	60.0323	60.0760	60.0023	60.0460
	Min.	60.1400	60.3205	60.0000	60.1805	60.1000	60.1703	60.0000	60.0703	60.0300	60.0737	60.0000	60.0437

Table 6-1 Plug Gage Limit Dimensions — Classes ZM, YM, and XM (Cont'd)

Basic Size		Class ZM (0.05IT11) [Note (1)]				Class YM (0.05IT9)				Class XM (0.05IT8)			
		C11 [Note (2)]		H11		D9		H9		F8		H8	
		GO	NOGO	GO	NOGO	GO	NOGO	GO	NOGO	GO	NOGO	GO	NOGO
80	Max.	80.1595	80.3400	80.0095	80.1900	80.1037	80.1740	80.0037	80.0740	80.0323	80.0760	80.0023	80.0460
	Min.	80.1500	80.3305	80.0000	80.1805	80.1000	80.1703	80.0000	80.0703	80.0300	80.0737	80.0000	80.0437
100	Max.	100.1810	100.3900	100.0110	100.2200	100.1243	100.2070	100.0043	100.0870	100.0387	100.0900	100.0027	100.0540
	Min.	100.1700	100.3790	100.0000	100.2090	100.1200	100.2027	100.0000	100.0827	100.0360	100.0873	100.0000	100.0513
120	Max.	120.1910	120.4000	120.0110	120.2200	120.1243	120.2070	120.0043	120.0870	120.0387	120.0900	120.0027	120.0540
	Min.	120.1800	120.3890	120.0000	120.2090	120.1200	120.2027	120.0000	120.0827	120.0360	120.0873	120.0000	120.0513
160	Max.	160.2225	160.4600	160.0125	160.2500	160.1500	160.2450	160.0050	160.1000	160.0461	160.1060	160.0031	160.0630
	Min.	160.2100	160.4475	160.0000	160.2375	160.1450	160.2400	160.0000	160.0950	160.0430	160.1029	160.0000	160.0599
200	Max.	200.2545	200.5300	200.0145	200.2900	200.1757	200.2850	200.0057	200.1150	200.0536	200.1220	200.0036	200.0720
	Min.	200.2400	200.5155	200.0000	200.2755	200.1700	200.2793	200.0000	200.1093	200.0500	200.1184	200.0000	200.0684
250	Max.	250.2945	250.5700	250.0145	250.2900	250.1757	250.2850	250.0057	250.1150	250.0536	250.1220	250.0036	250.0720
	Min.	250.2800	250.5555	250.0000	250.2755	250.1700	250.2793	250.0000	250.1093	250.0500	250.1184	250.0000	250.0684
300	Max.	300.3460	300.6500	300.0160	300.3200	300.1965	300.3200	300.0065	300.1300	300.0600	300.1370	300.0040	300.0810
	Min.	300.3300	300.6340	300.0000	300.3040	300.1900	300.3135	300.0000	300.1235	300.0560	300.1330	300.0000	300.0770
400	Max.	400.4180	400.7600	400.0180	400.3600	400.2170	400.3500	400.0070	400.1400	400.0664	400.1510	400.0044	400.0890
	Min.	400.4000	400.7420	400.0000	400.3420	400.2100	400.3430	400.0000	400.1330	400.0620	400.1466	400.0000	400.0846
500	Max.	500.5000	500.8800	500.0200	500.4000	500.2377	500.3850	500.0077	500.1550	500.0728	500.1650	500.0048	500.0970
	Min.	500.4800	500.8600	500.0000	500.3800	500.2300	500.3773	500.0000	500.1473	500.0680	500.1602	500.0000	500.0922

NOTES:

(1) Plug gage tolerance Class XXM, which is equal to the rounded 5% of International Tolerance IT11 (see Fig. 6-4).

(2) Workpiece hole tolerance G7 (see ANSI B4.2, Table 4).

Table 6-2 Plug Gage Limit Dimensions — Class XXM

		Class XXM (0.05IT7) [Note (1)]													
		G7 [Note (2)]		H7		K7		N7		P7		S7		U7	
Basic Size		GO	NOGO	GO	NOGO	GO	NOGO	GO	NOGO	GO	NOGO	GO	NOGO	GO	NOGO
1	Max.	1.0630	1.1200	1.0005	1.0100	0.9905	1.0000	0.9865	0.9960	0.9845	0.9940	0.9765	0.9860	0.9725	0.9820
	Min.	1.0600	1.1170	1.0000	1.0095	0.9900	0.9995	0.9860	0.9955	0.9840	0.9935	0.9760	0.9855	0.9720	0.9815
1.2	Max.	1.2630	1.3200	1.2005	1.2100	1.1905	1.2000	1.1065	1.1960	1.1845	1.1940	1.1765	1.1860	1.1725	1.1820
	Min.	1.2600	1.3170	1.2000	1.2095	1.1900	1.1995	1.1060	1.1955	1.1840	1.1935	1.1760	1.1855	1.1720	1.1815
1.6	Max.	1.6630	1.7200	1.6005	1.6100	1.5905	1.6000	1.5865	1.5960	1.5845	1.5940	1.5765	1.5860	1.5725	1.5820
	Min.	1.6600	1.7170	1.6000	1.6095	1.5900	1.5995	1.9860	1.9955	1.5840	1.5935	1.5760	1.5855	1.5720	1.5815
2	Max.	2.0630	2.1200	2.0005	2.0100	1.9905	2.0000	1.9865	1.9960	1.9845	1.9940	1.9765	1.9860	1.9725	1.9820
	Min.	2.0600	2.1170	2.0000	2.0095	1.9900	1.9995	1.9860	1.9955	1.9840	1.9935	1.9760	1.9855	1.9720	1.9815
2.5	Max.	2.5630	2.6200	2.5005	2.5100	2.4905	2.5000	2.4865	2.4960	2.4845	2.4940	2.4765	2.4860	2.4725	2.4820
	Min.	2.5600	2.6170	2.5000	2.5095	2.4900	2.4995	2.4860	2.4955	2.4840	2.4935	2.4760	2.4855	2.4720	2.4815
3	Max.	3.0630	3.1200	3.0005	3.0100	2.9905	3.0000	2.9865	2.9960	2.9845	2.9940	2.9765	2.9860	2.9725	2.9820
	Min.	3.0600	3.1170	3.0000	3.0095	2.9900	2.9995	2.9860	2.9955	2.9840	2.9935	2.9760	2.9855	2.9720	2.9815
4	Max.	4.0737	4.1450	4.0006	4.0120	3.9916	4.0030	3.9846	3.9960	3.9806	3.9920	3.9736	3.9850	3.9696	3.9810
	Min.	4.0700	4.1413	4.0000	4.0114	3.9910	4.0024	3.9840	3.9954	3.9800	3.9914	3.9730	3.9844	3.9690	3.9804
5	Max.	5.0737	5.1450	5.0006	5.0120	4.9916	5.0030	4.9846	4.9960	4.9806	4.9920	4.9736	4.9850	4.9696	4.9810
	Min.	5.0700	5.1413	5.0000	5.0114	4.9910	5.0024	4.9840	4.9954	4.9800	4.9914	4.9730	4.9844	4.9690	4.9804
6	Max.	6.0737	6.1450	6.0006	8.0120	5.9916	6.0030	5.9846	5.9980	5.9806	5.9920	5.9736	5.9850	5.9696	5.9810
	Min.	6.0700	6.1413	6.0000	6.0114	5.9910	6.0024	5.9840	5.9954	5.9800	5.9914	5.9730	5.9844	5.9690	5.9804
8	Max.	8.0845	8.1700	8.0007	8.0150	7.9907	8.0050	7.9817	7.9960	7.9767	7.9910	7.9687	7.9830	7.9637	7.9780
	Min.	8.0800	8.1655	8.0000	8.0143	7.9900	8.0043	7.9810	7.9953	7.9760	7.9903	7.9680	7.9823	7.9630	7.9773
10	Max.	10.0845	10.1700	10.0007	10.0150	9.9907	10.0050	9.9817	9.9960	9.9767	9.9910	9.9687	9.9830	9.9637	9.9780
	Min.	10.0800	10.1655	10.0000	10.0143	9.9900	10.0043	9.9810	9.9953	9.9760	9.9903	9.9680	9.9823	9.9630	9.9773
12	Max.	12.1005	12.2050	12.0009	12.0180	11.9889	12.0060	11.9779	11.9950	11.9719	11.9890	11.9619	11.9790	11.9569	11.9740
	Min.	12.0950	12.1995	12.0000	12.0171	11.9880	12.0051	11.9770	11.9941	11.9710	11.9881	11.9610	11.9781	11.9560	11.9731
18	Max.	16.1005	16.2050	16.0009	16.0180	15.9889	16.0060	15.9779	15.9950	15.9719	15.9890	15.9619	15.9790	15.9569	15.9740
	Min.	16.0950	16.1995	16.0000	16.0171	15.9880	16.0051	15.9770	15.9941	15.9710	15.9881	15.9610	15.9781	15.9560	15.9731
20	Max.	20.1165	20.2400	20.0010	20.0210	19.9860	20.0060	19.9730	19.9930	19.9660	19.9860	19.9530	19.9730	19.9470	19.9670
	Min.	20.1100	20.2335	20.0000	20.0200	19.9850	20.0050	19.9720	19.9920	19.9650	19.9850	19.9520	19.9720	19.9460	19.9660
25	Max.	25.0080	25.0280	25.0010	25.0210	24.9860	25.0060	24.9730	24.9930	24.9660	24.9860	24.9530	24.9730	24.9400	24.9600
	Min.	25.0070	25.0270	25.0000	25.0200	24.9850	25.0050	24.9720	24.9920	24.9650	24.9850	24.9520	24.9720	24.9390	24.9590
30	Max.	30.0080	30.0280	30.0010	30.0210	29.9860	30.0060	29.9730	29.9930	29.9660	29.9860	29.9530	29.9730	29.9400	29.9600
	Min.	30.0070	30.0270	30.0000	30.0200	29.9850	30.0050	29.9720	29.9920	29.9650	29.9850	29.9520	29.9720	29.9390	29.9590
40	Max.	40.0102	40.0340	40.0012	40.0250	39.9832	40.0070	39.9682	39.9920	39.9592	39.9830	39.9422	39.9660	39.9252	39.9490
	Min.	40.0090	40.0328	40.0000	40.0238	39.9820	40.0058	39.9670	39.9908	39.9580	39.9818	39.9410	39.9648	39.9240	39.9478
50	Max.	50.0102	50.0340	50.0012	50.0250	49.9832	50.0070	49.9682	49.9920	49.9592	49.9830	49.9422	49.9660	49.9152	49.9390
	Min.	50.0090	50.0328	50.0000	50.0238	49.9820	50.0058	49.9670	49.9908	49.9580	49.9818	49.9410	49.9648	49.9140	49.9378
60	Max.	60.0115	60.0400	60.0015	60.0300	59.9805	60.0090	59.9625	59.9910	59.9505	59.9790	59.9295	59.9580	59.8955	59.9240
	Min.	60.0100	60.0385	60.0000	60.0285	59.9790	60.0075	59.9610	59.9895	59.9490	59.9775	59.9280	59.9565	59.8940	59.9225
80	Max.	80.0115	80.0400	80.0015	80.0300	79.9805	80.0090	79.9625	79.9910	79.9505	79.9790	79.9235	79.9520	79.8805	79.9090
	Min.	80.0100	80.0385	80.0000	80.0285	79.9790	80.0075	79.9610	79.9895	79.9490	79.9775	79.9220	79.9505	79.8790	79.9075
100	Max.	100.0137	100.0470	100.0017	100.0350	99.9767	100.0100	99.9567	99.9900	99.9427	99.9760	99.9087	99.9420	99.8557	99.8890
	Min.	100.0120	100.0453	100.0000	100.0333	99.9750	100.0083	99.9550	99.9883	99.9410	99.9743	99.9070	99.9403	99.8540	99.8873

Table 6-2 Plug Gage Limit Dimensions — Class XXM (Cont'd)

Basic Size		Class XXM (0.05IT7) [Note (1)]															
		G7 [Note (2)]		H7		K7		N7		P7		S7		U7			
		GO	NOGO	GO	NOGO	GO	NOGO	GO	NOGO	GO	NOGO	GO	NOGO	GO	NOGO		
120	Max.	120.0137	100.0470	120.0017	120.0350	119.9767	120.0100	119.9567	119.9900	119.9427	119.9760	119.9007	119.9340	119.8357	119.8690		
	Min.	120.0120	120.0453	120.0000	120.0333	119.9750	120.0083	119.9550	119.9883	119.9410	119.9743	119.8990	119.9323	119.8340	119.8673		
160	Max.	160.0160	160.0540	160.0020	160.0400	159.9740	160.0120	159.9500	159.9880	159.9340	159.9720	159.8770	159.9150	159.7870	159.8250		
	Min.	160.0140	160.0520	160.0000	160.0380	159.9720	160.0100	159.9480	159.9860	159.9320	159.9700	159.8750	159.9130	159.7850	159.8230		
200	Max.	200.0173	200.0610	200.0023	200.0460	199.9693	200.0130	199.9423	199.9860	199.9233	199.9670	199.8513	199.8950	199.7373	199.7810		
	Min.	200.0150	200.0587	200.0000	200.0437	199.9670	200.0107	199.9400	199.9837	199.9210	199.9647	199.8490	199.8927	199.7350	199.7787		
250	Max.	250.0173	250.0610	250.0023	250.0460	249.9693	250.0130	249.9423	249.9860	249.9233	249.9670	249.8333	249.8770	249.6893	249.7330		
	Min.	250.0150	250.0587	250.0000	250.0437	249.9670	250.0107	249.9400	249.9837	249.9210	249.9647	249.8310	249.8747	249.6870	249.7307		
300	Max.	300.0196	300.0690	300.0026	300.0520	299.9666	300.0160	299.9366	299.9860	299.9146	299.9640	299.8006	299.8500	299.6206	299.6700		
	Min.	300.0170	300.0664	300.0000	300.0494	299.9640	300.0134	299.9340	299.9834	299.9120	299.9614	299.7980	299.8474	299.6180	299.6674		
400	Max.	400.0208	400.0750	400.0028	400.0570	399.9628	400.0170	399.9298	399.9840	399.9048	399.9590	399.7588	399.8130	399.5318	399.5860		
	Min.	400.0180	400.0722	400.0000	400.0542	399.9600	400.0142	399.9270	399.9812	399.9020	399.9562	399.7560	399.8102	399.5290	399.5832		
500	Max.	500.0231	500.0830	500.0031	500.0630	499.9581	500.0180	499.9231	499.9830	499.8951	499.9550	499.7111	499.7710	499.4231	499.4830		
	Min.	500.0200	500.0799	500.0000	500.0599	499.9550	500.0149	499.9200	499.9799	499.8920	499.9519	499.7080	499.7679	499.4200	499.4799		

NOTES:
(1) Plug gage tolerance Class XXM, which is equal to the rounded 5% of International Tolerance IT11 (see Fig. 6-4).
(2) Workpiece hole tolerance G7 (see ANSI B4.2, Table 4).

Table 6-3 Ring and Snap Gage Limit Dimensions — Classes ZM, YM, and XXM

		Class ZM (0.05IT11) [Note (1)]				Class YM (0.05IT9)				Class XXM (0.05IT7)			
		c11 [Note (2)]		h11		d9		h9		f7		h7	
Basic Size		GO	NOGO	GO	NOGO	GO	NOGO	GO	NOGO	GO	NOGO	GO	NOGO
1	Max.	0.9400	0.8830	1.0000	0.9430	0.9800	0.9562	1.0000	0.9762	0.9940	0.9845	1.0000	0.9905
	Min.	0.9370	0.8800	0.9970	0.9400	0.9788	0.9550	0.9988	0.9750	0.9935	0.9840	0.9995	0.9900
1.2	Max.	1.1400	1.0830	1.2000	1.1430	1.1800	1.1562	1.2000	1.1762	1.1940	1.1845	1.2000	1.1905
	Min.	1.1370	1.0800	1.1970	1.1400	1.1788	1.1550	1.1988	1.1750	1.1935	1.1840	1.1995	1.1900
1.6	Max.	1.5400	1.4830	1.6000	1.5430	1.5800	1.5562	1.6000	1.5762	1.5940	1.5845	1.6000	1.5905
	Min.	1.5370	1.4800	1.5970	1.5400	1.5788	1.5550	1.5988	1.5750	1.5935	1.5840	1.5995	1.5900
2	Max.	1.9400	1.8830	2.0000	1.9430	1.9800	1.9562	2.0000	1.9762	1.9940	1.9845	2.0000	1.9905
	Min.	1.9370	1.8800	1.9970	1.9400	1.9788	1.9550	1.9988	1.9750	1.9935	1.9840	1.9995	1.9900
2.5	Max.	2.4400	2.3830	2.5000	2.4430	2.4800	2.4562	2.5000	2.4762	2.4940	2.4845	2.5000	2.4905
	Min.	2.4370	2.3800	2.4970	2.4400	2.4788	2.4550	2.4988	2.4750	2.4935	2.4840	2.4995	2.4900
3	Max.	2.9400	2.8830	3.0000	2.9430	2.9800	2.9562	3.0000	2.9762	2.9940	2.9845	3.0000	2.9905
	Min.	2.9370	2.8800	2.9970	2.9400	2.9788	2.9550	2.9988	2.9750	2.9935	2.9840	2.9995	2.9900
4	Max.	3.9300	3.8587	4.0000	3.9287	3.9700	3.9415	4.0000	3.9715	3.9900	3.9786	4.0000	3.9886
	Min.	3.9263	3.8550	3.9963	3.9250	3.9685	3.9400	3.9985	3.9700	3.9894	3.9780	3.9994	3.9880
5	Max.	4.9300	4.8587	5.0000	4.9287	4.9700	4.9415	5.0000	4.9715	4.9900	4.9786	5.0000	4.9886
	Min.	4.9263	4.8550	4.9963	4.9250	4.9685	4.9400	4.9985	4.9700	4.9894	4.9780	4.9994	4.9880
6	Max.	5.9300	5.8587	6.0000	5.9287	5.9700	5.9415	6.0000	5.9715	5.9900	5.9786	6.0000	5.9886
	Min.	5.9263	5.8550	5.9963	5.9250	5.9685	5.9400	5.9985	5.9700	5.9894	5.9780	5.9994	5.9880
8	Max.	7.9200	7.8345	8.0000	7.9145	7.9600	7.9258	8.0000	7.9658	7.9870	7.9727	8.0000	7.9857
	Min.	7.9155	7.8300	7.9955	7.9100	7.9582	7.9240	7.9982	7.9640	7.9863	7.9720	7.9993	7.9850
10	Max.	9.9200	9.8345	10.0000	9.9145	9.9600	9.9258	10.0000	9.9658	9.9870	9.9727	10.0000	9.9857
	Min.	9.9155	9.8300	9.9955	9.9100	9.9582	9.9240	9.9982	9.9640	9.9863	9.9720	9.9993	9.9850
12	Max.	11.9050	11.8005	12.0000	11.8955	11.9500	11.9091	12.0000	11.9591	11.9840	11.9669	12.0000	11.9829
	Min.	11.8995	11.7950	11.9945	11.8900	11.9479	11.9070	11.9979	11.9570	11.9831	11.9660	11.9991	11.9820
18	Max.	15.9050	15.8005	16.0000	15.8955	15.9500	15.9091	16.0000	15.9591	15.9840	15.9669	16.0000	15.9829
	Min.	15.8995	15.7950	15.9945	15.8900	15.9479	15.9070	15.9979	15.9570	15.9831	15.9660	15.9991	15.9820
20	Max.	19.8900	19.7665	20.0000	19.8765	19.9350	19.8856	20.0000	19.9506	19.9800	19.9600	20.0000	19.9800
	Min.	19.8835	19.7600	19.9935	19.8700	19.9324	19.8830	19.9974	19.9480	19.9790	19.9590	19.9990	19.9790
25	Max.	24.8900	24.7665	25.0000	24.8765	24.9350	24.8856	25.0000	24.9506	24.9800	24.9600	25.0000	24.9800
	Min.	24.8835	24.7600	24.9935	24.8700	24.9324	24.8830	24.9974	24.9480	24.9790	24.9590	24.9990	24.9790
30	Max.	29.8900	29.7665	30.0000	29.8765	29.9350	29.8856	30.0000	29.9506	29.9800	29.9600	30.0000	29.9800
	Min.	29.8835	29.7600	29.9935	29.8700	29.9324	29.8830	29.9974	29.9480	29.9790	29.9590	29.9990	29.9790
40	Max.	39.8800	39.7280	40.0000	39.8480	39.9200	39.8611	40.0000	39.9411	39.9750	39.9512	40.0000	39.9762
	Min.	39.8720	39.7200	39.9920	39.8400	39.9169	39.8580	39.9969	39.9380	39.9738	39.9500	39.9988	39.9750
50	Max.	49.8700	49.7180	50.0000	49.8480	49.9200	49.8611	50.0000	49.9411	49.9750	49.9512	50.0000	49.9762
	Min.	49.8620	49.7100	49.9920	49.8400	49.9189	49.8580	49.9969	49.9380	49.9738	49.9500	49.9988	49.9750
60	Max.	59.8600	59.6795	60.0000	59.8195	59.9000	59.8297	60.0000	59.9297	59.9700	59.9415	60.0000	59.9715
	Min.	59.8505	59.6700	59.9905	59.8100	59.8963	59.8260	59.9963	59.9260	59.9685	59.9400	59.9985	59.9700
80	Max.	79.8500	79.6695	80.0000	79.8195	79.9000	79.8297	80.0000	79.9297	79.9700	79.9415	80.0000	79.9715
	Min.	79.8405	79.6600	79.9905	79.8100	79.8963	79.8260	79.9963	79.9260	79.9685	79.9400	79.9985	79.9700
100	Max.	99.8300	99.6210	100.0000	99.7910	99.8800	99.7973	100.0000	99.9173	99.9640	99.9307	100.0000	99.9667
	Min.	99.8190	99.6100	99.9890	99.7800	99.8963	99.7930	99.9957	99.9130	99.9623	99.9290	99.9983	99.9650

Table 6-3 Ring and Snap Gage Limit Dimensions — Classes ZM, YM, and XXM (Cont'd)

		Class ZM (0.05IT11) [Note (1)]				Class YM (0.05IT9)				Class XXM (0.05IT7)			
		c11 [Note (2)]		h11		d9		h9		f7		h7	
Basic Size		GO	NOGO	GO	NOGO	GO	NOGO	GO	NOGO	GO	NOGO	GO	NOGO
120	Max.	119.8200	119.6110	120.0000	119.7910	119.8800	119.7973	120.0000	119.9173	119.9640	119.9307	120.0000	119.9667
	Min.	119.8090	119.6000	119.9890	119.7800	119.8757	119.7930	199.9957	119.9130	119.9623	119.9290	119.9983	119.9650
160	Max.	159.7600	159.5525	160.0000	159.7625	159.8550	159.7600	160.0000	159.9050	159.9570	159.9190	160.0000	159.9620
	Min.	159.7775	159.5400	159.9875	159.7500	159.8500	159.7550	159.9950	159.9000	159.9550	159.9170	159.9980	159.9600
200	Max.	199.7600	199.4845	200.0000	199.7245	199.8300	199.7207	200.0000	199.8907	199.9500	199.9063	200.0000	199.9563
	Min.	199.7455	199.4700	199.9855	199.7100	199.8243	199.7150	199.9943	199.8850	199.9477	199.9040	199.9977	199.9540
250	Max.	249.7200	249.4445	250.0000	249.7245	249.8300	249.7207	250.0000	249.8907	249.9500	249.9063	250.0000	249.9563
	Min.	249.7055	249.4300	249.9855	249.7100	249.8243	249.7150	249.9943	249.8850	249.9477	249.9040	249.9977	249.9540
300	Max.	299.6700	299.3660	300.0000	299.6960	299.8100	299.6865	300.0000	299.8765	299.9440	299.8946	300.0000	299.9506
	Min.	299.6540	299.3500	299.9840	299.6800	299.8035	299.6800	299.9935	299.8700	299.9414	299.8920	299.9974	299.9480
400	Max.	399.6000	399.2580	400.0000	399.8580	399.7900	399.6570	400.0000	399.8670	399.9380	399.8838	400.0000	399.9458
	Min.	399.5820	399.2400	399.9820	399.6400	399.7830	399.6500	399.9930	399.8600	399.9352	399.8810	399.9972	399.9430
500	Max.	499.5200	499.1400	500.0000	499.6200	499.7700	499.6227	500.0000	499.8527	499.9320	499.8721	500.0000	499.9401
	Min.	499.5000	499.1200	499.9800	499.6000	499.7623	499.6150	499.9923	499.8450	499.9289	499.8690	499.9969	499.9370

NOTES:
(1) Plug gage tolerance Class ZM, which is equal to the rounded 5% of International Tolerance IT11 (see Fig. 6-4).
(2) Workpiece hole tolerance C11 (see ANSI B4.2, Table 2).

Table 6-4 Ring and Snap Gage Limit Dimensions — Class XXXM

		Class XXXM (0.05IT6) [Note (1)]													
		g6 [Note (2)]		h6		k6		n6		p6		s6		u6	
Basic Size		GO	NOGO	GO	NOGO	GO	NOGO	GO	NOGO	GO	NOGO	GO	NOGO	GO	NOGO
1	Max.	0.9980	0.9923	1.0000	0.9943	1.0060	1.0003	1.0100	1.0043	1.0120	1.0063	1.0200	1.0143	1.0240	1.0183
	Min.	0.9977	0.9920	0.9997	0.9940	1.0057	1.0000	1.0097	1.0040	1.0117	1.0060	1.0197	1.0140	1.0237	1.0180
1.2	Max.	1.1980	1.1923	1.2000	1.1943	1.2060	1.2003	1.2100	1.2043	1.2120	1.2063	1.2200	1.2143	1.2240	1.2183
	Min.	1.1977	1.1920	1.1997	1.1940	1.2057	1.2000	1.2097	1.2040	1.2117	1.2060	1.2197	1.2140	1.2237	1.2180
1.6	Max.	1.5980	1.5923	1.6000	1.5943	1.6060	1.6003	1.6100	1.6043	1.6120	1.6063	1.6200	1.6143	1.6240	1.6183
	Min.	1.5977	1.5920	1.5997	1.5940	1.6057	1.6000	1.6097	1.6040	1.6117	1.6060	1.6197	1.6140	1.6237	1.6180
2	Max.	1.9980	1.9923	2.0000	1.9943	2.0060	2.0003	2.0100	2.0043	2.0120	2.0063	2.0200	2.0143	2.0240	2.0183
	Min.	1.9977	1.9920	1.9997	1.9940	2.0057	2.0000	2.0097	2.0040	2.0117	2.0060	2.0197	2.0140	2.0237	2.0180
2.5	Max.	2.4980	2.4923	2.5000	2.4943	2.5060	2.5003	2.5100	2.5043	2.5120	2.5063	2.5200	2.5143	2.5240	2.5183
	Min.	2.4977	2.4920	2.4997	2.4940	2.5057	2.5000	2.5097	2.5040	2.5117	2.5060	2.5197	2.5140	2.5237	2.5180
3	Max.	2.9980	2.9923	3.0000	2.9943	3.0060	3.0003	3.0100	3.0043	3.0120	3.0063	3.0200	3.0143	3.0240	3.0183
	Min.	2.9977	2.9920	2.9997	2.9940	3.0057	3.0000	3.0097	3.0040	3.0117	3.0060	3.0197	3.0140	3.0237	3.0180
4	Max.	3.9960	3.9884	4.0000	3.9924	4.0090	4.0014	4.0160	4.0084	4.0200	4.0124	4.0270	4.0194	4.0310	4.0234
	Min.	3.9956	3.9880	3.9996	3.9920	4.0086	4.0000	4.0156	4.0080	4.0196	4.0120	4.0266	4.0190	4.0306	4.0230
5	Max.	4.9960	4.9884	5.0000	4.9924	5.0090	5.0014	5.0160	5.0084	5.0200	5.0124	5.0270	5.0194	5.0310	5.0234
	Min.	4.9956	4.9880	4.9996	4.9920	5.0086	5.0010	5.0156	5.0080	5.0196	5.0120	5.0266	5.0190	5.0306	5.0230
6	Max.	5.9960	5.9884	6.0000	5.9924	6.0090	6.0014	6.0160	6.0084	6.0200	6.0124	6.0270	6.0194	6.0310	6.0234
	Min.	5.9956	5.9880	5.9996	5.9920	6.0086	6.0010	6.0156	6.0080	6.0196	6.0120	6.0266	6.0190	6.0306	6.0230
8	Max.	7.9950	7.9865	8.0000	7.9915	8.0100	8.0015	8.0190	8.0105	8.0240	8.0155	8.0320	8.0235	8.0370	8.0285
	Min.	7.9945	7.9860	7.9995	7.9910	8.0095	8.0010	8.0185	8.0100	8.0235	8.0150	8.0315	8.0230	8.0365	8.0280
10	Max.	9.9950	9.9865	10.0000	9.9915	10.0100	10.0015	10.0190	10.0105	10.0240	10.0155	10.0320	10.0235	10.0370	10.0285
	Min.	9.9945	9.9860	9.9995	9.9910	10.0095	10.0010	10.0185	10.0100	10.0235	10.0150	10.0315	10.0230	10.0365	10.0280
12	Max.	11.9940	11.9836	12.0000	11.9896	12.0120	12.0016	12.0230	12.0126	12.0290	12.0186	12.0390	12.0286	12.0440	12.0336
	Min.	11.9934	11.9830	11.9994	11.9890	12.0114	12.0010	12.0224	12.0120	12.0284	12.0180	12.0384	12.0280	12.0434	12.0330
18	Max.	15.9940	15.9836	16.0000	15.9896	16.0120	16.0016	16.0230	16.0126	16.0290	16.0186	16.0390	16.0286	16.0440	16.0336
	Min.	15.9934	15.9830	15.9994	15.9890	16.0114	16.0010	16.0224	16.0120	16.0284	16.0180	16.0384	16.0280	16.0434	16.0330
20	Max.	19.9930	19.9807	20.0000	19.9877	20.0150	20.0027	20.0280	20.0157	20.0350	20.0227	20.0480	20.0357	20.0540	20.0417
	Min.	19.9923	19.9800	19.9993	19.9870	20.0143	20.0020	20.0273	20.0150	20.0343	20.0220	20.0473	20.0350	20.0533	20.0410
25	Max.	24.9930	24.9807	25.0000	24.9877	25.0150	25.0027	25.0280	25.0157	25.0350	25.0227	25.0480	25.0357	25.0610	25.0487
	Min.	24.9923	24.9800	24.9993	24.9870	25.0143	25.0020	25.0273	25.0150	25.0343	25.0220	25.0473	25.0350	25.0603	25.0480
30	Max.	29.9930	29.9807	30.0000	29.9877	30.0150	30.0027	30.0280	30.0157	30.0350	30.0227	30.0480	30.0357	30.0480	30.0357
	Min.	29.9923	29.9800	29.9993	29.9870	30.0143	30.0020	30.0273	30.0150	30.0343	30.0220	30.0473	30.0350	30.0603	30.0350
40	Max.	39.9910	39.9758	40.0000	39.9848	40.0180	40.0028	40.0330	40.0178	40.0420	40.0268	40.0590	40.0438	40.0760	40.0608
	Min.	39.9902	39.9750	39.9992	39.9840	40.0172	40.0020	40.0322	40.0170	40.0412	40.0260	40.0582	40.0430	40.0752	40.0600
50	Max.	49.9910	49.9758	50.0000	49.9848	50.0180	50.0028	50.0330	50.0178	50.0420	50.0268	50.0590	50.0438	50.0860	50.0708
	Min.	49.9902	49.9750	49.9992	49.9840	50.0172	50.0020	50.0322	50.0170	50.0412	50.0260	50.0582	50.0430	50.0852	50.0700
60	Max.	59.9900	59.9720	60.0000	59.9820	60.0210	60.0030	60.0390	60.0210	60.0510	60.0330	60.0720	60.0540	60.1060	60.0880
	Min.	59.9890	59.9710	59.9990	59.9810	60.0200	60.0020	60.0380	60.0200	60.0500	60.0320	60.0710	60.0530	60.1050	60.0870
80	Max.	79.9900	79.9720	80.0000	79.9820	80.0210	80.0030	80.0390	80.0210	80.0510	80.0330	80.0780	80.0600	80.1210	80.1030
	Min.	79.9890	79.9710	79.9990	79.9810	80.0200	80.0020	80.0380	80.0200	80.0500	80.0320	80.0770	80.0590	80.1200	80.1020
100	Max.	99.9880	99.9671	100.0000	99.9791	100.0250	100.0041	100.0450	100.0241	100.0590	100.0381	100.0930	100.0721	100.1460	100.1251
	Min.	99.9869	99.9660	99.9989	99.9780	100.0239	100.0030	100.0439	100.0230	100.0579	100.0370	100.0919	100.0710	100.1449	100.1240

Table 6-4 Ring and Snap Gage Limit Dimensions — Class XXXM (Cont'd)

		Class XXXM (0.05IT6) [Note (1)]													
		g6 [Note (2)]		h6		k6		n6		p6		s6		u6	
Basic Size		GO	NOGO	GO	NOGO	GO	NOGO	GO	NOGO	GO	NOGO	GO	NOGO	GO	NOGO
120	Max.	119.9880	119.9671	120.0000	119.9791	120.0250	120.0041	120.0450	120.0241	120.0590	120.0381	120.1010	120.0801	120.1660	120.1451
	Min.	119.9869	119.9660	119.9989	119.9780	120.0239	120.0030	120.0439	120.0230	120.0579	120.0370	120.0999	120.0790	120.1649	120.1440
160	Max.	159.9860	159.9623	160.0000	159.9763	160.0280	160.0043	160.0520	160.0283	160.0680	160.0443	160.2150	160.1913	160.2150	160.1913
	Min.	159.9847	159.9610	159.9987	159.9750	160.0267	160.0030	180.0507	160.0270	160.0667	160.0430	160.2137	160.1900	160.2137	160.1900
200	Max.	199.9850	199.9575	200.0000	199.9725	200.0330	200.0055	200.0600	200.0325	200.0790	200.0515	200.1510	200.1235	200.2650	200.2375
	Min.	199.9835	199.9560	199.9985	199.9710	200.0315	200.0040	200.0585	200.0310	200.0775	200.0500	200.1495	200.1220	200.2635	200.2360
250	Max.	249.9850	249.9575	250.0000	249.9725	250.0330	250.0055	250.0600	250.0325	250.0790	250.0515	250.1690	250.1415	250.3130	250.2855
	Min.	249.9835	249.9560	249.9985	249.9710	250.0315	250.0040	250.0585	250.0310	250.0775	250.0500	250.1675	250.1400	250.3115	250.2840
300	Max.	299.9830	299.9526	300.0000	299.9686	300.0360	300.0056	300.0660	300.0356	300.0880	300.0576	300.2020	300.1716	300.3820	300.3516
	Min.	299.9614	299.9510	299.9984	299.9680	300.0344	300.0040	300.0644	300.0340	300.0864	300.0560	300.2004	300.1700	300.3804	300.3500
400	Max.	399.9820	399.9478	400.0000	399.9658	400.0400	400.0058	400.0730	400.0388	400.0980	400.0638	400.2440	400.2098	400.4710	400.4368
	Min.	399.9802	399.9460	399.9982	399.9640	400.0382	400.0040	400.0712	400.0370	400.0962	400.0620	400.2422	400.2080	400.4692	400.4350
500	Max.	499.9800	499.9420	500.0000	499.9620	500.0450	500.0070	500.0800	500.0420	500.1080	500.0700	500.2920	500.2540	500.5800	500.5420
	Min.	499.9780	499.9400	499.9980	499.9600	500.0430	500.0050	500.0780	500.0400	500.1060	500.0680	500.2900	500.2520	500.5780	500.5400

NOTES:
(1) Plug gage tolerance Class XXXM, which is equal to the rounded 5% of International Tolerance IT6 (see Fig. 6-4)
(2) Workpiece hole tolerance g6 (see ANSI B4.2, Table 2).

and NOGO gage limit dimensions based on the tolerances in Fig. 6-4 and the first choice sizes from ASME B4.2.

When GO gage limit dimensions are calculated for gages with wear allowances, the applicable gagemakers' tolerances from Fig. 6-4 must be added to or subtracted from the GO gage limits of sizes shown in Tables 6-1 through 6-4.

All gagemakers' tolerances, wear allowances, and measurement uncertainties must be held within the workpiece's size limits to meet the absolute gage tolerancing policy.

7 USAGE

7.1 General

Functional gages inspect for violations of the MMC concept created by the use of the MMC concept. Functional gages are dimensioned and toleranced relative to the virtual condition of the features they check (see examples of gage policy and wear allowance in Nonmandatory Appendix A). Gages should be used in a manner that closely duplicates how the feature being gaged will function. If the part is to be used in an assembly, the gage design should duplicate assembly conditions.

7.2 Environmental Conditions

7.2.1 Temperature. All part dimensions and tolerances apply at a temperature of 20°C (68°F). If both the gage and the workpiece are at 20°C (68°F) there is no measurement error caused by temperature. For other conditions, the effects of thermal expansion on the gage and the workpiece shall be considered. Should the gage and the workpiece be at the same temperature that is other than 20°C (68°F), both will expand by an amount that can be calculated by the formula

$$KL\ (T - 20)$$

where
K = coefficient of expansion
L = length
T = temperature, °C

With the same coefficients of expansion, no temperature-related measurement uncertainty is introduced. However, when dealing with different coefficients of expansion, temperature-related measurement uncertainty becomes a factor. If the gage or the workpiece is constructed of more than one component and these components have different coefficients of expansion, the structure should be examined to see if an additional uncertainty could occur because of twist or bend. Among the many other factors to consider are

(a) *Slowly Changing Temperature.* Should the air temperature slowly change over time and thermal conductivities that are in the structures of the gage and the workpiece happen to be high, uncertainty caused by temperature can be scrutinized based on the premise that the temperatures of the gage and the workpiece are uniform but not equal.

(b) *Quickly Changing Temperature.* If minor, fast air temperature changes take place and if the gage and the workpiece are of large mass, the effect of the temperature changes could be small. In these situations, not enough heat flows in and out of the gage and the workpiece to change the temperature significantly. Rapid and/or large magnitude air temperature fluctuations may impose differential temperature changes on the gage and the workpiece that can cause them to twist and bend. The uncertainty of this shall be taken into consideration and avoided, if possible.

(c) Radiant Energy Such as Sunlight and Artificial Lighting. Sunlight should be avoided and artificial lighting and radiant energy outside the visible spectrum should be held to a minimum. Indirect lighting is often effective. Lighting should be as uniform as possible to prevent uneven heating of gage and workpiece. One of the most prevalent problems caused by radiant energy is in the flatness of large surfaces. Some other factors of temperature that shall be considered are workpieces not stabilized to the inspection environment, air from heating or cooling ducts, and the body heat of the inspector. See ASME B89.6.2 for further information on environmental conditions.

7.2.2 Humidity. The presence of excessive humidity can cause deterioration of gage elements due to corrosion of metal surfaces and can also cause discomfort to personnel. Both of these factors can have a negative effect on gaging accuracy. Therefore, it is important to have a measuring environment where humidity is maintained at a level that does not allow this to occur. It is recommended that the relative humidity shall not exceed 45%. See ASME B89.6.2 for further information on environmental conditions.

7.2.3 Contamination. Contamination of the measuring environment can have detrimental effects on gage accuracy. Therefore, it is important to maintain a clean environment that is free of grease, grime, and dirt. Gage precision will be affected by the presence of foreign particles, especially when tolerances are small.

7.3 Certification and Calibration

7.3.1 Certification. Certification is a process that is done either when the gage is first brought into the facility or after the gage is reworked. A gage is certified by being checked in a controlled environment to see that all of the dimensions and tolerances are met. A gage can be certified as a master gage for use in checking other gages. A master gage is tightly toleranced. A gage can be certified for use in a sample checking area for checking parts and be held to a more open tolerance. A shop gage is used on the shop floor to check a part as it comes off the machine. A part can be checked on a sample checking gage when the shop gage shows that a part is out of tolerance. A gage used in a shop is not required to be as accurate as a master or sample checking gage, and so only needs to be accurate to a greater tolerance range, but still within specified gage tolerances.

7.3.2 Calibration. Calibration is what is done in given time frames, according to the usage of the gage and material of the gage and part. Calibration is done after the gage is certified. The time frame is stated either on the gage or on documentation with the gage. The dimensions and tolerances are checked again to see that they still meet the dimensional requirements of the gage. If they meet the requirements of the gage drawing, the gage is still certified, but this is not a recertification of the gage. If the gage does not meet specifications, it can be downgraded from a master gage to a sample checking gage or in another way. The gage can also become out of tolerance. If this happens, the gage is either scrapped or reworked. If a gage is reworked, then it shall be recertified.

7.3.3 Frequency. The frequency of use of a gage can have deteriorating effects over time. Depending on the gage design, the effects of wear, damage, burrs, or dimensional instability can cause measuring errors if gage deterioration is not detected accurately.

7.3.4 Methodology

(a) Control of Geometric Characteristics. The composite tolerance on size and geometric characteristics of fixed gages shall not exceed 50% of the applicable tolerance on the workpiece feature being gaged. For a more complete explanation of the 50% rule, see para. 4.5.1. Geometric tolerances that may be used on gages include the same geometric characteristic symbols that are used on workpieces: straightness, flatness, circularity, cylindricity, profile of a line, profile of a surface, perpendicularity, parallelism, angularity, position, concentricity, symmetry, circular runout, and total runout. See ASME Y14.5-2009.

(b) Fixed Limit Gage Size Checking. There are many methods that may be used to determine the gage size. It is important that the gaging surfaces of the snap gage, the gage block, and the setting master disc (depending on the method used) be carefully wiped clean before any measurements are performed. For setting master discs, it is also recommended that the disc should be greased with a thin film of petroleum jelly and then carefully wiped, without rubbing off the petroleum jelly. Four basic methods for checking the sizes of fixed limit gages are as follows:

(1) Setting Master Disc Method. For a GO snap gage, two setting master discs are used. The snap gage should pass over the setting master disc for a new GO snap gage in a vertical direction under the working load after having been brought carefully to rest in contact with the disc and then released. Inertia forces are thus avoided.

The GO snap gage should not pass over the wear check disc when this is applied in the same manner described above. If the GO snap gage passes over the wear check reference disc, then the gage should be reworked or replaced. The wear check disc is slightly larger than the setting master disc.

For a NOGO snap gage, the snap gage should just pass over the appropriate setting master disc when this is applied in the manner described above.

(2) Gage Block Method. This method uses a set of gage blocks and is appropriate to both GO and NOGO snap gages. A combination of gage blocks is wrung to the appropriate workpiece limit. The gage block combination is then progressively increased or decreased as required until the snap gage just passes over the gage block combination in a vertical direction under the working load. An acceptable alternative is for the gage blocks, applied vertically to the snap gage, to just pass through the gap under their own weight.

The size of the gage block combination should be noted and compared with the GO and NOGO gage limits as appropriate.

(3) Setting Master Disc and Gage Block Method. This method uses a setting master disc with a diameter smaller than the working size of the snap gage used in conjunction with a set of gage blocks and is appropriate to both GO and NOGO snap gages. The gage block combination is adjusted so that the gap gage just passes over the combined width of the gage block(s) and the setting master disc in a vertical direction under the working load.

The sum of the sizes of the gage block(s) and the setting master disc should be noted and compared with the GO and NOGO gage limit as appropriate.

(4) Comparison to Setting Masters by Indication. A right angle plate is placed on a surface plate and the snap gage to be calibrated is mounted on the right angle plate with its gaging surfaces parallel to the surface plate. An indicator (mechanical or electronic, depending on accuracy requirement) mounted on a transfer stand is used to transfer the known size from the calibrated setting master to the gaging surfaces of the snap gage, and any deviation from the known size may be recorded from the indicator reading.

NOTE: All of the preceding methods are applicable for fixed or adjustable snap gages except the setting master disc method, which is mainly used for fixed snap gages.

7.4 Referee Gaging

In situations where mediation is required to accept/reject a part, a referee gage may be required. This gage takes precedence over all other gages and is the final arbiter on whether a part is good or bad.

There are many different applications for gages. This Standard mainly deals with gaging finished product requirements. There are also requirements for in-process gaging procedures. It is considered good gaging practice to have two sets of gages available. One set will be used for in-process gaging and the other for final inspection.

If workpieces are rejected by the in-process gages, they can be set aside for a final inspection procedure using the more tightly toleranced final inspection gage. Since this gage is stored in a controlled environment more conducive to gage preservation and appropriate usage, it is generally the more reliable of the gages and used as the final arbiter in the status of the workpiece. The more tightly toleranced gages are known as referee gages.

7.4.1 In-Process Gaging. In-process gaging has several uses. One use is to audit the product of a controlled process. GO and functional gages will not show the actual quantitative value of the part, however, they will show if a part is outside of the acceptable limits. Since gaging will not satisfy the quantitative data collection required for statistical process capability studies, if such data is required, augmenting inspection methods shall be used. Another benefit is that in-process gaging can be used in place of building nearly duplicate final product gaging. Normally, this set of in-process gages used by manufacturing personnel will be provided with a larger wear allowance than the final acceptance gages. This is because the in-process gage will receive use in an environment more hostile to optimum gage handling and preservation. These gages tend to wear out faster than a gage used in an inspection-controlled environment.

7.4.2 Final Acceptance Gaging. Final acceptance gaging may have tighter tolerances and is likely to be housed in a controlled environment more conducive to gage preservation and appropriate usage. It is generally the more reliable of the gages and is used as the final arbiter in determining the status of the workpiece. Worn gages may actually make better final acceptance gages, because as long as they do not violate the boundary they are designed to verify, more good parts will be accepted by them than by the newer gage with more material. If a process is not reliable, gaging 100% of the product as final acceptance may be required.

7.5 Alignment Principle

The principle of alignment should be followed as closely as possible in all instruments for measuring dimensions. For example, the axis or centerplane of the feature or dimension being measured should be aligned with the appropriate reference element of the gage. The appropriate alignment may be perpendicular to the axis or centerplane, oriented to the datums to which the feature is controlled, or oriented to the desired geometry of the feature being gaged. Whatever the appropriate alignment is, it should be observed during gaging for the best results.

7.6 Measurement Force

All measuring and gaging operations involving this Standard are understood to be implemented with zero measuring force.

NOTE: This statement is not meant to supersede drawing notes that describe part restraint necessary to measure parts that are subject to variation in the free state.

If a measurement is carried out with a measuring force exerted on the part other than zero, its result should be corrected accordingly. A correction, however, is not always required for parts where the measurement force exerted is not sufficient to interfere with the accuracy of measurements as they pertain to part function.

7.7 Handling

Where appropriate, it is recommended that gages be insulated against the warmth of the hand of the user as this is likely to significantly affect the gage dimensions.

8 FIXTURES

8.1 General

There are two common types of fixtures. The first is designed to hold and seat the workpiece during manufacture. The second is designed as a checking fixture used to hold (when appropriate) and seat the workpiece during inspection.

8.2 Similarities to Gages

Fixtures and gages share the same datum feature element representation. Unlike gages, fixtures do not normally contain elements representing the controlled features.

8.2.1 Datums. Depending on the specified material condition, part features are represented by simulated datum features using standard gage components (off-the-shelf, catalogue listed), such as collets, arbors, pins, bushings, etc. Datum target points are contacted by spherical locators, datum target lines by tangent surfaces on dowel pins, datum target areas by rest pads or jig legs, and part datum feature planar surfaces by ground tool stock.

Dimensions locating and interrelating part features originate from the datum reference frames specified on the workpiece drawing. Dimensions that locate and interrelate gage elements originate from simulated datum features (fixtures), also identified as datums in accordance with ASME Y14.5-2009 on gage drawings. Parts and gages have corresponding basic dimensions, geometric characteristics, and datum references. As on part drawings, datum features on gages shown perpendicular, coaxial, or symmetrical to each other shall be controlled for location or orientation to avoid incomplete drawing specifications.

Measurement uncertainty (set-up error) can occur when form and other geometric tolerances are not specified to refine and interrelate part and gage datum features. Tolerance stack-ups and candidate reference frames (see ASME Y14.5.1M) occur when part location in three-dimensional space is uncertain due to inaccurate part or gage datum features.

Gage fixture features shall make physical contact with or engage part datum features, and contact or engagement shall be maintained and verified before other part features are gaged. Verification of physical contact or engagement shall be included in the design of functional gages.

8.2.2 Overriding Constraints. Fixtures, although not usually as costly as gages, require an initial investment of capital to design and construct. It is assumed that a fixture will pay for itself over time by making workpiece fabrication and measurement faster and more accurate.

8.2.3 Repeatability. As with other tools used to assist in the manufacture and inspection of workpieces, repeatability of measurement is greatly affected by the form and orientation of the elements of the fixture that contact the datum features on the part. The better the form and orientation, and the less times a part is removed from the fixture between measurements, the more repeatable the measurements.

8.3 Differences From Gages

The only difference between a fixture and a gage is that the fixture contains no elements to represent the controlled features. It is constructed with gage or fixture elements that represent the part's datum features but none of the controlled features, and may include clamping elements where appropriate. It is understood that, unlike a gage, a checking fixture will be required to be used in conjunction with some method of collecting variables data, such as a computer-controlled coordinate measuring machine.

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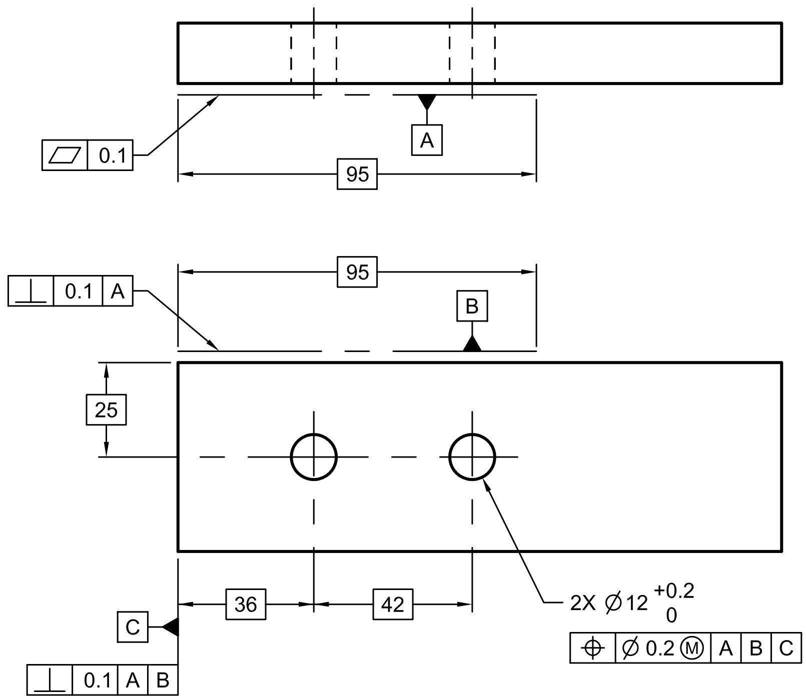
MANDATORY APPENDIX I
ILLUSTRATIONS OF GAGING POLICY

The figures in this Mandatory Appendix are intended only as illustrations of gaging applications and policies. The absence of a figure illustrating the desired application is neither reason to assume inapplicability nor basis for drawing rejection. In some instances, the figure shows added detail for emphasis; in other instances, the figure is incomplete by intent.

Fig. I-1 Workpiece for Gaging Policy Examples

WORKPIECE



Inner Boundary	
MMC Hole	12.0
− Geo Tol at MMC	− 0.2
Inner Boundary Hole	11.8

Outer Boundary	
LMC Hole	12.2
+ Geo Tol at LMC	+ 0.4
Outer Boundary Hole	12.6

WORKPIECE APPLIED TO GAGE

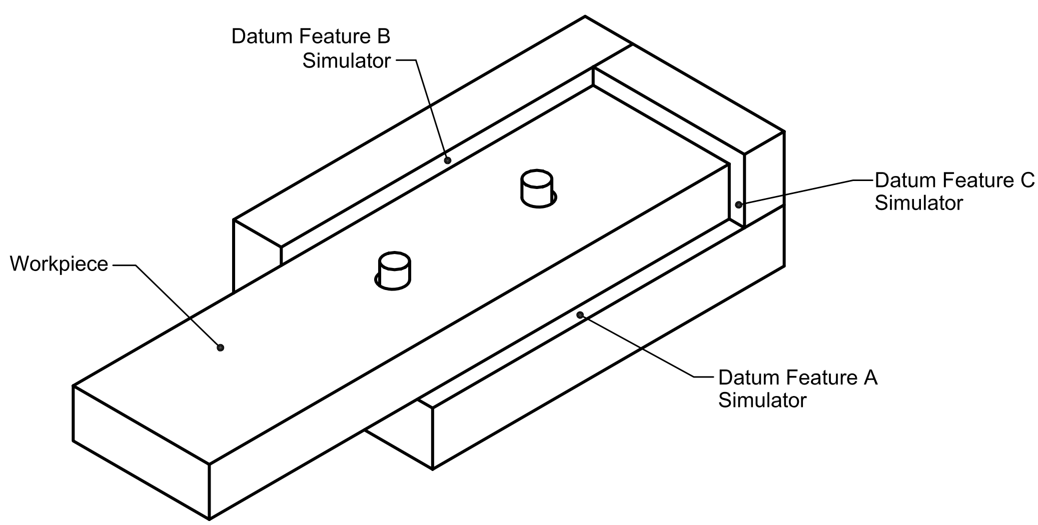
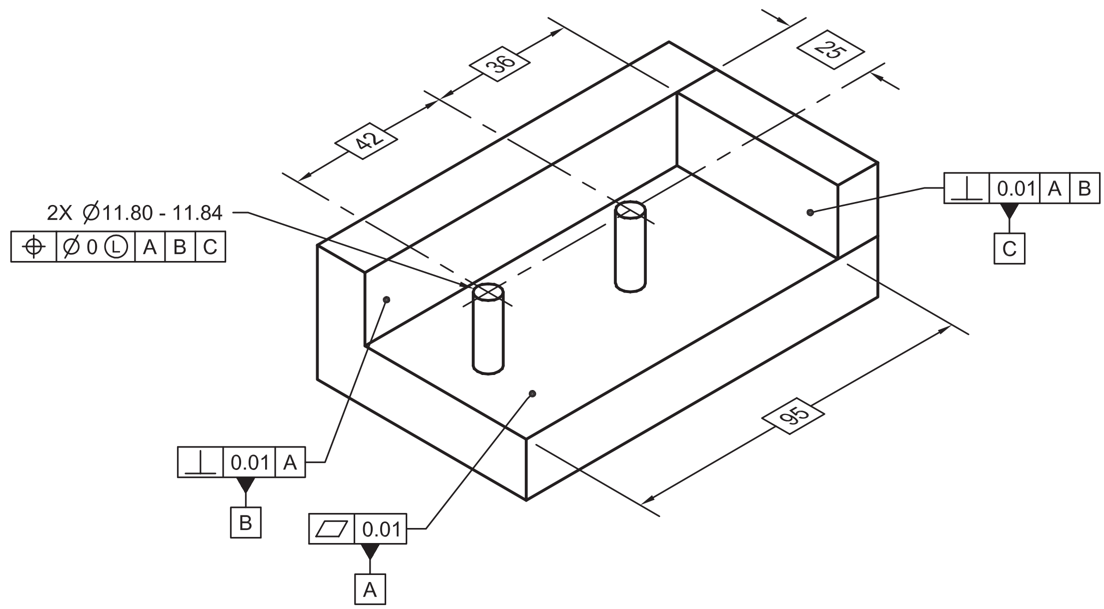


Fig. I-2 Absolute Gaging Policy Example

ABSOLUTE TOLERANCING GAGE



Inner Boundary	
Ø LMC Gage Pin	11.8
− Geo Tol at LMC	− 0
Ø Inner Boundary Gage Pin	11.8

Outer Boundary	
Ø MMC Gage Pin	11.84
+ Geo Tol at MMC	+ 0.04
Ø Outer Boundary Gage Pin	11.88

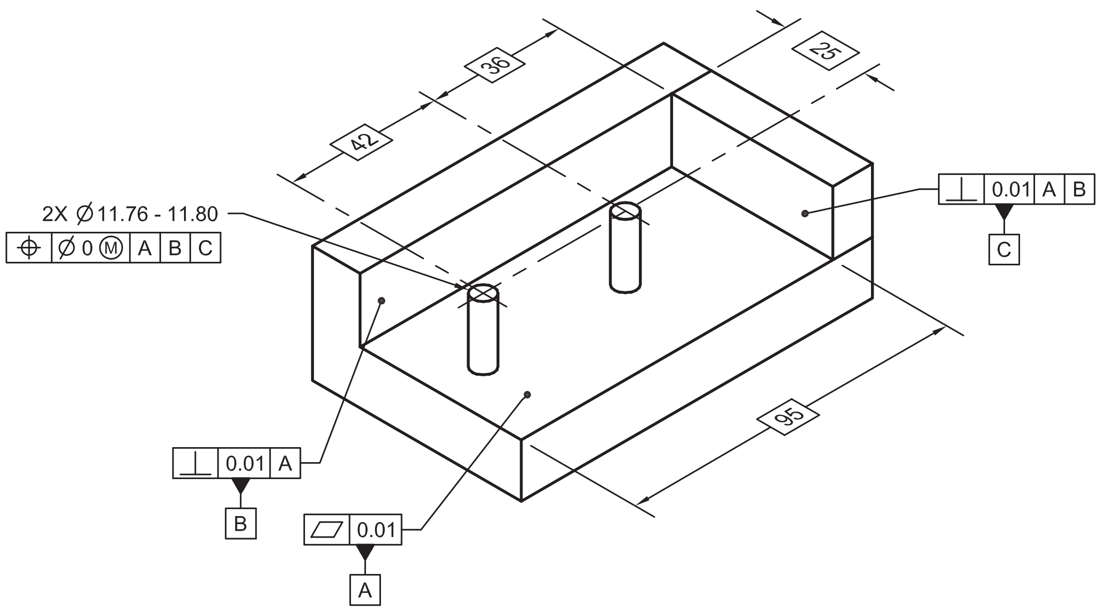
Since the inner boundary of the holes being gaged is not larger than the inner boundary of the gage pin, no out-of-tolerance workpieces will be accepted by the gage.

4.3.1

Fig. I-3(a) Optimistic Gaging Policy Example

Fig. I-3(a)

OPTIMISTIC TOLERANCING GAGE



EXAMPLE 1: Not Quite Optimistic.

Inner Boundary	
⌀ LMC Gage Pin	11.76
− Geo Tol at LMC	− 0.04
⌀ Inner Boundary Gage Pin	11.72

Outer Boundary	
⌀ MMC Gage Pin	11.8
+ Geo Tol at MMC	+ 0
⌀ Outer Boundary Gage Pin	11.8

Technically, since the outer boundary of the gage pin is not bigger than the inner boundary of the hole being gaged, no good (in-tolerance) workpiece will be rejected by the gage pin. But, since most would agree that a 11.8 diameter pin will not fit into a hole made at its 11.8 diameter inner boundary, the following option is called Optimistic.

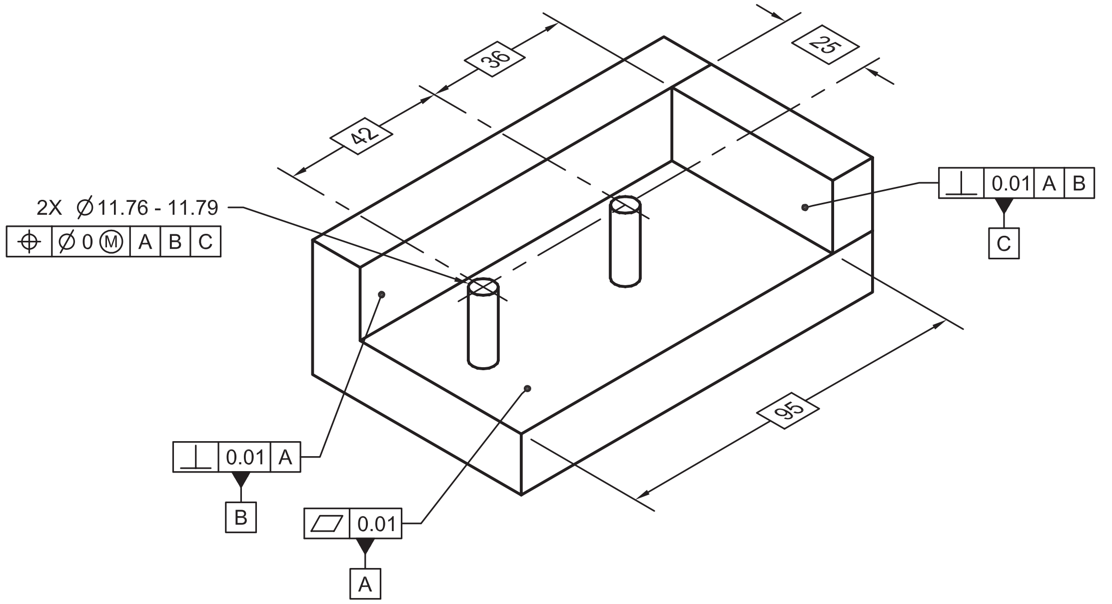
See Fig. I3(b) for Example 2.

4.3.2

Fig. I-3(b) Optimistic Gaging Policy Example

Fig. I-3(b)

OPTIMISTIC TOLERANCING GAGE



EXAMPLE 2: Optimistic.

Inner Boundary	
Ø LMC Gage Pin	11.76
− Geo Tol at LMC	− 0.03
Ø Inner Boundary Gage Pin	11.73

Outer Boundary	
Ø MMC Gage Pin	11.79
+ Geo Tol at MMC	+ 0
Ø Outer Boundary Gage Pin	11.79

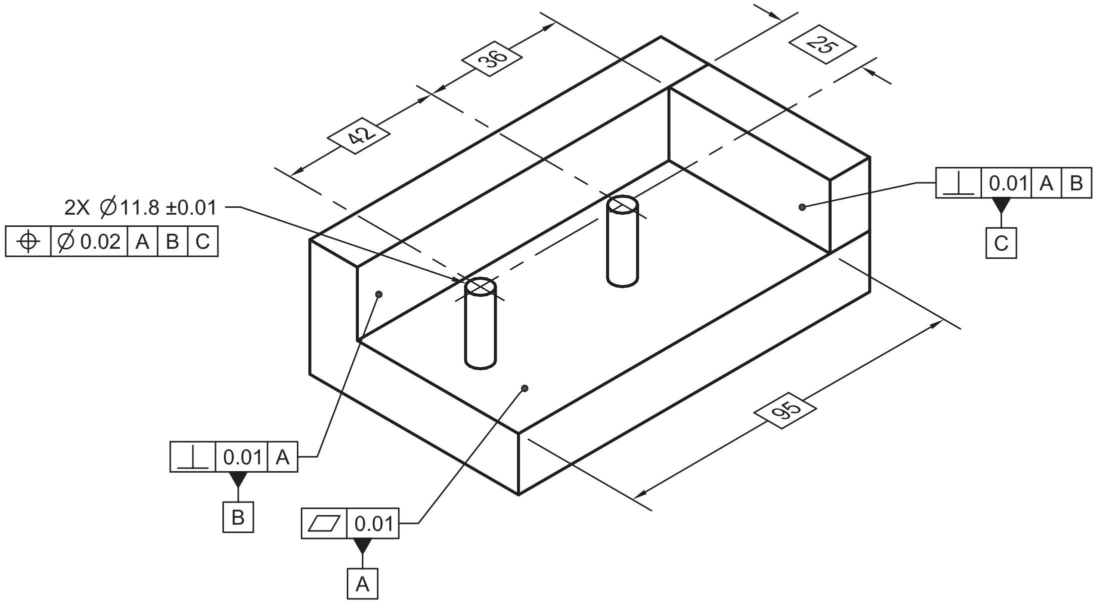
The amount of reduction of the outer boundary and the maximum material condition of the gage pin must be based on a careful consideration of how much reduction is necessary to assure that no borderline, technically in-tolerance, workpieces are rejected by the gage.

See Fig. I3(a) for Example 1.

5.2.6

Fig. I-4 Tolerant Gaging Policy Example

TOLERANT TOLERANCING GAGE



Inner Boundary

Ø LMC Gage Pin	11.79
− Geo Tol at LMC	− 0.02
Ø Inner Boundary Gage Pin	11.77

Outer Boundary

Ø MMC Gage Pin	11.81
+ Geo Tol at MMC	+ 0.02
Ø Outer Boundary Gage Pin	11.83

The inner boundary of the gage pin is smaller than the worst case acceptable hole. If the gage pin is produced at a size or condition that occupies less area around true position than the hole being gaged, the gage will accept a small percentage of out-of-tolerance workpieces. The MMC and the outer boundary of the gage pin is larger than the inner boundary of the hole being gaged. If the gage pin is produced at a size or condition that occupies more area around true position than the hole being gaged, the gage will reject a small percentage of in-tolerance workpieces.

4.3.3

MANDATORY APPENDIX II MATERIAL CONDITION EXPLANATION

Figure II-1 shows the differences between, as well as the advantages and disadvantages derived from, each material condition symbol. It is controlled with zero positional tolerancing at MMC to allow the total workpiece hole tolerance to be shown in the size requirements. Each hole diameter is 11.8 to 12.2. This will generate an inner boundary diameter for the hole of 11.8 (11.8 – 0) and an outer boundary of 12.6 (12.2 + 0.4). The difference between these two boundaries equals a tolerance of 0.8 (12.6 – 11.8) between the inner and outer hole boundaries.

Therefore, the gage pins, as shown in Fig. II-2, can be sized and geometrically controlled by 2 × 11.80 – 11.84 DIA with a zero positional tolerance at MMC. If the MMC modifier is used in the gage pin's feature control frame, it will generate an inner boundary for the gage pin of a diameter of 11.76 (11.80 − 0.04) and an outer boundary of 11.84 (11.84 + 0). The actual smallest gage pin diameter is 11.8.

For comparison, if the gage pins, as shown in Fig. II-3, were to use a positional tolerance of zero at LMC with the gage pin size limits remaining at 11.80 to 11.84, each gage pin will generate an inner boundary diameter of 11.8 (11.8 – 0) and an outer boundary diameter of 11.88 (11.84 + 0.04). The actual smallest gage pin diameter will be 11.8.

If a hole is produced that is in violation of its positional tolerance, it will most likely be rejected by either an MMC- or LMC-controlled gage pin, since the actual smallest gage pin diameter (in either the MMC- or LMC-controlled gage) is 11.8. However, in the MMC-controlled gage pin, because of its allowed movement (bonus tolerance) as it departs from MMC, there is a remote possibility that a technically bad part may be accepted. If, for example, an 11.8 hole is produced out of position (which violates its zero at MMC tolerance) by the same amount and in the same direction as its gage pin, the 11.8 gage pin may accept the hole. Any other type of hole movement will cause the gage pin's outer boundary and physical size to interfere and the hole will be rejected.

In an LMC-controlled gage pin, since the inner boundary of the gage pin is not smaller than the inner boundary of the hole on the workpiece, an out-of-tolerance workpiece hole will not be accepted even in the most favorable position.

However, since an LMC-controlled gage pin will generate an outer boundary diameter of 11.88, a greater number of technically in-tolerance workpiece holes will be rejected by the gage than will be rejected by an MMC-controlled gage pin (since the MMC-controlled gage pin's outer boundary diameter will be only 11.84).

Therefore, a small statistical possibility exists that an MMC-controlled gage pin may accept an out-of-tolerance workpiece hole. This possibility is much smaller than if the gage pin had been given a size tolerance that allowed it to be smaller than the MMC concept virtual condition boundary of the hole being inspected. Much larger than the possibility of an MMC-controlled gage pin accepting out-of-tolerance workpieces is the possibility that an LMC-controlled gage pin will reject a greater percentage of workpieces that are in tolerance than an MMC-controlled gage pin will. This increased possibility that in-tolerance workpieces may be rejected by an LMC-controlled gage pin exists because outer boundaries of gage pins are more likely encountered than inner boundaries by holes being inspected, and the LMC-controlled gage pin generates a larger outer boundary than the MMC-controlled gage pin.

In both MMC- and LMC-controlled gage pins, the total tolerance used by the gages discussed in this section is the same: the MMC-controlled gage pin uses the tolerance difference between the 11.84 and 11.76 diameter boundaries it generated, while the LMC-controlled gage pin uses the tolerance difference between the 11.88 and 11.80 diameter boundaries it generated. In each case, the total tolerance used is a diameter of 0.08. This is 10% of the tolerance between the 12.6 outer boundary and 11.8 inner boundary generated by the hole on the workpiece to be gaged. Since the total tolerance used by both the MMC- and LMC-controlled gages is the same, the cost of manufacturing the gages is assumed to be the same.

Gages controlled with RFS shall also be considered. The same workpiece shown in Fig. II-1 may be gaged using gage pins controlled at RFS. This gage option may not use a zero positional tolerance, since no bonus tolerance is to be derived by a departure from either MMC or LMC gage pin sizes. Therefore, the gage pin size tolerance will be reduced by the portion of the tolerance that will be put into the feature control frame to replace the zero tolerance. For example, as shown in Fig. II-4, if the gage pin size tolerance is a diameter of 11.80 to 11.82, then a positional tolerance of 0.02 RFS may be used in the feature control frame. If no axial out of straightness is experienced by the gage pin, then the gage pin will generate an inner boundary of a diameter of 11.78 (11.80 − 0.02) and an outer boundary of 11.84 (11.82 + 0.02). As with the MMC- and LMC-controlled gage tolerancing concepts, the actual smallest gage pin diameter is 11.8. This method only uses a diameter of 0.06 gage tolerance (11.84 − 11.78). This is less tolerance than is available to either the MMC- or the LMC-controlled gages (which both have a range of 0.08). This RFS-controlled gage is therefore theoretically more expensive to manufacture than the MMC- or LMC-controlled gages described. As with the MMC concept gage, a remote possibility exists that an RFS-controlled gage pin moving in the same direction as the hole being gaged could accept an out-of-tolerance hole.

Fig. II-1 Workpiece for Material Condition Modifier Examples

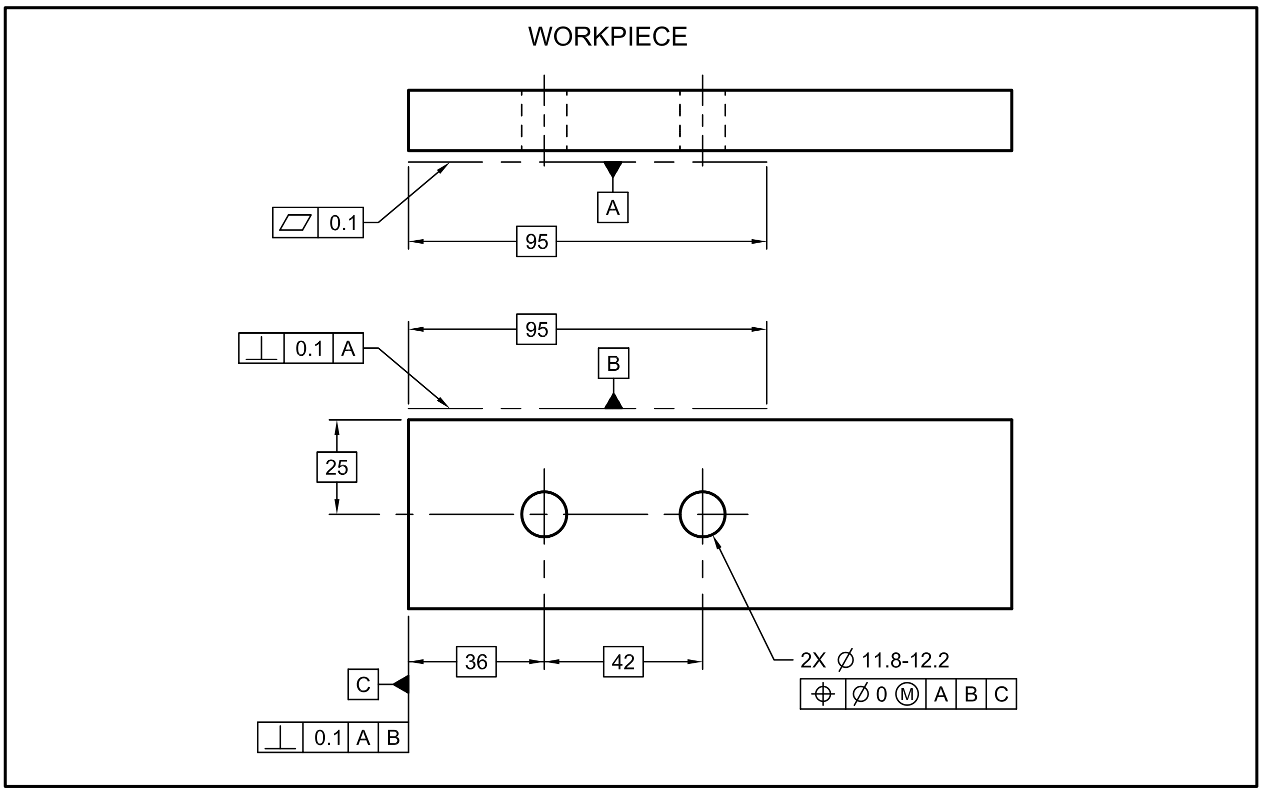


Fig. II-2 MMC Modifier for Gages

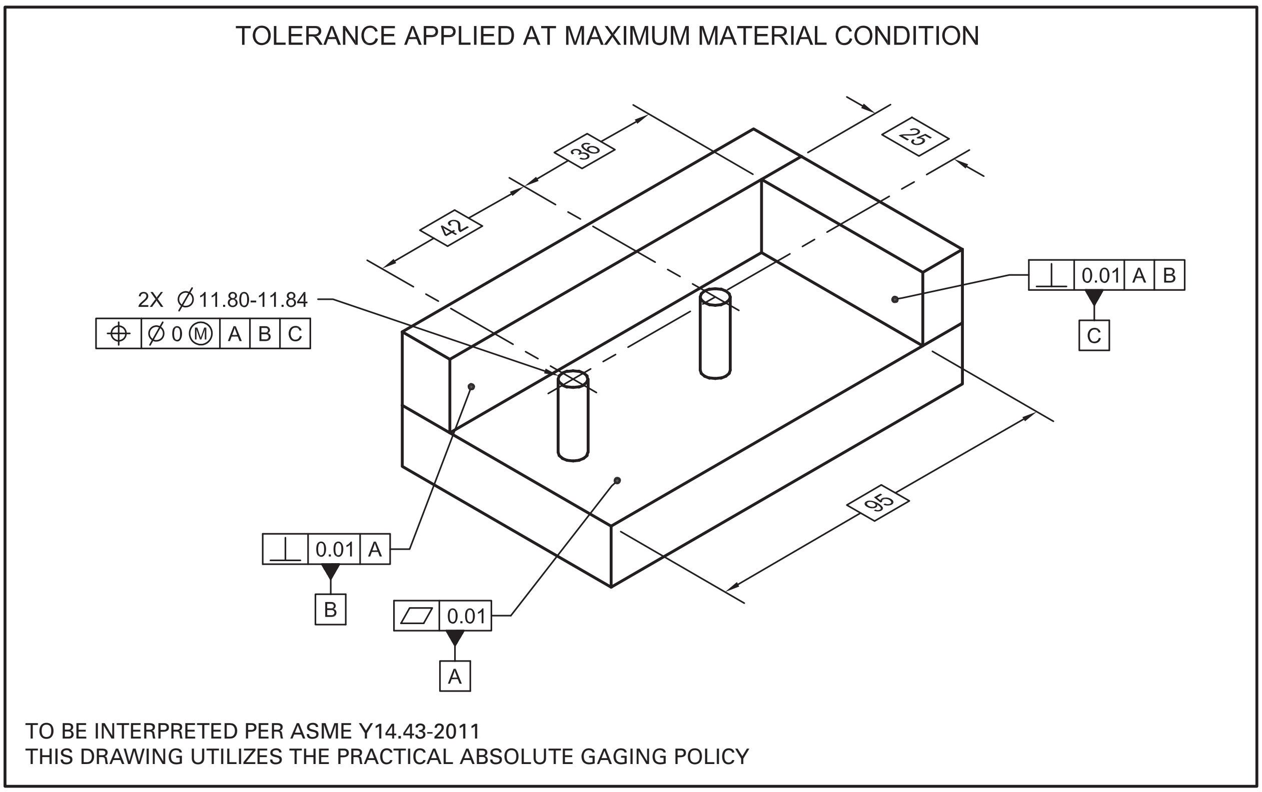


Fig. II-3 LMC Modifier for Gages

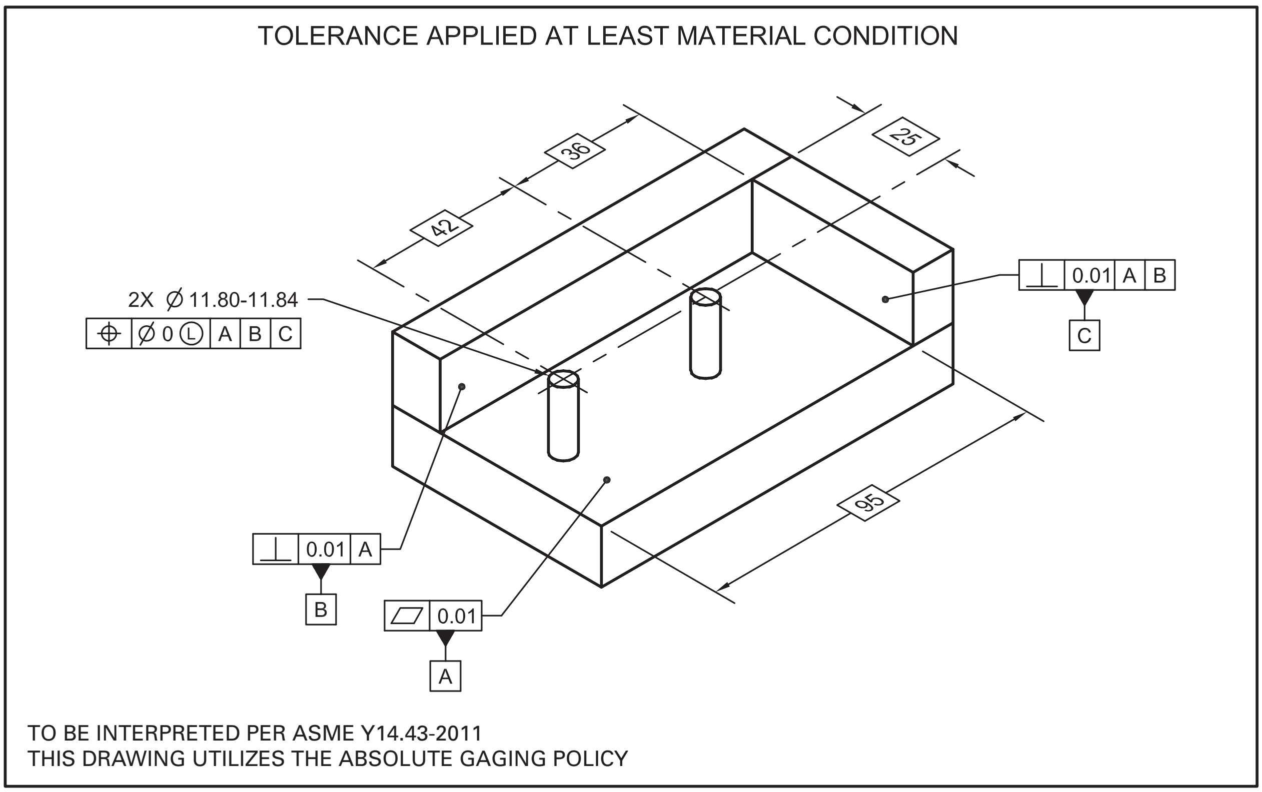
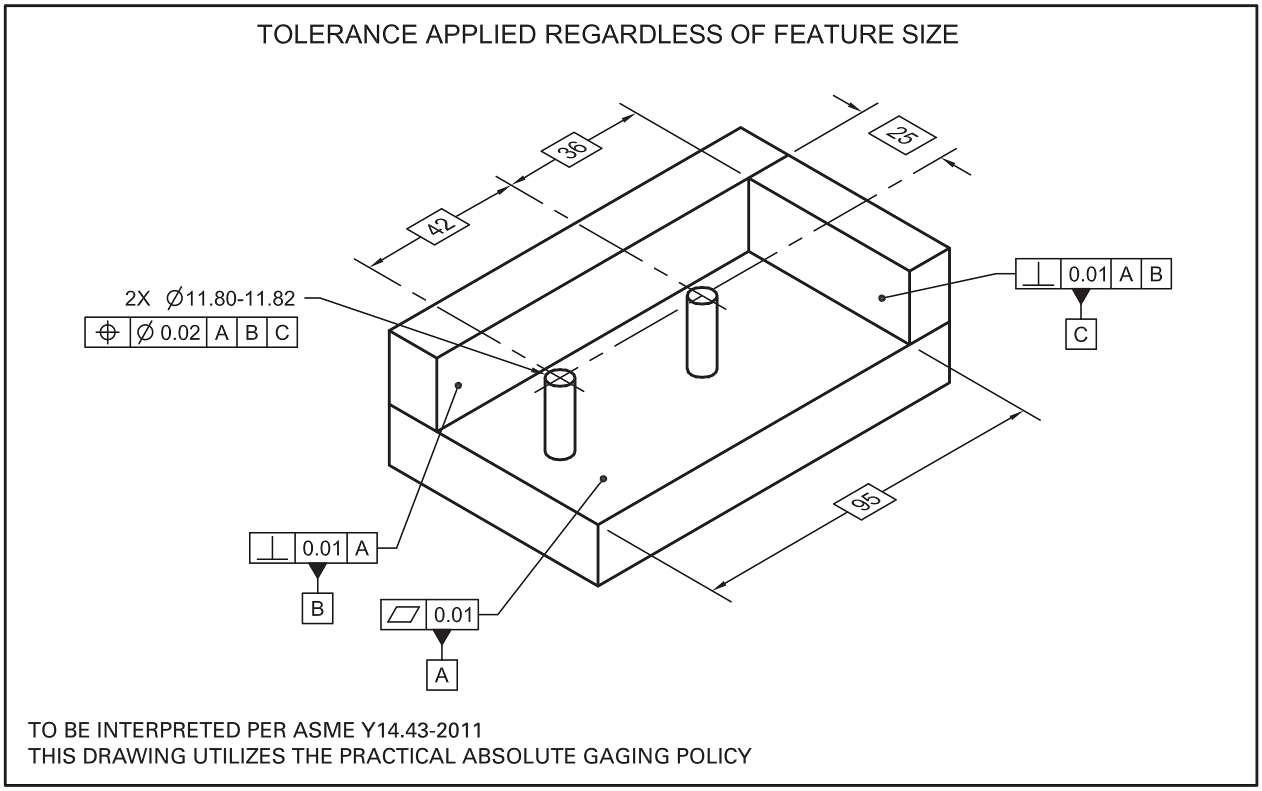


Fig. II-4 RFS Modifier for Gages



NONMANDATORY APPENDIX A
EXAMPLES OF GAGE CHARACTERISTICS

A-1 CHARACTERISTICS

The characteristics of a gage are based on how the designer chooses to apply the different principles available, such as gaging policy, percent of workpiece tolerance used, material condition modifier, and wear factor allowance. With all these choices available, it is possible for a single workpiece drawing to provide the basis for several gages to be designed with different characteristics. Different gages developed from a single workpiece might include a shop floor gage, a referee gage, and a master gage, with each gage requiring a higher degree of accuracy. Understanding these different principles will aid the gage designer with the task of designing a gage to perform a specific functional requirement. It is mandatory for each gage drawing to identify the functional characteristics of the gage using drawing notes, associated documentation, or marking on the gage to fully describe these specific requirements. Tables A-1 through A-3 and Figs. A-1 through A-4(f) show gage design examples based on different functional characteristics from the use of various policies, material conditions, and wear allowance.

A-2 GAGING POLICY

The gaging policy should be the first decision made, as this will define the functional acceptance characteristic of the gage. Other gage design decisions will be developed in support of the desired policy.

The choices are absolute, practical absolute, tolerant, and optimistic policies.

The absolute policy is intended to ensure that no out-of-tolerance part is accepted by the gage. To do this, the worst-case inner boundary of the gage pin shall be equal to or larger than the MMC/virtual condition of the workpiece hole. [See Tables A-2 and A-3, and Figs. A-3(a) through A-4(f).]

The practical absolute policy is designed to apply a statistical probability to the principle of never accepting a noncompliant part, while recognizing the slight chance of accepting a noncompliant part. [See Table A-1 and Figs. A-2(a) through (d).]

The tolerant policy is a designed condition where the tolerances are assigned to fall between the acceptable/rejectable limits. Unlike the practical absolute policy, which requires that a very specific set of circumstances occur in order to accept a noncompliant workpiece, the tolerant method is designed to allow a much larger set of circumstances to occur and is more likely to accept noncompliant workpieces. It is also possible that a gage designed to the tolerant policy and built near the upper tolerance range will not accept any noncompliant workpieces and reject only a small number of compliant workpieces. (See Tables A-2 and A-3.)

The optimistic policy may be used when no compliant workpieces are to be rejected and the acceptance of borderline noncompliant parts will not be detrimental to the final product. (See Tables A-2 and A-3.)

Wear allowance and the effect of the material modifiers shall be considered in the design of all gages.

A-3 PERCENT OF WORKPIECE TOLERANCE USED BY GAGE

The gage tolerance is based on a percentage of the workpiece tolerance (as defined by the difference between LMC and virtual condition). This percentage value is determined by the gage designer and may vary from one gage to another as function changes. This Standard uses 10% of the workpiece tolerance applied to the location of the gage pins as the basis in the figures contained herein. This 10% value is illustrated as either the total gage tolerance or the combination of gage tolerance plus wear allowance. The percentage value chosen for the gage tolerance is applied to the gage pin size tolerance with the location tolerance of position (TOP) of zero at MMC (or LMC). The gage pin location TOP, when used with the RFS method, will get a portion of the size tolerance applied to the location tolerance, since zero tolerance at RFS is not allowed.

There are two methods of gage tolerancing illustrated in this Nonmandatory Appendix.

The first method, called direct percentage, is when the gage tolerance (10%) is applied to the gage pin size with the location TOP of zero at MMC or LMC. The effects of bonus tolerance being added to the specified tolerance will increase the boundary beyond the original percentage value. When RFS is applied, the specified tolerance causes the inner boundary to be less than the MMC pin diameter, which increases the boundary beyond the original percentage value. The use of the direct percentage method will create gages that yield a total tolerance boundary larger than the original percentage value. These gages intrude further into the workpiece tolerance, thus reducing the total acceptance range of the workpiece.

The second method, called adjusted boundary, is to select the desired tolerance percentage value as the total boundary for the gage and develop the resulting gage elements, including the effect of bonus and specified tolerance, within these values. When this method is used with the MMC, LMC, or RFS modifiers, it yields size and location tolerance values that are less than the direct percentage values. This is due to the addition of the bonus to the specified tolerance for the gage elements and may be more expensive to build. However, it does provide the largest remaining workpiece acceptance range and will reject fewer good parts.

A-4 MATERIAL CONDITION MODIFIER USED ON GAGE ELEMENTS

Selection of appropriate material condition modifiers is important in determining where the gage size elements fall within the gage tolerance range. Each modifier contributes a different characteristic to the gage and examples are shown in Figs. A-1 through A-4. Consideration should be given to understanding where the gage pin size occurs within the tolerance band. Inner and outer boundaries are also shown to indicate the total tolerance used by the gage.

A-5 WEAR ALLOWANCE

When gage element wear is considered a factor in the gage design, a percentage of the gage tolerance can be applied to increase the gage element lower size limit to account for wear. Wear allowance applied to a new gage will reject a larger number of good parts, and as it wears oward the lower size limit, will tend to accept more good parts. Minimum pin actual local size of the gage element shall be indicated on the gage so that the gage is removed from service or repaired when the wear limit of any element is reached. Wear allowance is shown in this Nonmandatory Appendix only with the absolute and practical absolute methods, but could be applied as desired to any of the other gaging policies.

Fig. A-1 Workpiece and Associated Gage

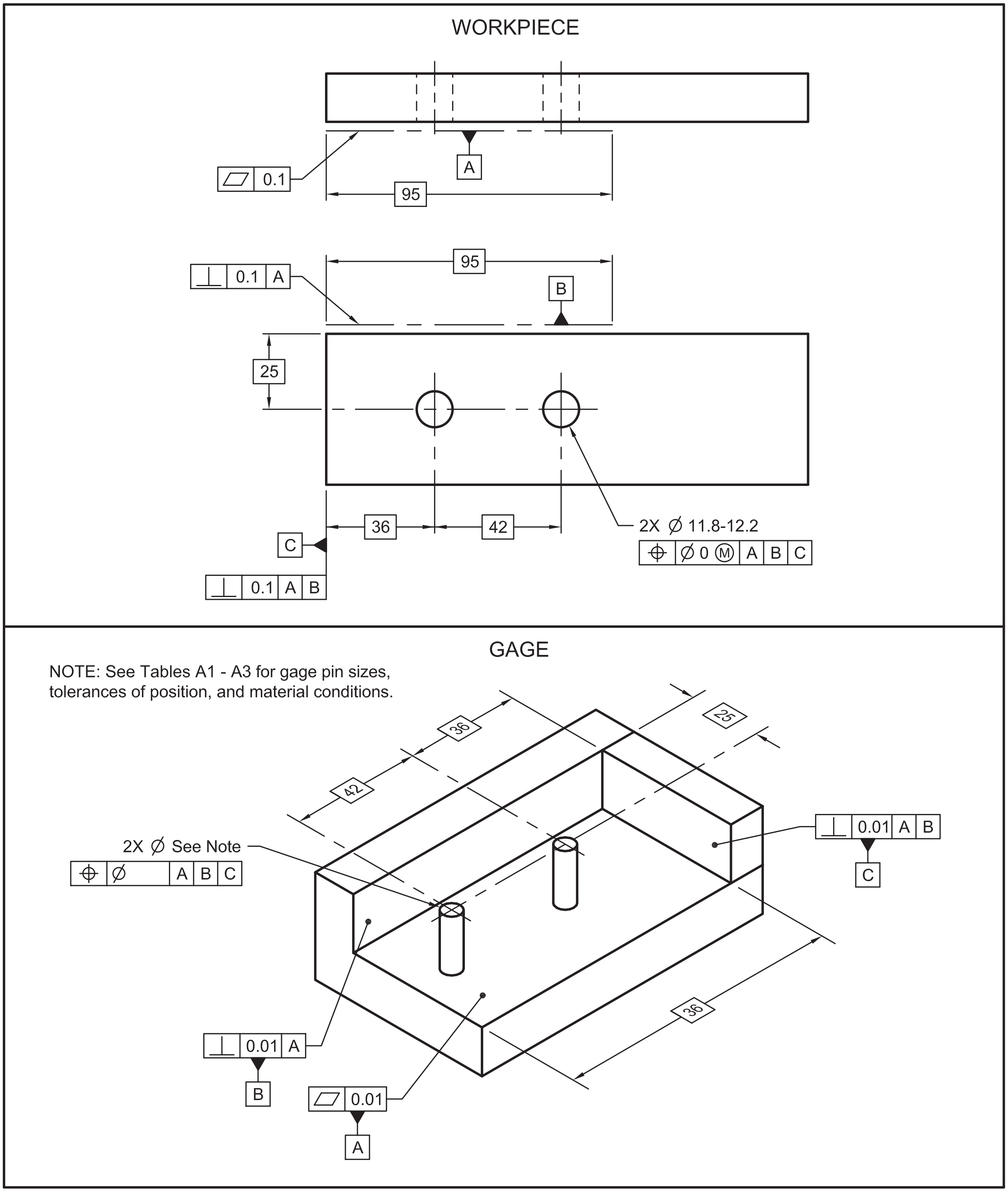


Fig. A-2(a) Practical Absolute — Direct Percentage Tolerance Method

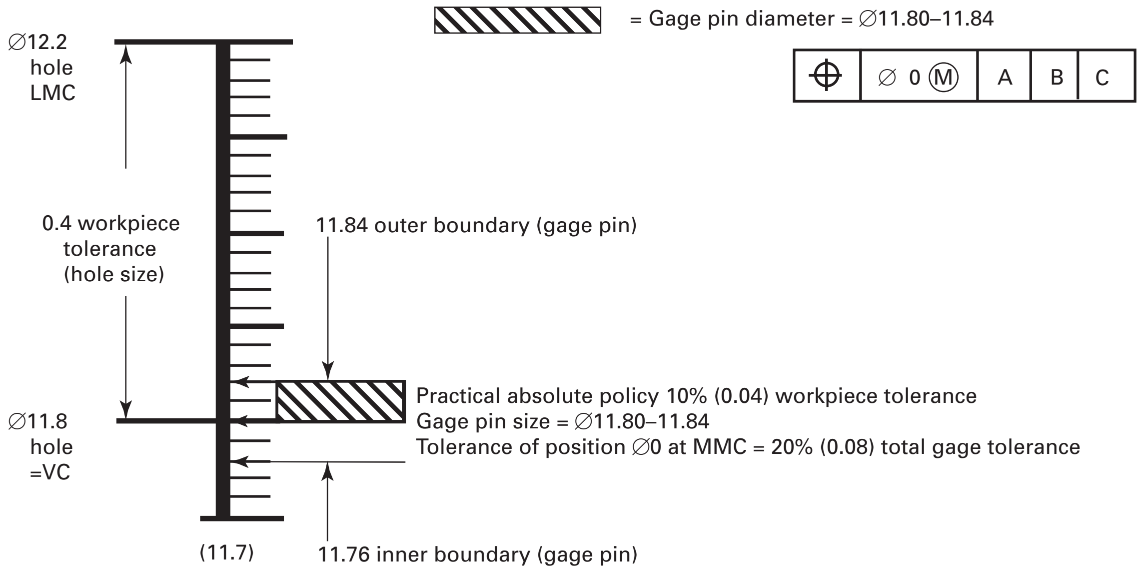


Fig. A-2(b) Practical Absolute — Direct Percentage Tolerance Method

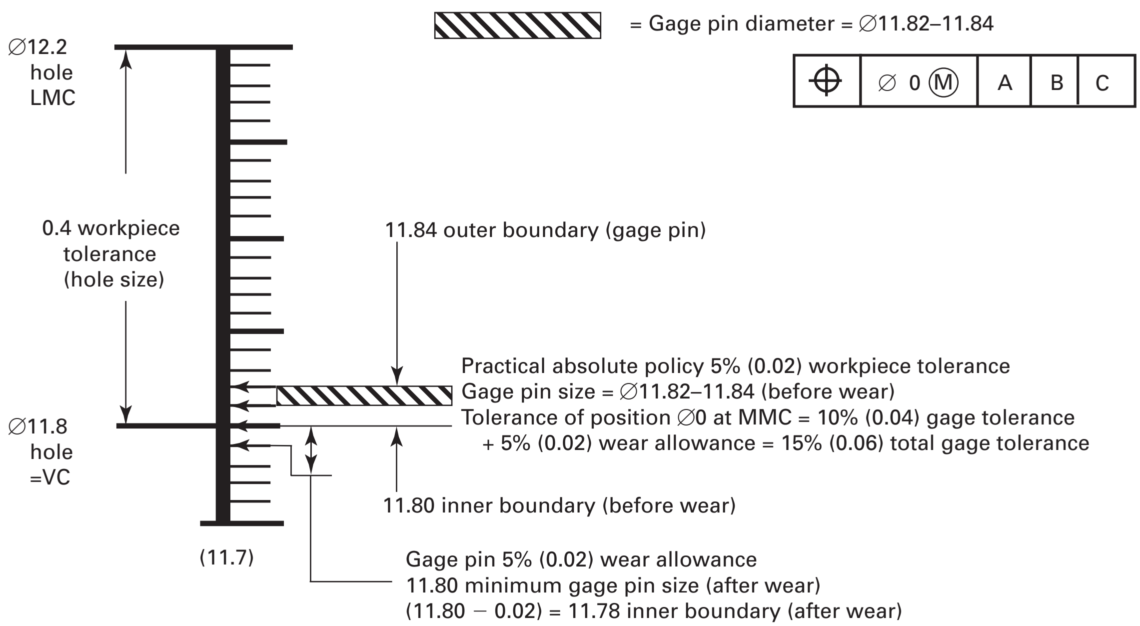


Fig. A-2(c) Practical Absolute — Direct Percentage Tolerance Method

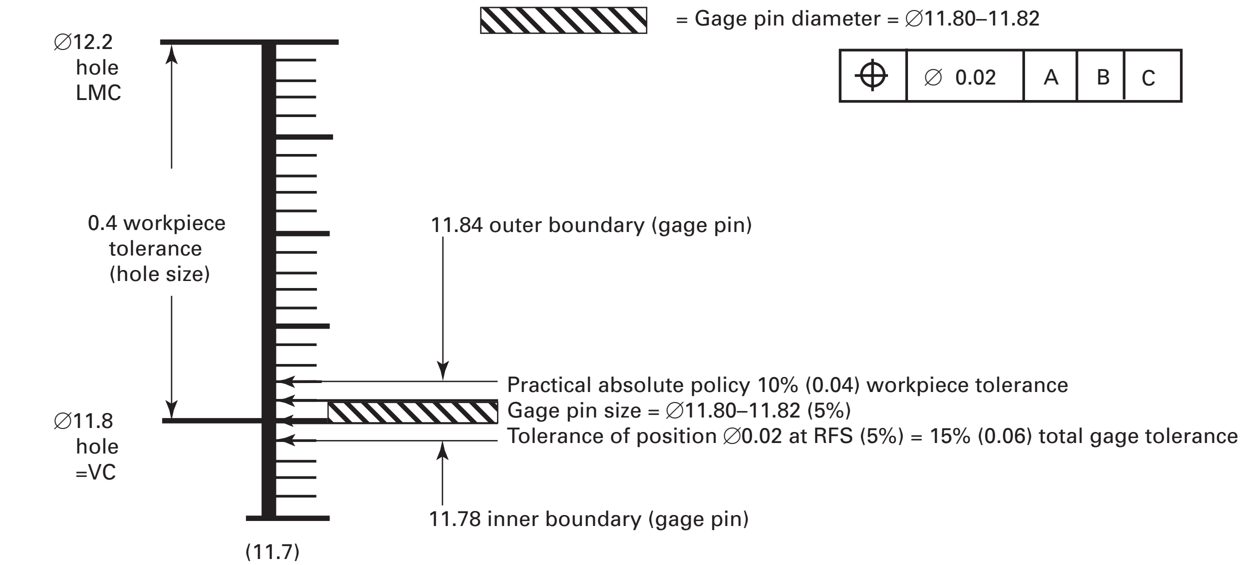


Fig. A-2(d) Practical Absolute — Direct Percentage Tolerance Method

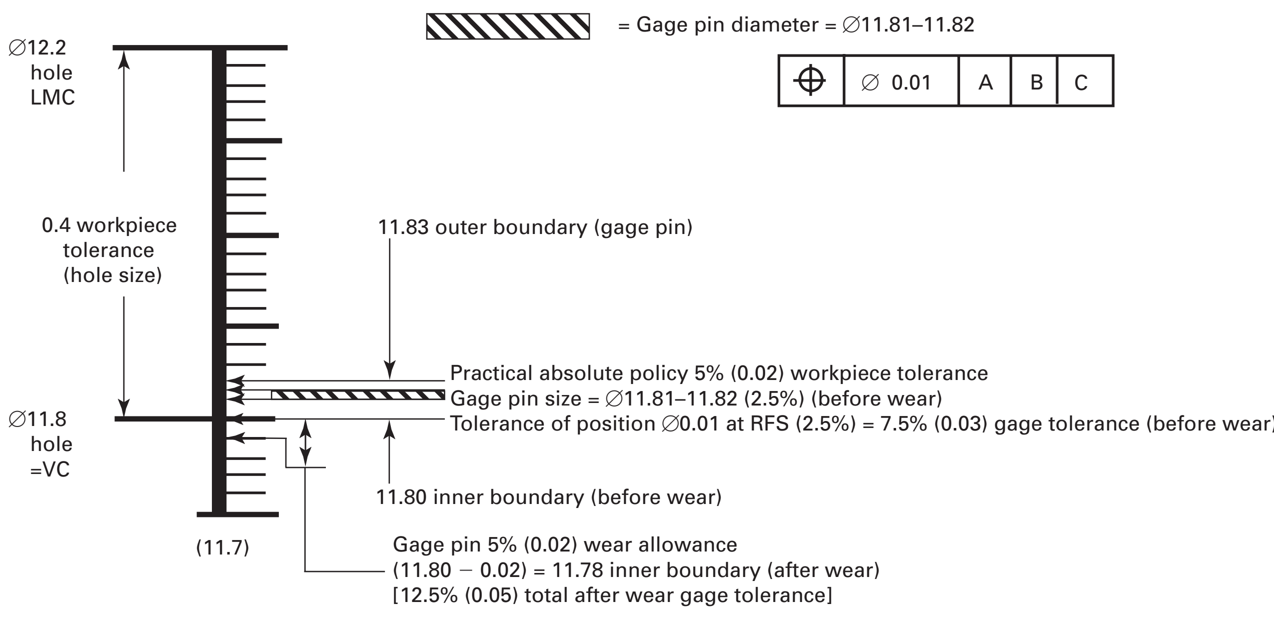


Fig. A-3(a) Absolute — Direct Percentage Based Gage Tolerance Method

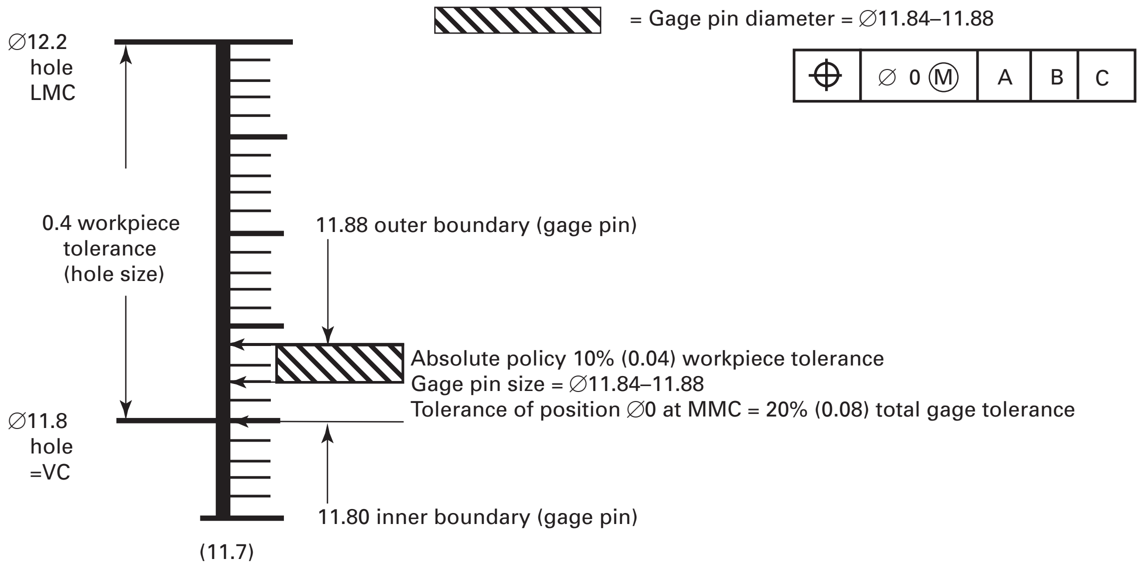


Fig. A-3(b) Absolute — Direct Percentage Based Gage Tolerance Method

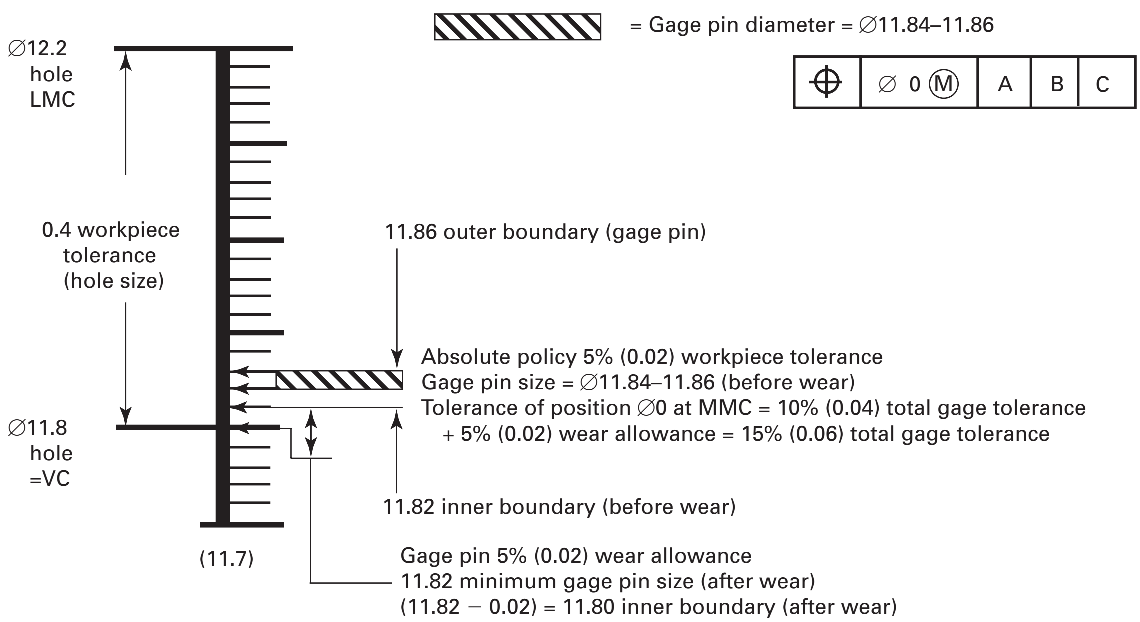


Fig. A-3(c) Absolute — Direct Percentage Based Gage Tolerance Method

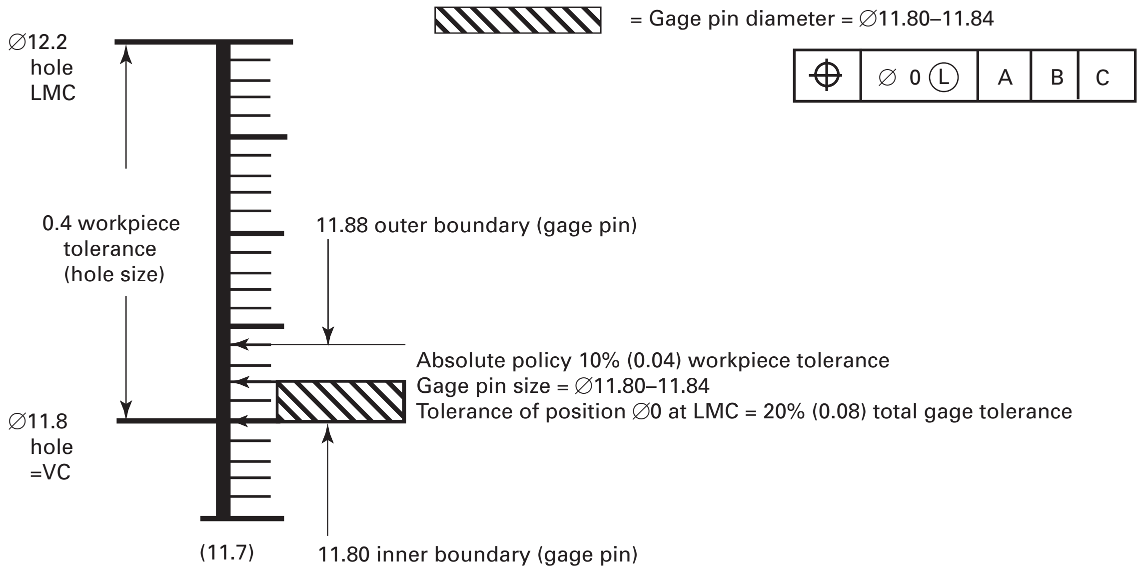


Fig. A-3(d) Absolute — Direct Percentage Based Gage Tolerance Method

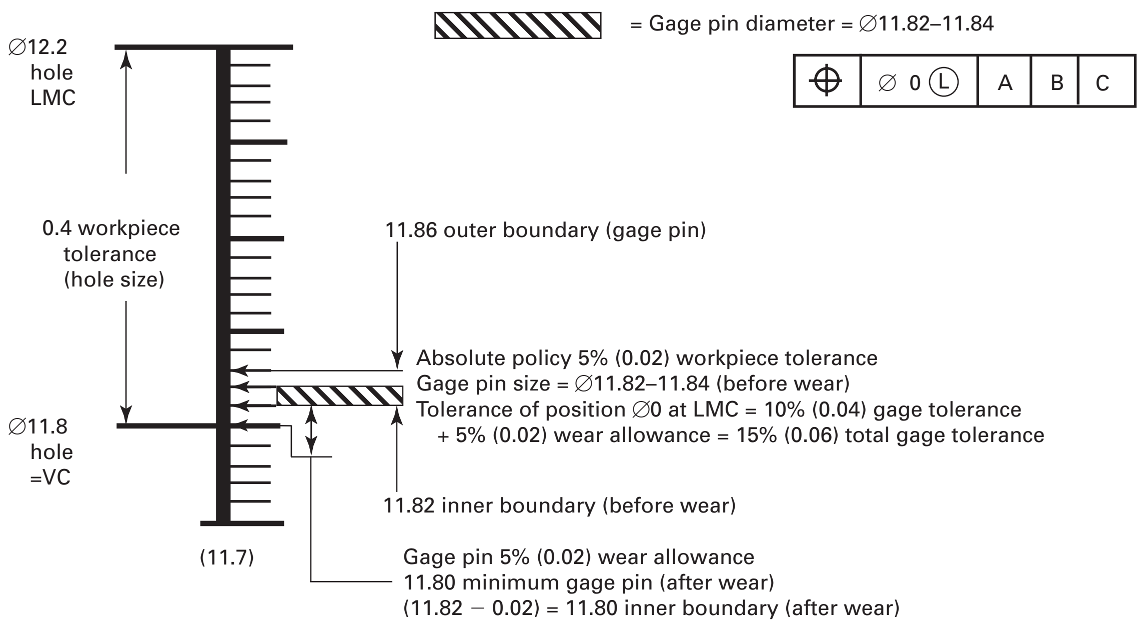


Fig. A-3(e) Absolute — Direct Percentage Based Gage Tolerance Method

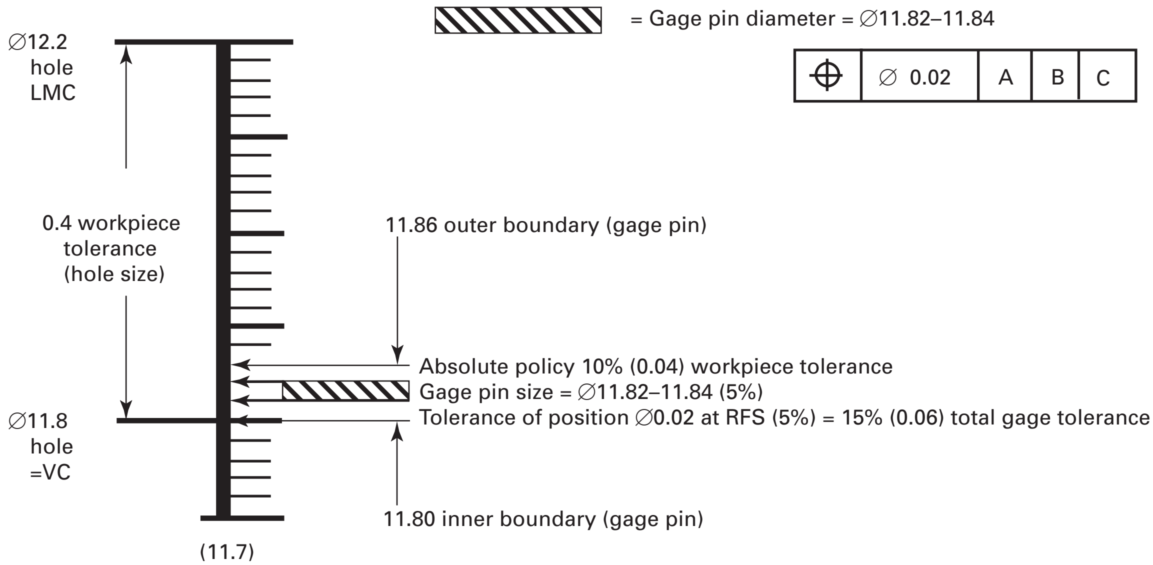


Fig. A-3(f) Absolute — Direct Percentage Based Gage Tolerance Method

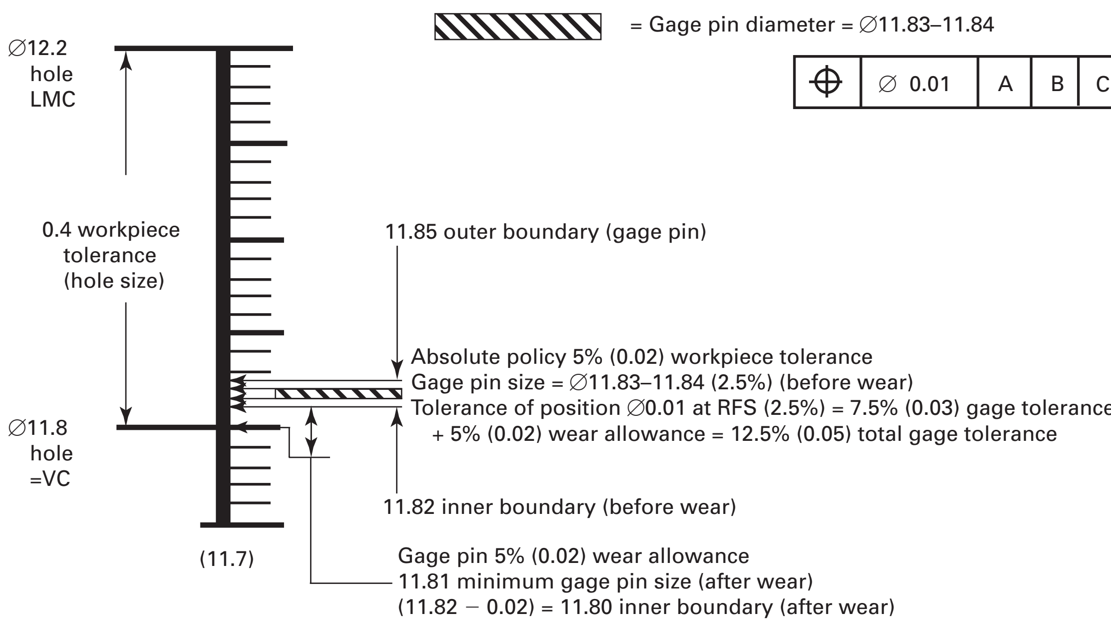


Fig. A-4(a) Absolute — Adjusted Boundary Based Gage Tolerance Method

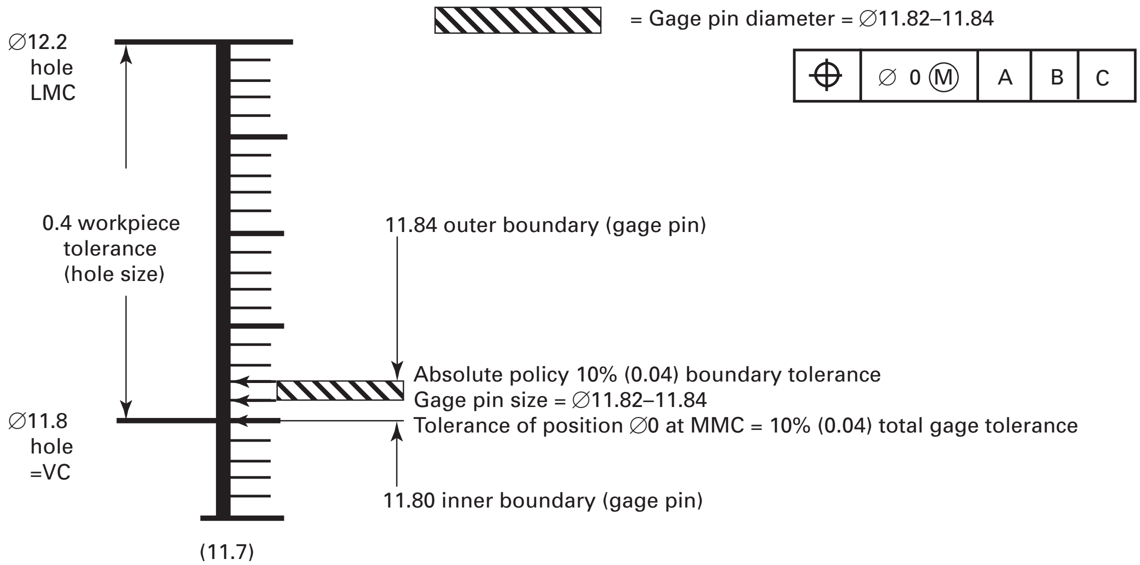


Fig. A-4(b) Absolute — Adjusted Boundary Based Gage Tolerance Method

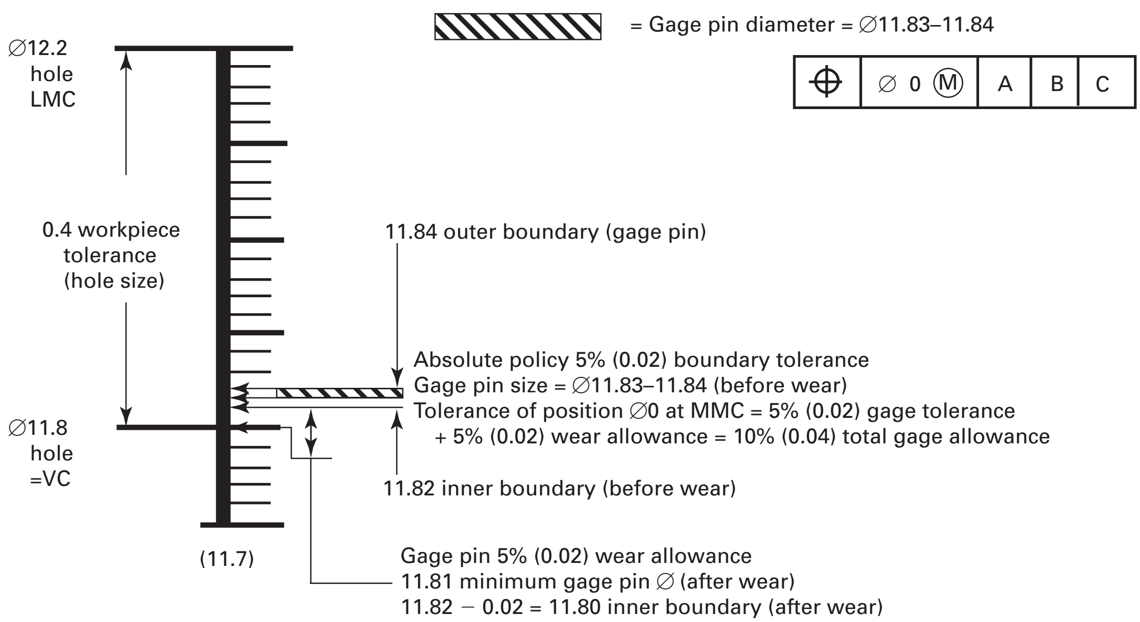


Fig. A-4(c) Absolute — Adjusted Boundary Based Gage Tolerance Method

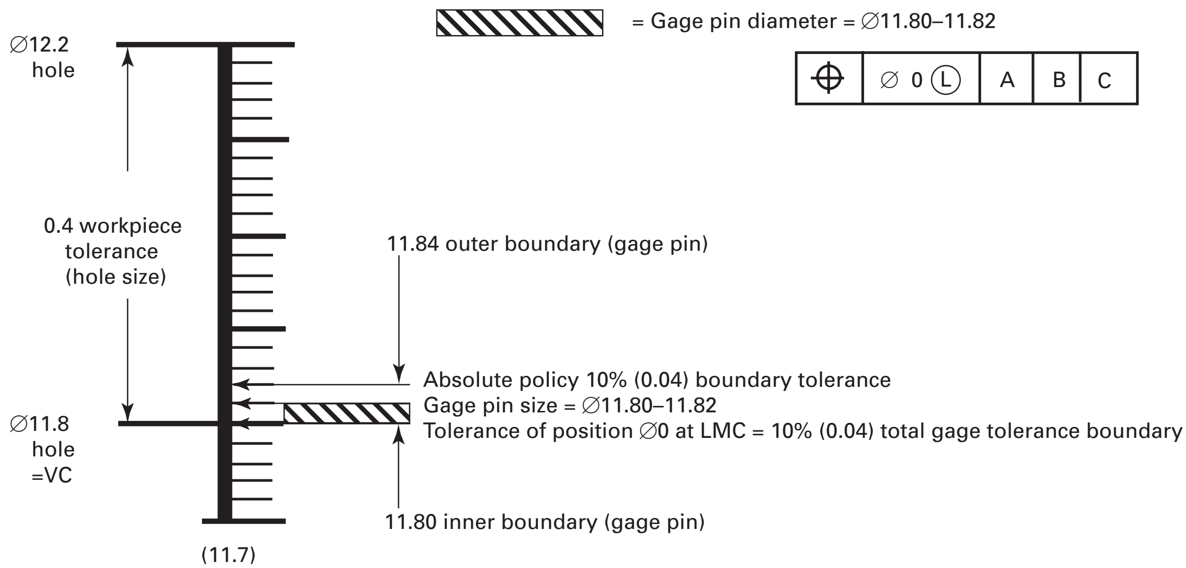


Fig. A-4(d) Absolute — Adjusted Boundary Based Gage Tolerance Method

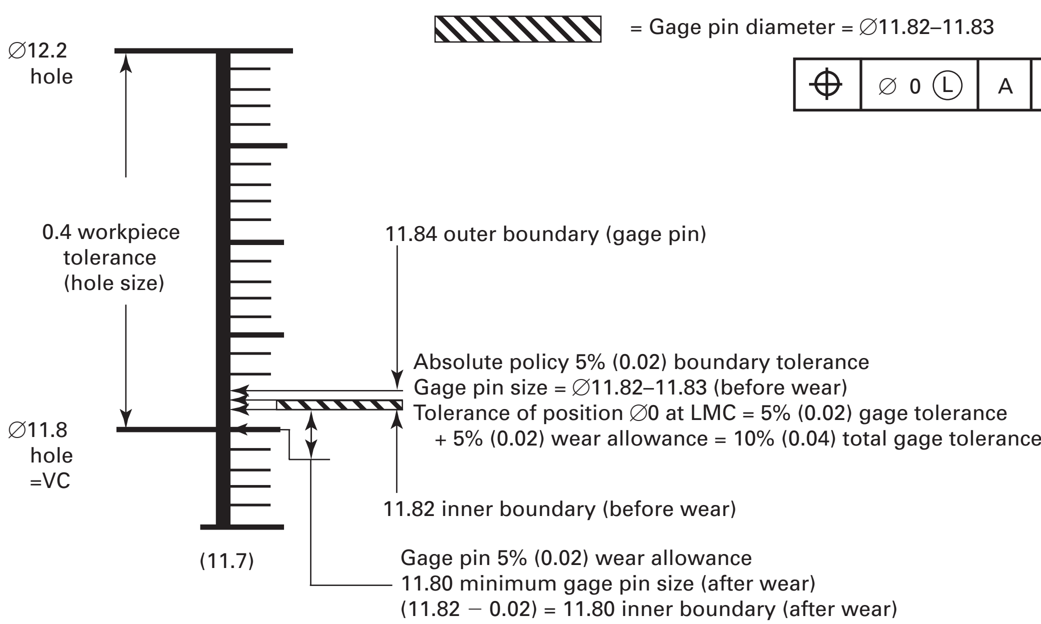


Fig. A-4(e) Absolute — Adjusted Boundary Based Gage Tolerance Method

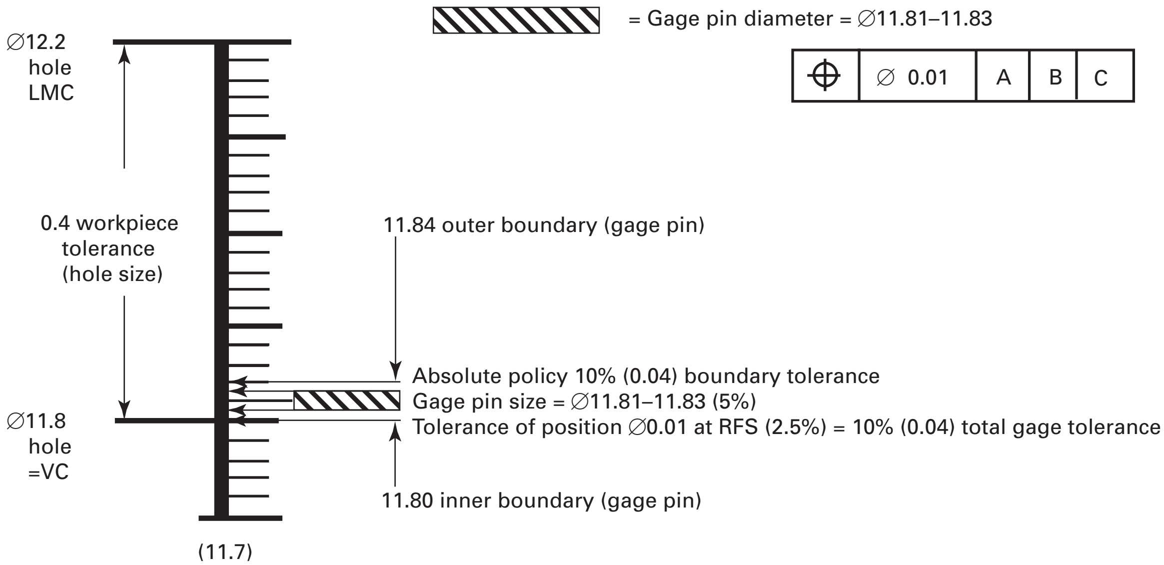


Fig. A-4(f) Absolute — Adjusted Boundary Based Gage Tolerance Method

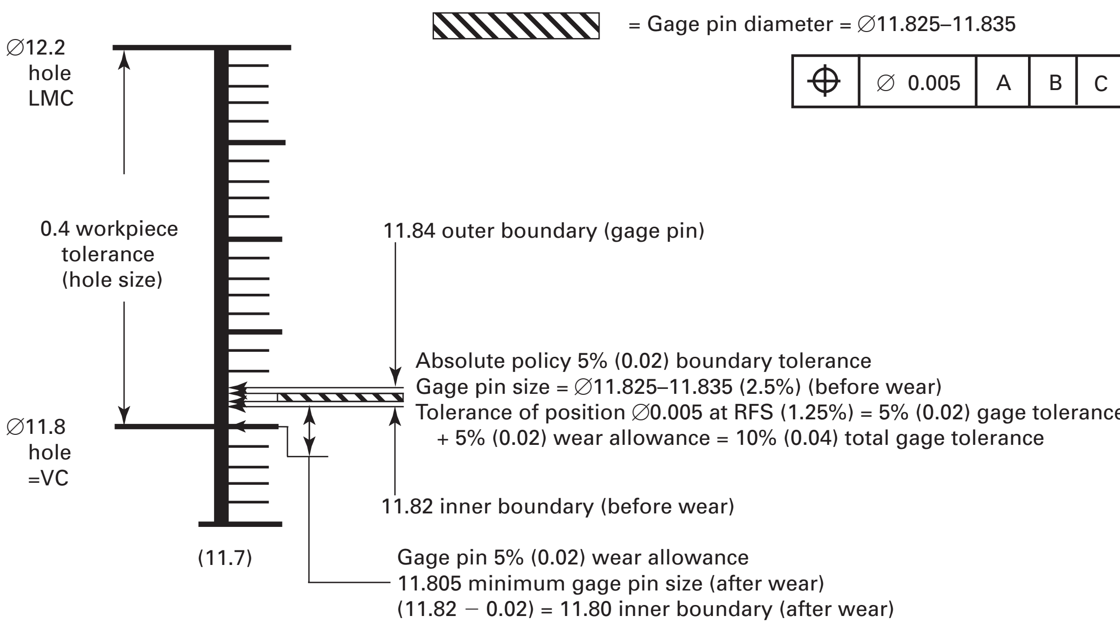


Table A-1 Practical Absolute Direct Percentage Tolerance Method

Gaging Policy	MMC	LMC	RFS
No wear allowance: (XX%) = total percent of workpiece size tolerance used by gage	Statistically based gage tolerance 0.04 (10% workpiece tolerance): Pin ∅ 11.80–11.84 TOP ∅ 0 (20%) [Note (1)] MMC 11.84 = ∅ 0 tol. LMC 11.80 = ∅ 0.04 tol. (OB = 11.84) (IB = 11.76) See Fig. A-2(a)	Statistically based gage tolerance 0.04 (10% of workpiece tolerance): Not recommended	Statistically based gage tolerance 0.04 (10% of workpiece tolerance): Pin ∅ 11.80–11.82 TOP ∅ 0.02 (15%) [Note (1)] MMC 11.82 = ∅ 0.02 tol. LMC 11.80 = ∅ 0.02 tol. (OB = 11.84) (IB = 11.78) See Fig. A-2(c)
With 5% wear allowance (added to pin inner boundary): (XX%) = total percent of workpiece size tolerance used by gage before wear allowance	Statistically based gage tolerance 0.02 (5% of workpiece tolerance): Pin ∅ 11.82–11.84 TOP ∅ 0 (10%) [Note (1)] MMC 11.84 = ∅ 0 tol. LMC 11.82 = ∅ 0.02 tol. (OB = 11.84) (IB = 11.80) See Fig. A-2(b)	Statistically based gage tolerance 0.02 (5% of workpiece tolerance): Not recommended	Statistically based gage tolerance 0.02 (5% of workpiece tolerance): Pin ∅ 11.81–11.82 TOP ∅ 0.01 (7.5%) [Note (1)] MMC 11.82 = ∅ 0.01 tol. LMC 11.81 = ∅ 0.01 tol. (OB = 11.83) (IB = 11.80) See Fig. A-2(d)

NOTE:

(1) The practical absolute policy [see Figs. A-2(a) through (d)] uses 10% (0.04) of the workpiece hole size tolerance (11.8–12.2) for the gage pin size tolerance (11.80–11.84). The gage pin minimum size limit is equal to the MMC/virtual condition of the workpiece, and by applying zero position at MMC, an inner boundary (11.76) is created that is smaller than the LMC gage pin/MMC hole (11.80). This allows a gage to be produced with an LMC pin (equal to workpiece virtual condition) with a location tolerance equal to the maximum bonus tolerance (0.04). This results in creating a gage pin inner boundary that falls below the virtual condition of the workpiece. The workpiece (using ∅0 positional tolerance at MMC) is required to have a perfectly located MMC hole. While this method appears to comply with the absolute policy of never accepting a bad part, it allows the gage to accept a noncompliant workpiece with an MMC/virtual condition hole that is mislocated in the same direction and amount (diameter of 0.04) as the gage pin. This method does not satisfy the intent of the absolute policy of not accepting out-of-tolerance parts because the inner boundary of the gage is allowed to be less than the workpiece virtual condition. This worst-case situation has a low probability of occurrence, (and should be used when a 100% compliant acceptance requirement is not mandatory, and the tolerant method is undesirable.) The practical absolute policy applied at zero tolerance at MMC is illustrated in figures shown in this Standard. Similar results can be obtained by dividing the tolerance between the gage pin size and the location tolerance applied at RFS. This results in only slightly reduced tolerances for the gage fabrication. The use of zero tolerance at LMC is not recommended because the statistical benefit is negated when LMC gage pin size is restricted to zero positional tolerance. The zero tolerance at LMC method is best applied in support of the absolute policy.
When a 100% compliant acceptance method is required, the absolute policy shall be used. The absolute policy [see Figs. A-3(a) through A-4(f)] of designing gages will mathematically support the policy of not accepting out-of-tolerance workpieces. The absolute policy extends the gage tolerance further into the workpiece tolerance, thus reducing the acceptance range of good parts. This may be offset slightly by the use of LMC modifier on the gage with the proper size tolerance. The same conditions described apply when wear allowance is applied.

Table A-2 Direct Percentage Gage Tolerance Method

Gaging Policy	MMC	LMC	RFS
Absolute			
No wear allowance: (XX%) = total percent of workpiece size tolerance used by gage	Direct percentage gage tolerance 0.04 (10% of workpiece tolerance): Pin ∅11.84–11.88 TOP ∅0 (20%) [Note (1)] MMC 11.88 = ∅ 0 tol. LMC 11.84 = ∅ 0.04 tol. (OB = 11.88) (IB = 11.80) See Fig. A-3(a)	Direct percentage gage tolerance 0.04 (10% of workpiece tolerance): Pin ∅ 11.80–11.84 TOP ∅ 0 (20%) [Note (1)] MMC 11.80 = ∅ 0 tol. LMC 11.84 = ∅ 0.04 tol. (OB = 11.88) (IB = 11.80) See Fig. A-3(c)	Direct percentage gage tolerance 0.04 (10% of workpiece tolerance): Pin ∅ 11.82–11.84 TOP ∅ 0.02 (15%) [Note (1)] MMC 11.84 = ∅ 0.02 tol. LMC 11.82 = ∅ 0.02 tol. (OB = 11.86) (IB = 11.80) See Fig. A-3(e)
With 5% wear allowance (added to pin inner boundary): (XX%) = total percent of workpiece size tolerance used by gage before wear allowance	Direct percentage gage tolerance 0.02 (5% of workpiece tolerance): Pin ∅ 11.84–11.86 TOP ∅ 0 (10%) [Note (1)] MMC 11.86 = ∅ 0 tol. LMC 11.84 = ∅ 0.02 tol. (OB = 11.86) (IB = 11.82) See Fig. A-3(b)	Direct percentage gage tolerance 0.02 (5% of workpiece tolerance): Pin ∅ 11.82–11.84 TOP ∅ 0 (10%) [Note (1)] MMC 11.82 = ∅ 0 tol. LMC 11.84 = ∅ 0.02 tol. (OB = 11.86) (IB = 11.82) See Fig. A-3(d)	Direct percentage gage tolerance 0.02 (5% of workpiece tolerance): Pin ∅ 11.83–11.84 TOP ∅ 0.01 (7.5%) [Note (1)] MMC 11.84 = ∅ 0.01 tol. LMC 11.83 = ∅ 0.01 tol. (OB = 11.85) (IB = 11.82) See Fig. A-3(f)
Tolerant			
No wear allowance: (XX%) = total percent of workpiece size tolerance used by gage	Direct percentage gage tolerance 0.04 (10% of workpiece tolerance): Pin ∅ 11.78–11.82 TOP ∅ 0 (20%) MMC 11.82 = ∅ 0 tol. LMC 11.78 = ∅ 0.04 tol. (OB = 11.82) (IB = 11.74)	Direct percentage gage tolerance 0.04 (10% of workpiece tolerance): Pin ∅ 11.78–11.82 TOP ∅ 0 (20%) MMC 11.78 = ∅ 0 tol. LMC 11.82 = ∅ 0.04 tol. (OB = 11.86) (IB = 11.78)	Direct percentage gage tolerance 0.04 (10% of workpiece tolerance): Pin ∅ 11.78–11.80 TOP ∅ 0.02 (15%) MMC 11.80 = ∅ 0.02 tol. LMC 11.78 = ∅ 0.02 tol. (OB = 11.82) (IB = 11.76)
With 5% wear allowance (added to pin inner boundary): (XX%) = total percent of workpiece size tolerance used by gage before wear allowance	Direct percentage gage tolerance 0.02 (5% of workpiece tolerance): Pin ∅ 11.80–11.82 TOP ∅ 0 (10%) MMC 11.82 = ∅ 0 tol. LMC 11.80 = ∅ 0.02 tol. (OB = 11.82) (IB = 11.78)	Direct percentage gage tolerance 0.02 (5% of workpiece tolerance): Pin ∅ 11.80–11.82 TOP ∅ 0 (10%) MMC 11.80 = ∅ 0 tol. LMC 11.82 = ∅ 0.02 tol. (OB = 11.84) (IB = 11.80)	Direct percentage gage tolerance 0.02 (5% of workpiece tolerance): Pin ∅ 11.80–11.81 TOP ∅ 0.01 (7.5%) MMC 11.81 = ∅ 0.01 tol. LMC 11.80 = ∅ 0.01 tol. (OB = 11.82) (IB = 11.79)
Optimistic			
No wear allowance: (XX%) = total percent of workpiece size tolerance used by gage	Direct percentage gage tolerance 0.04 (10% of workpiece tolerance): Pin ∅ 11.76–11.80 TOP ∅ 0 (20%) MMC 11.80 = ∅ 0 tol. LMC 11.76 = ∅ 0.04 tol. (OB = 11.80) (IB = 11.72)	Direct percentage gage tolerance 0.04 (10% of workpiece tolerance): Pin ∅ 11.76–11.80 TOP ∅ 0 (20%) MMC 11.76 = ∅ 0 tol. LMC 11.80 = ∅ 0.04 tol. (OB = 11.84) (IB = 11.76)	Direct percentage gage tolerance 0.04 (10% of workpiece tolerance): Pin ∅ 11.76–11.78 TOP ∅ 0.02 (15%) MMC 11.78 = ∅ 0.02 tol. LMC 11.76 = ∅ 0.02 tol. (OB = 11.80) (IB = 11.74)
With 5% wear allowance (added to pin inner boundary): (XX%) = total percent of workpiece size tolerance used by gage before wear allowance	Direct percentage gage tolerance 0.02 (5% of workpiece tolerance): Pin ∅ 11.78–11.80 TOP ∅ 0 (10%) MMC 11.80 = ∅ 0 tol. LMC 11.78 = ∅ 0.02 tol. (OB = 11.80) (IB = 11.76)	Direct percentage gage tolerance 0.02 (5% of workpiece tolerance): Pin ∅ 11.78–11.80 TOP ∅ 0 (10%) LMC 11.78 = ∅ 0 tol. MMC 11.80 = ∅ 0.02 tol. (OB = 11.82) (IB = 11.78)	Direct percentage gage tolerance 0.02 (5% of workpiece tolerance): Pin ∅ 11.78–11.79 TOP ∅ 0.01 (7.5%) MMC 11.79 = ∅ 0.01 tol. LMC 11.78 = ∅ 0.01 tol. (OB = 11.80) (IB = 11.77)

NOTE:
(1) See Table A-1, Note (1).

Table A-3 Adjusted Boundary Gage Tolerance Method

Gaging Policy	MMC	LMC	RFS
Absolute			
No wear allowance: (XX%) = total percent of workpiece size tolerance used by gage	Adjusted boundary gage tolerance 0.04 (10% of workpiece tolerance): Pin ∅ 11.82–11.84 TOP ∅ 0 (10%) [Note (1)] MMC 11.84 = ∅0 tol. LMC 11.82 = ∅0.02 tol. (OB = 11.84) (IB = 11.80) See Fig. A-4(a)	Adjusted boundary gage tolerance 0.04 (10% of workpiece tolerance): Pin ∅ 11.80–11.82 TOP ∅ 0 (10%) [Note (1)] MMC 11.80 = ∅ 0 tol. LMC 11.82 = ∅ 0.02 tol. (OB = 11.84) (IB = 11.80) See Fig. A-4(c)	Adjusted boundary gage tolerance 0.04 (10% of workpiece tolerance): Pin ∅ 11.81–11.83 TOP ∅ 0.01 (10%) [Note (1)] MMC 11.83 = ∅ 0.01 tol. LMC 11.81 = ∅ 0.01 tol. (OB = 11.84) (IB = 11.80) See Fig. A-4(e)
With 5% wear allowance (added to pin inner boundary): (XX%) = total percent of workpiece size tolerance used by gage before wear allowance	Adjusted boundary gage tolerance 0.02 (5% of workpiece tolerance): Pin ∅ 11.83–11.84 TOP ∅ 0 (5%) [Note (1)] MMC 11.84 = ∅ 0 tol. LMC 11.83 = ∅ 0.01 tol. (OB = 11.84) (IB = 11.82) See Fig. A-4(b)	Adjusted boundary gage tolerance 0.02 (5% of workpiece tolerance): Pin ∅ 11.82–11.83 TOP ∅ 0 (5%) [Note (1)] MMC 11.82 = ∅ 0 tol. LMC 11.83 = ∅ 0.01 tol. (OB = 11.84) (IB = 11.82) See Fig. A-4(d)	Adjusted boundary gage tolerance 0.02 (5% of workpiece tolerance): Pin ∅ 11.825–11.835 TOP ∅ 0.005 (5%) [Note (1)] MMC 11.835 = ∅ 0.005 tol. LMC 11.825 = ∅ 0.005 tol. (OB = 11.84) (IB = 11.82) See Fig. A-4(f)
Tolerant			
No wear allowance: (XX%) = total percent of workpiece size tolerance used by gage	Adjusted boundary gage tolerance 0.04 (10% of workpiece tolerance): Pin ∅ 11.80–11.82 TOP ∅ 0 (10%) MMC 11.82 = ∅ 0 tol. LMC 11.80 = ∅ 0.02 tol. (OB = 11.82) (IB = 11.78)	Adjusted boundary gage tolerance 0.04 (10% of workpiece tolerance): Pin ∅ 11.78–11.80 TOP ∅ 0 (10%) MMC 11.78 = ∅ 0 tol. LMC 11.80 = ∅ 0.02 tol. (OB = 11.82) (IB = 11.78)	Adjusted boundary gage tolerance 0.04 (10% of workpiece tolerance): Pin ∅ 11.79–11.81 TOP ∅ 0.01 (10%) MMC 11.81 = ∅ 0.01 tol. LMC 11.79 = ∅ 0.01 tol. (OB = 11.82) (IB = 11.78)
With 5% wear allowance (added to pin inner boundary): (XX%) = total percent of workpiece size tolerance used by gage before wear allowance	Adjusted boundary gage tolerance 0.02 (5% of workpiece tolerance): Pin ∅ 11.81–11.82 TOP ∅ 0 (5%) MMC 11.82 = ∅ 0 tol. LMC 11.81 = ∅ 0.01 tol. (OB = 11.82) (IB = 11.80)	Adjusted boundary gage tolerance 0.02 (5% of workpiece tolerance): Pin ∅ 11.80–11.81 TOP ∅ 0 (5%) MMC 11.80 = ∅ 0 tol. LMC 11.81 = ∅ 0.01 tol. (OB = 11.82) (IB = 11.80)	Adjusted boundary gage tolerance 0.02 (5% of workpiece tolerance): Pin ∅ 11.805–11.815 TOP ∅ 0.005 (5%) MMC 11.815 = ∅ 0.005 tol. LMC 11.805 = ∅ 0.005 tol. (OB = 11.82) (IB = 11.80)
Optimistic			
No wear allowance: (XX%) = total percent of workpiece size tolerance used by gage	Adjusted boundary gage tolerance 0.04 (10% of workpiece tolerance): Pin ∅ 11.78–11.80 TOP ∅ 0 (10%) MMC 11.80 = ∅ 0 tol. LMC 11.78 = ∅ 0.02 tol. (OB = 11.80) (IB = 11.76)	Adjusted boundary gage tolerance 0.04 (10% of workpiece tolerance): Pin ∅ 11.76–11.78 TOP ∅ 0 (10%) MMC 11.76 = ∅ 0 tol. LMC 11.78 = ∅ 0.02 tol. (OB = 11.80) (IB = 11.76)	Adjusted boundary gage tolerance 0.04 (10% of workpiece tolerance): Pin ∅ 11.77–11.79 TOP ∅ 0.01 (10%) MMC 11.79 = ∅ 0.01 tol. LMC 11.77 = ∅ 0.01 tol. (OB = 11.80) (IB = 11.76)
With 5% wear allowance (added to pin inner boundary): (XX%) = total percent of workpiece size tolerance used by gage before wear allowance	Adjusted boundary gage tolerance 0.02 (5% of workpiece tolerance): Pin ∅ 11.79–11.80 TOP ∅ 0 (5%) MMC 11.80 = ∅ 0 tol. LMC 11.79 = ∅ 0.01 tol. (OB = 11.80) (IB = 11.78)	Adjusted boundary gage tolerance 0.02 (5% of workpiece tolerance): Pin ∅ 11.78–11.79 TOP ∅ 0 (5%) MMC 11.78 = ∅ 0 tol. LMC 11.79 = ∅ 0.01 tol. (OB = 11.80) (IB = 11.78)	Adjusted boundary gage tolerance 0.02 (5% of workpiece tolerance): Pin ∅ 11.785–11.795 TOP ∅ 0.005 (5%) MMC 11.795 = ∅ 0.005 tol. LMC 11.785 = ∅ 0.005 tol. (OB = 11.80) (IB = 11.78)

NOTE:
(1) See Table A-1, Note (1).

NONMANDATORY APPENDIX B
GAGING EXAMPLES AND ILLUSTRATIONS

B-1 GENERAL

This Nonmandatory Appendix contains examples of the principles explained in this Standard. Each example also demonstrates gaging and fixturing principles for figures or text represented (shown in parentheses) in ASME Y14.5-2009, or ASME Y14.5M-1994 as noted. Some of the original figures taken from ASME Y14.5 have been altered or made more complete to allow the gages and fixtures to be better represented here. Dimensions and tolerances shown in gage figures apply at the assembly level.

Fig. B-1 Multiple Surface Datums (Fig. 4-23)
Fig. B-2 Inclined Datum Features (Fig. 4-7)
Fig. B-3 Cylindrical Datum Features (Fig. 4-8)
Fig. B-4 Cylindrical and Rectangular Datum Features (Fig. 4-5)
Fig. B-5 Internal Cylindrical and Rectangular Datum Features (Fig. 4-15)
Fig. B-6 Simultaneous Position and Profile Tolerances (Fig. 4-39)
Fig. B-7 Two Rectangular Datum Features of Size at MMB (Fig. 7-4)
Fig. B-8 Rectangular Feature of Size at MMB (Fig. 7-64)
Fig. B-9 Size and Planar Datum Features
Fig. B-10 Controlling Rotation With Datum Features of Size (Fig. 4-9)
Fig. B-11 Controlling Rotation With Datum Features of Size Using Translation Symbol (Fig. 4-19)
Fig. B-12 Interrelated Datum Reference Frames (Fig. 7-55)
Fig. B-13 Two Datum Features, Single Datum Axis (Fig. 7-59)
Fig. B-14 Hole Pattern as a Datum (Fig. 4-26)
Fig. B-15 Application of Moveable Datum Targets (ASME Y14.5M-1994, Figs. 4-47 and 4-48)
Fig. B-16 Irregular Closed Feature Used as a Datum Feature [para. 4.17(b) and Fig. 8-19]
Fig. B-17 Radial Hole Pattern Located by Composite Position (Fig. 7-42)
Fig. B-18 Datum Targets on a Complex Part (Fig. 4-54)
Fig. B-19 Push Pin Gages for Part With Clearance Holes (Fig. 4-8)
Fig. B-20 Push Pin Gages for Part With Threaded Holes (Fig. 7-21)
Fig. B-21 Sequential Gaging (Fig. 4-18)
Fig. B-22 Curved Surface as a Datum Feature (Figs. 4-28 and 4-29)
Fig. B-23 Outer Boundary of a Pattern of Pins Applied at MMB (Fig. 4-35)
Fig. B-24 Customized Datum Reference Frame (Fig. 4-46)
Fig. B-25 Basic Location of Angular Orientation Planar Datum Feature Simulator (Fig. 4-31)
Fig. B-26 Basic Location of Angular Orientation Curved Datum Feature Simulator (Fig. 4-29)
Fig. B-27 Datum Feature Referenced at MMB (Fig. 4-32, altered)
Fig. B-28 Planar Datum Feature Referenced at MMB [Fig. 4-31(c)]
Fig. B-29 Planar Datum Feature Referenced at Basic [Fig. 4-31(b)]

B-2 SOFT GAGING

Soft gaging is the term used when a set of coordinate measurement data, such as data generated by a coordinate measuring machine (CMM), is compared with a design model for purposes of part acceptance/rejection. In general terms, the soft gaging process works as follows:

Step 1: A part's nominal geometry is modeled with CAD software.

Step 2: The design model is imported into the soft gaging software where tolerance attributes are attached to part features. (Some CAD systems perform this step internally.)

Step 3: The soft gaging software is used to generate a worst-case model based on the nominal CAD geometry varying by the amount allowed by the tolerances. This worst-case model is called a soft gage.

Step 4: A part is measured on a CMM, generating a cloud of coordinate data points.

Step 5: The soft gaging software compares this cloud of points (or sometimes a reverse-engineered design model based on it) with the soft gage model and displays out-of-tolerance conditions.

Advantages of this method are that complex shapes may be measured with accuracy and little or no hard tooling. The major disadvantage is that, as with most CMM measurements, the acceptance of a feature is based on a sample of points, allowing the possibility that small out-of-tolerance areas might not be evaluated.

Fig. B-1 Multiple Surface Datums

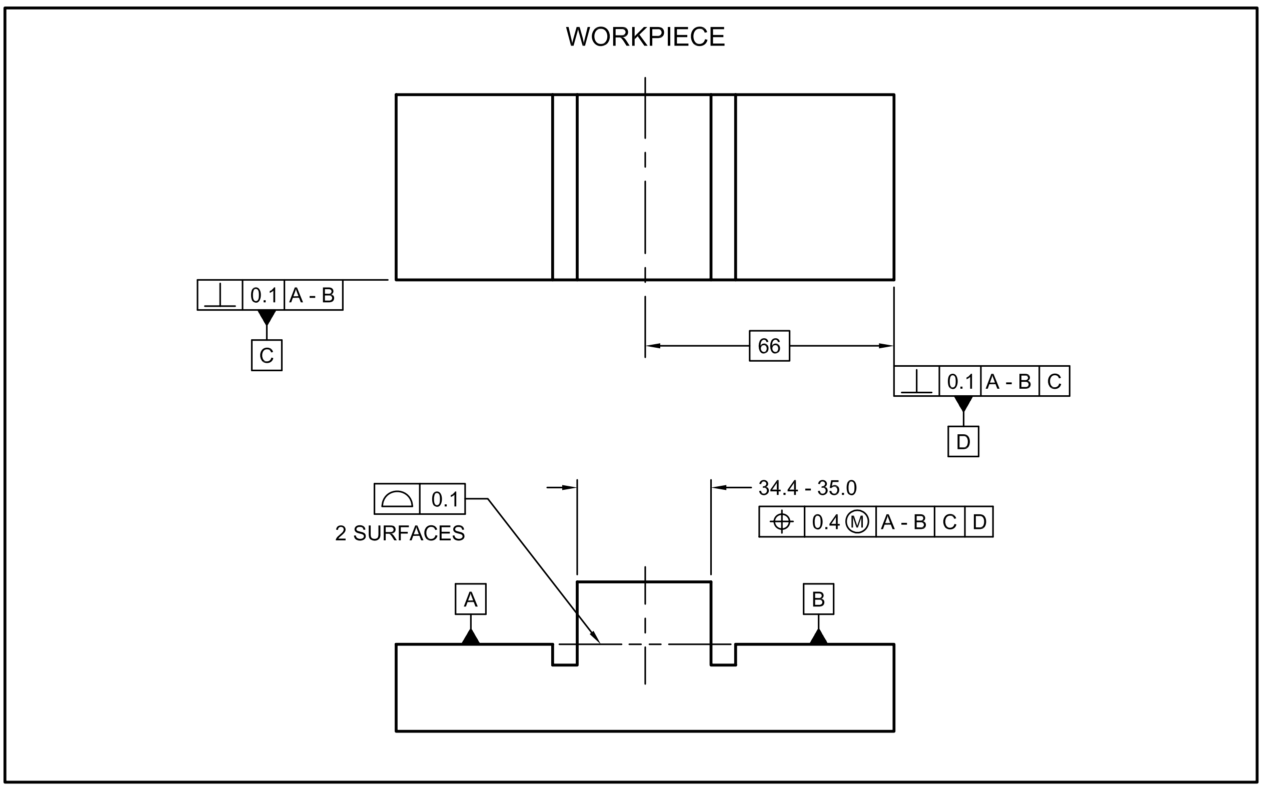


Fig. B-1 Multiple Surface Datums (Cont'd)

Fig. B-1(a)

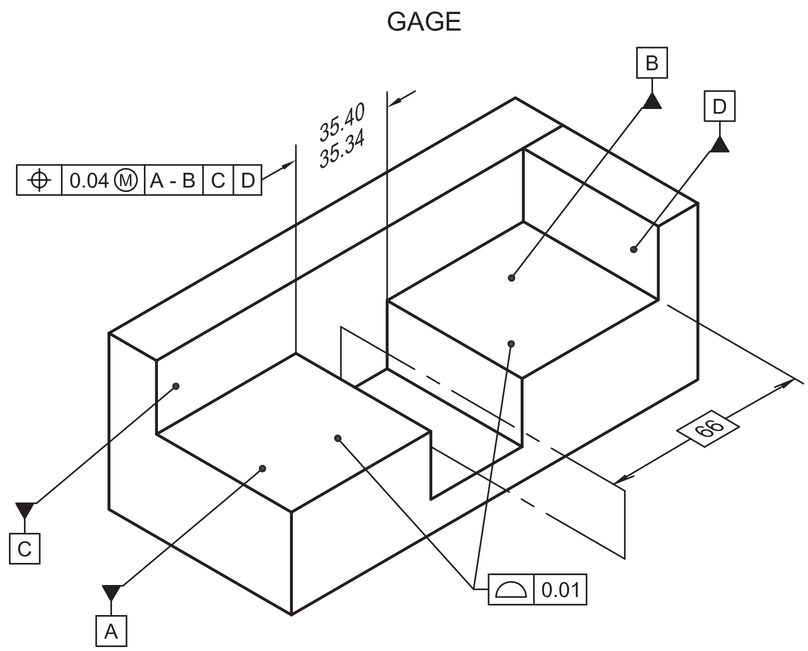


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Fig. B-1(b)

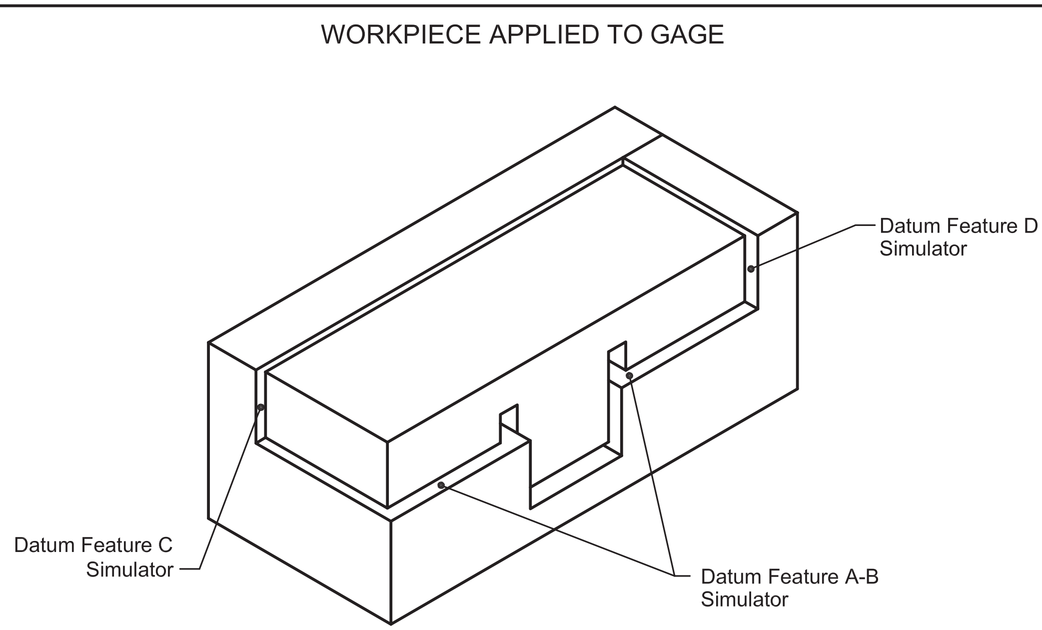

Fig. B-2 Inclined Datum Features

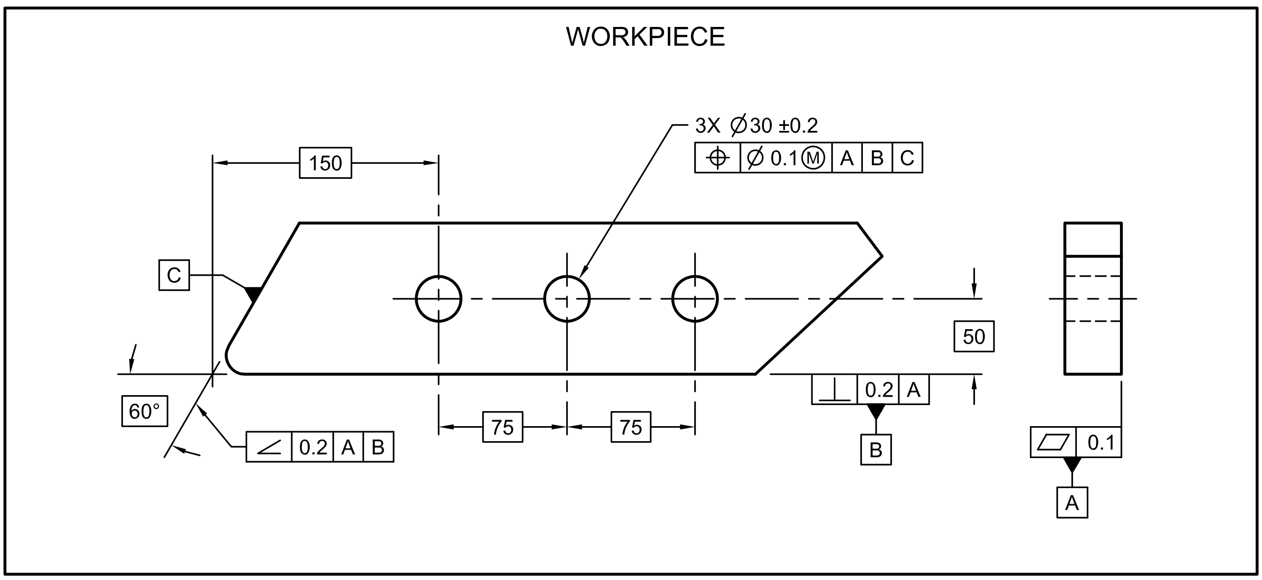

Fig. B-2 Inclined Datum Features (Cont'd)

Fig. B-2(a)

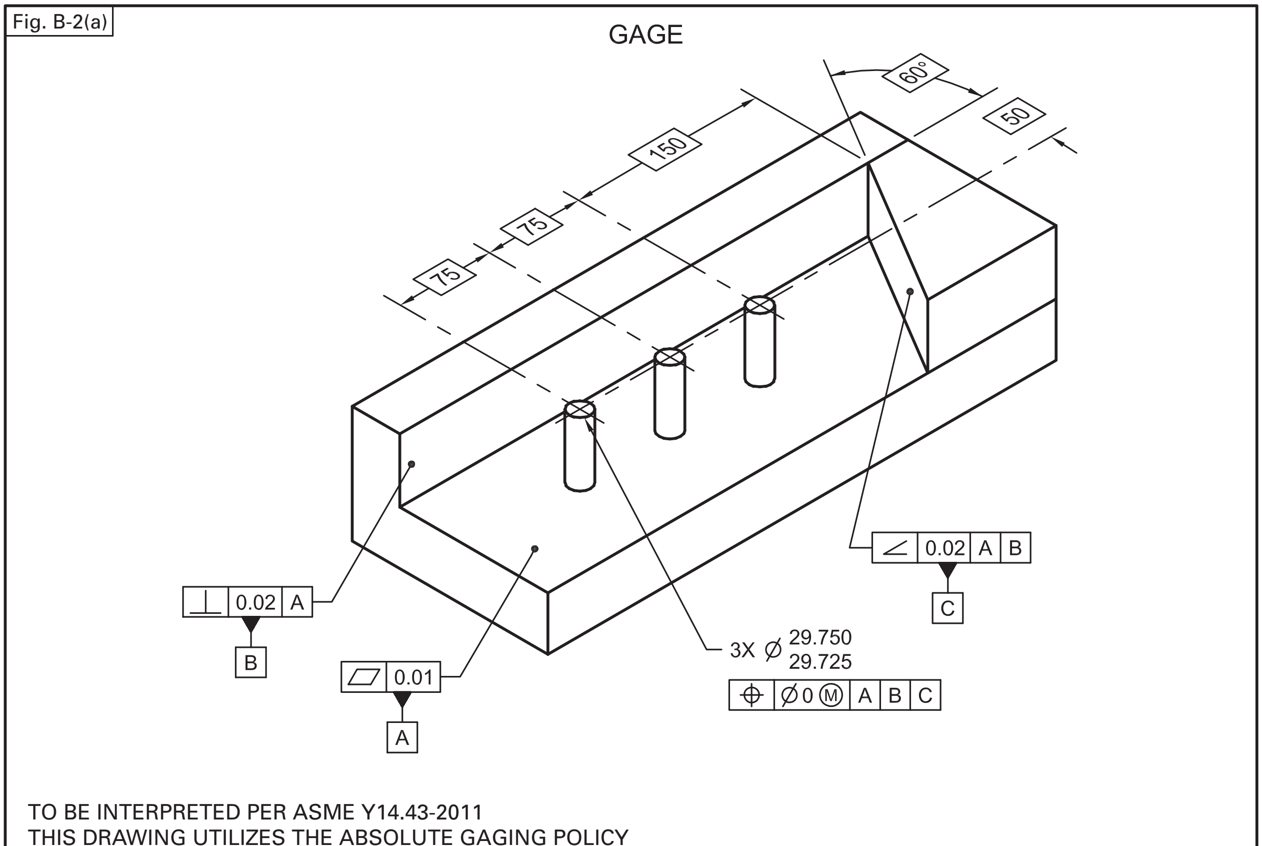

Fig. B-2(b)

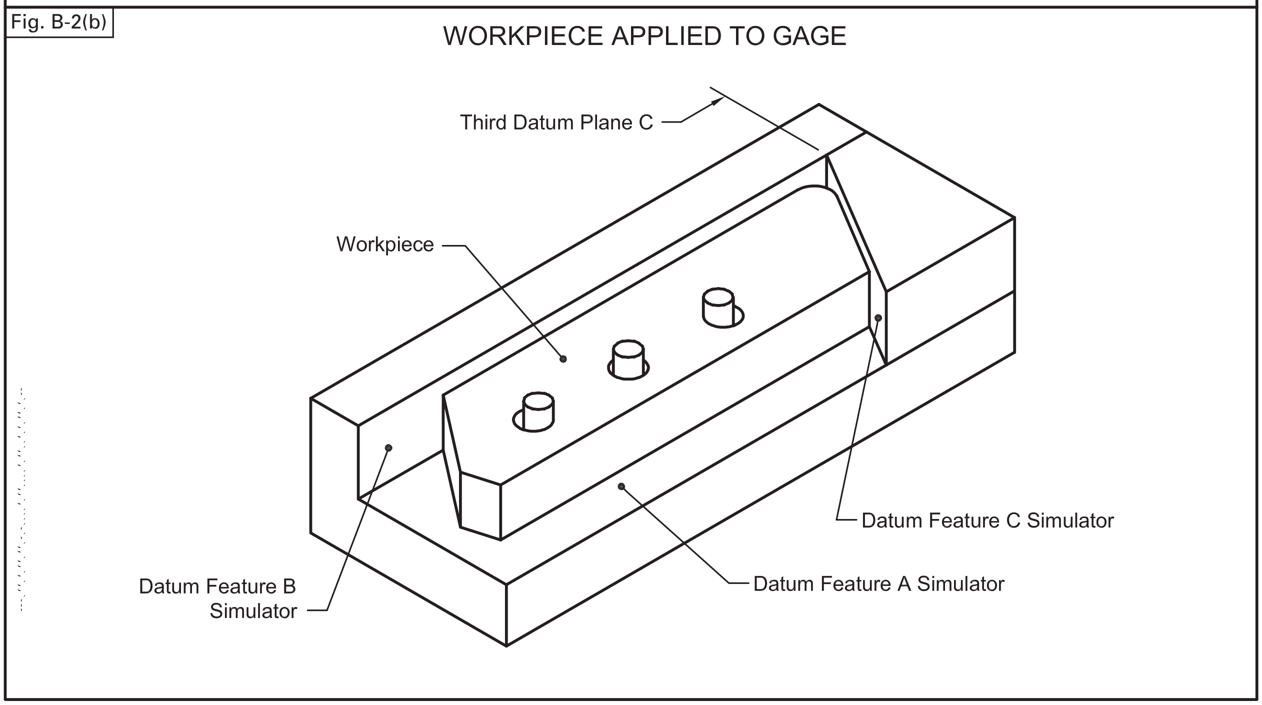

Fig. B-3 Cylindrical Datum Features

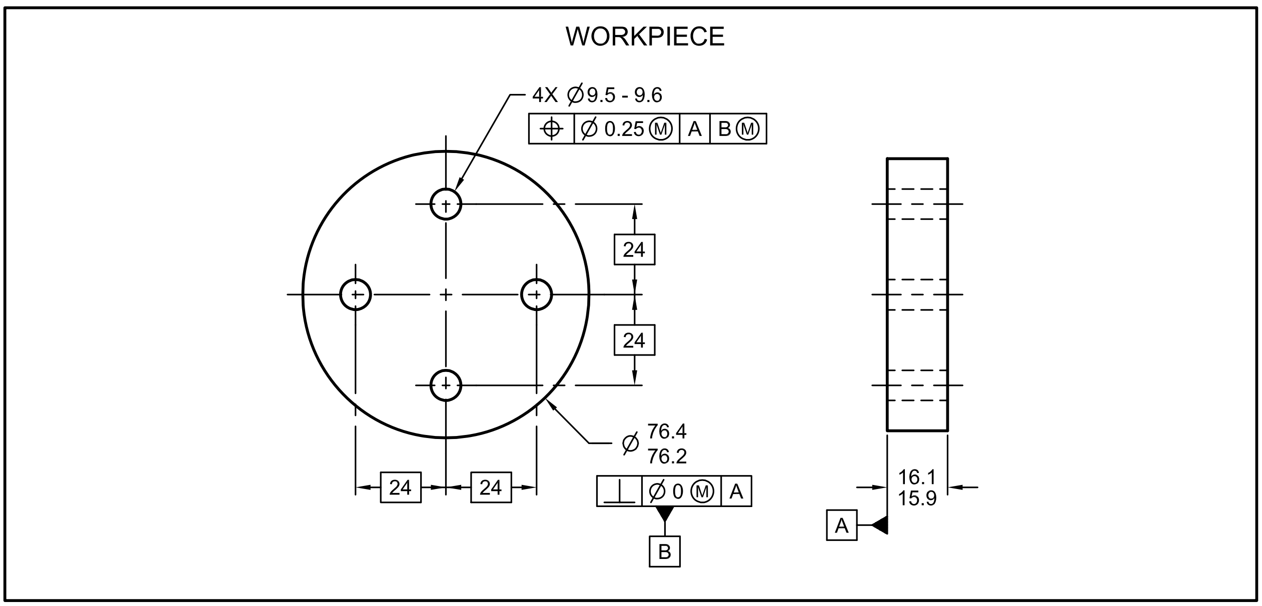

Fig. B-3 Cylindrical Datum Features (Cont'd)

Fig. B-3(a)

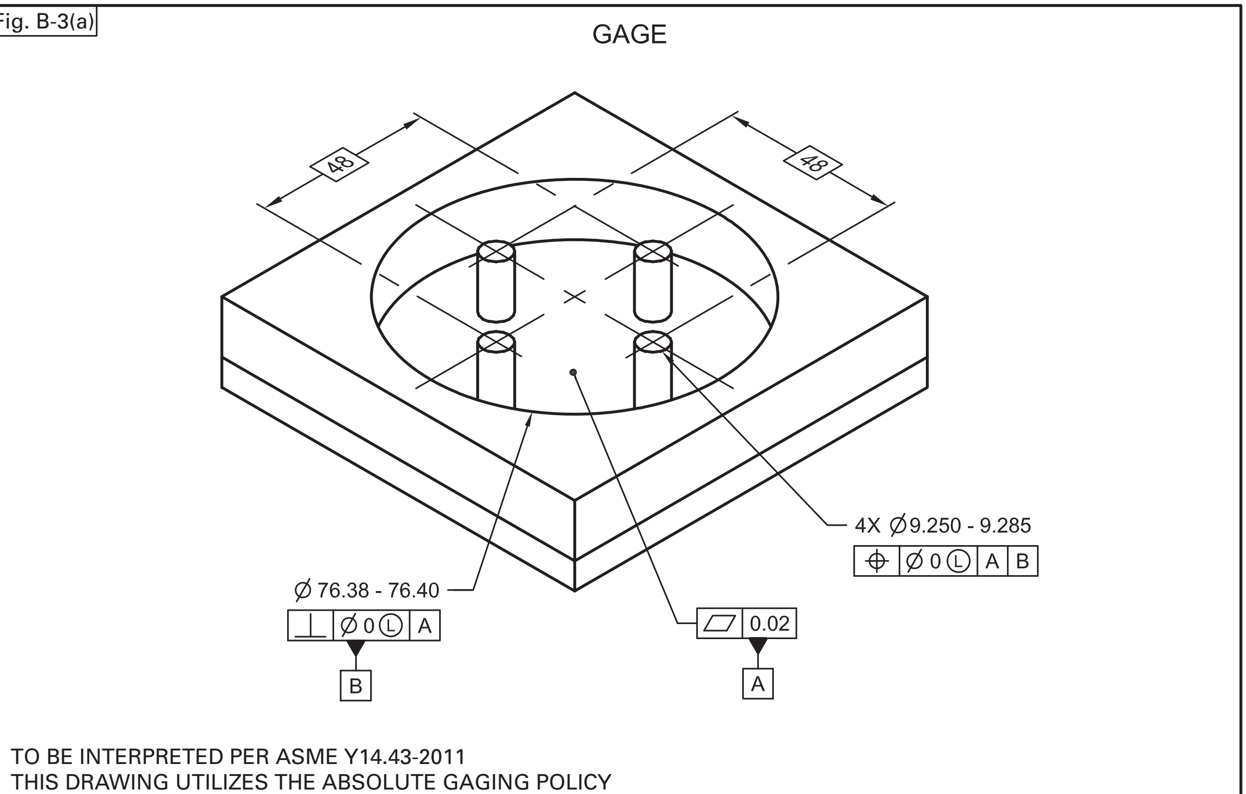

Fig. B-3(b)

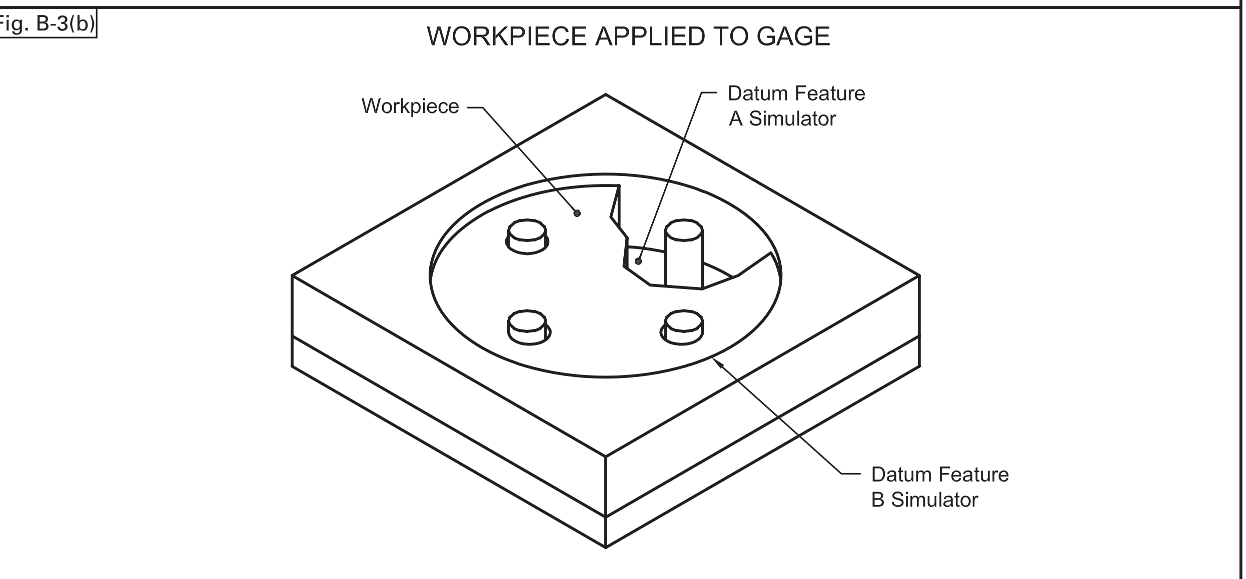

Fig. B-4 Cylindrical and Rectangular Datum Features

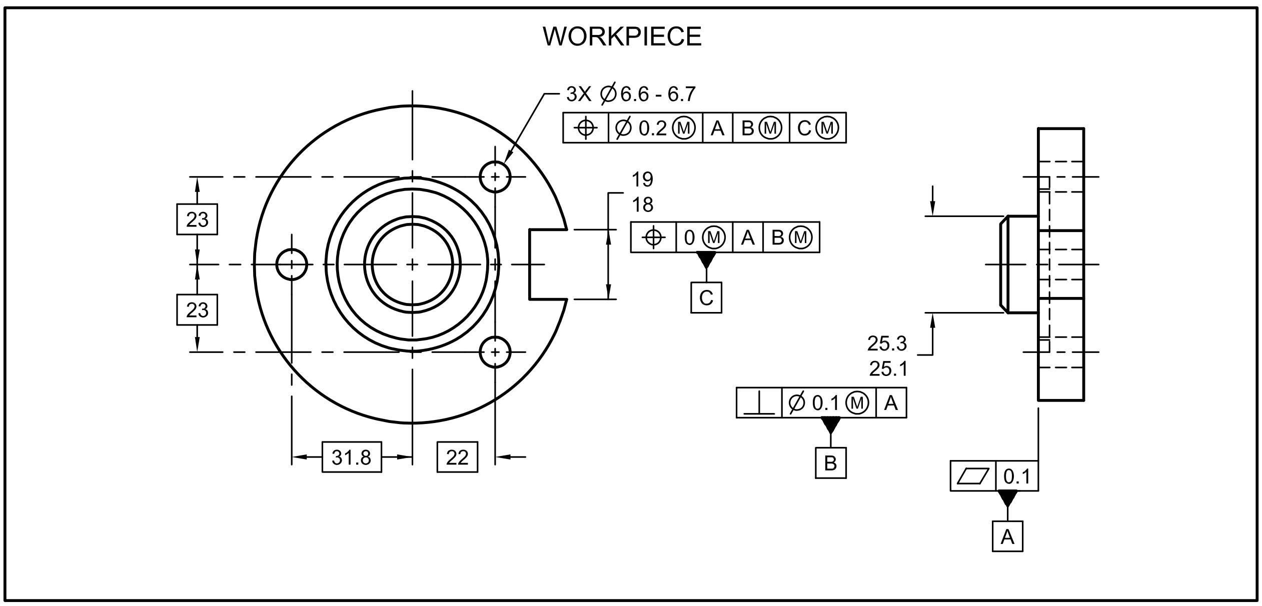

Fig. B-4 Cylindrical and Rectangular Datum Features (Cont'd)

Fig. B-4(a)

GAGE

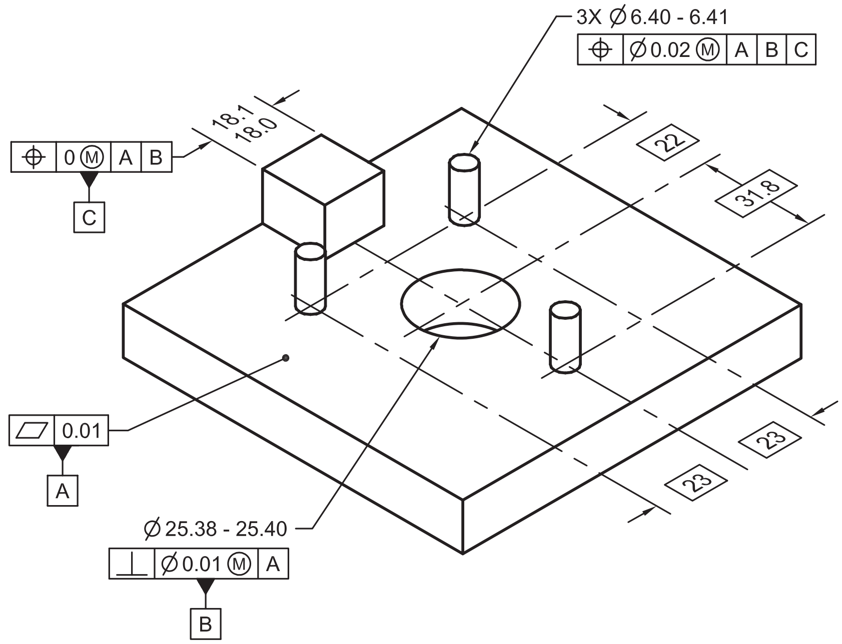

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Fig. B-4(b)

CROSS SECTION OF WORKPIECE APPLIED TO GAGE

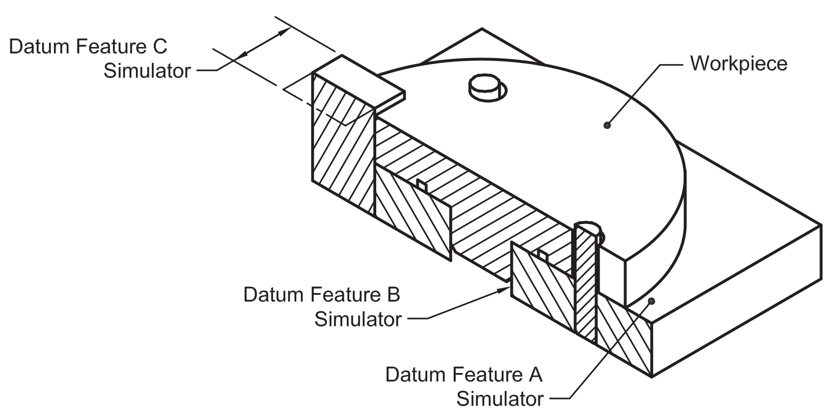


Fig. B-5 Internal Cylindrical and Rectangular Datum Features

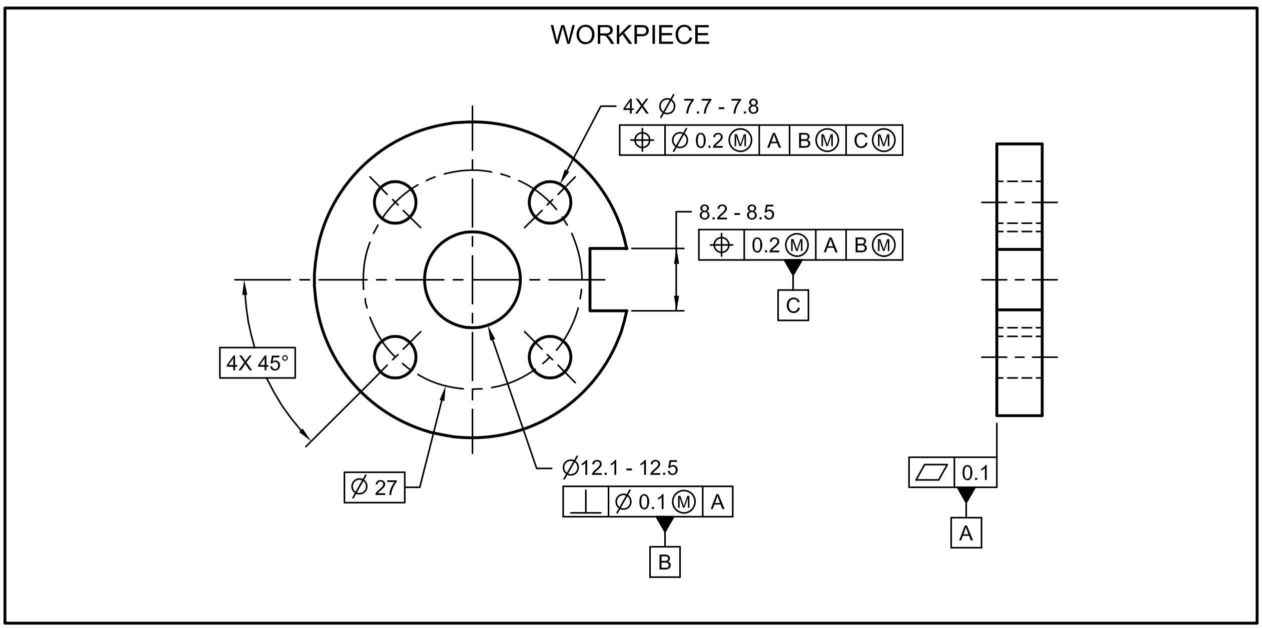


Fig. B-5 Internal Cylindrical and Rectangular Datum Features (Cont'd)

Fig. B-5(a)

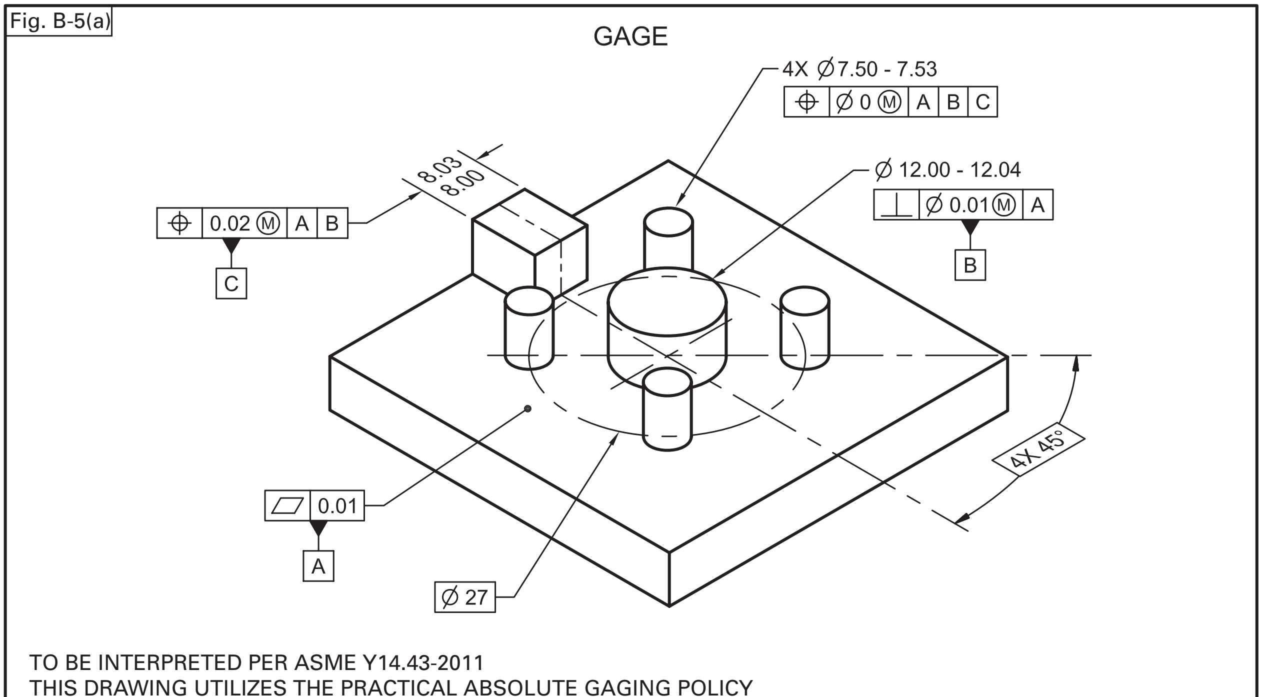


Fig. B-5(b)

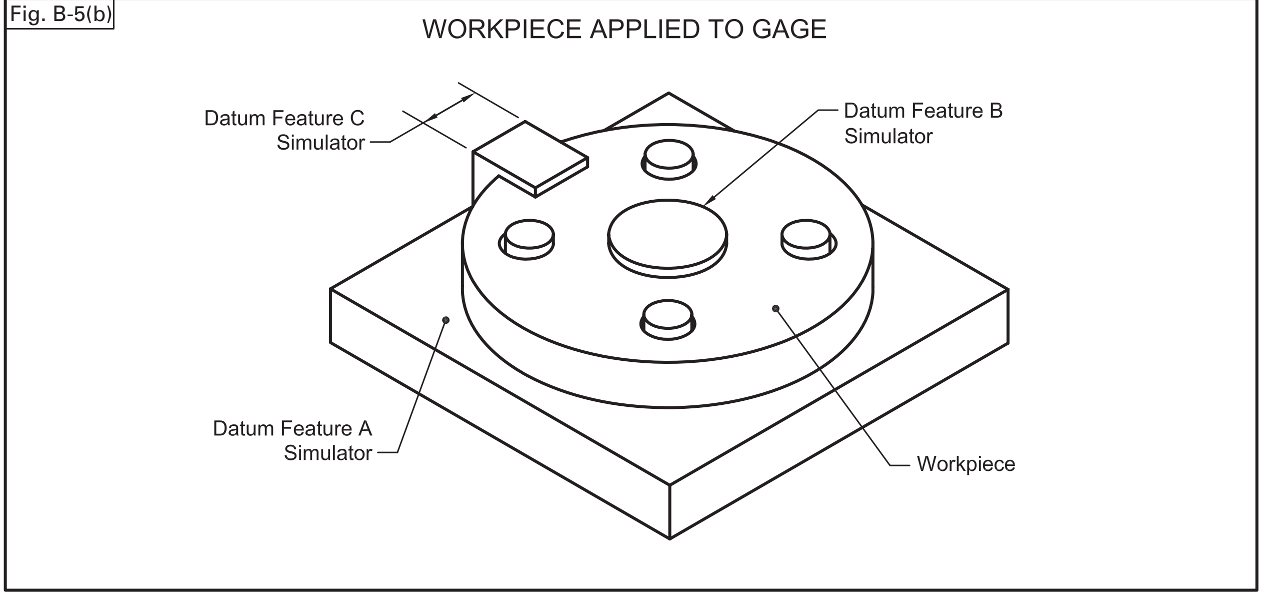


Fig. B-6 Simultaneous Position and Profile Tolerances

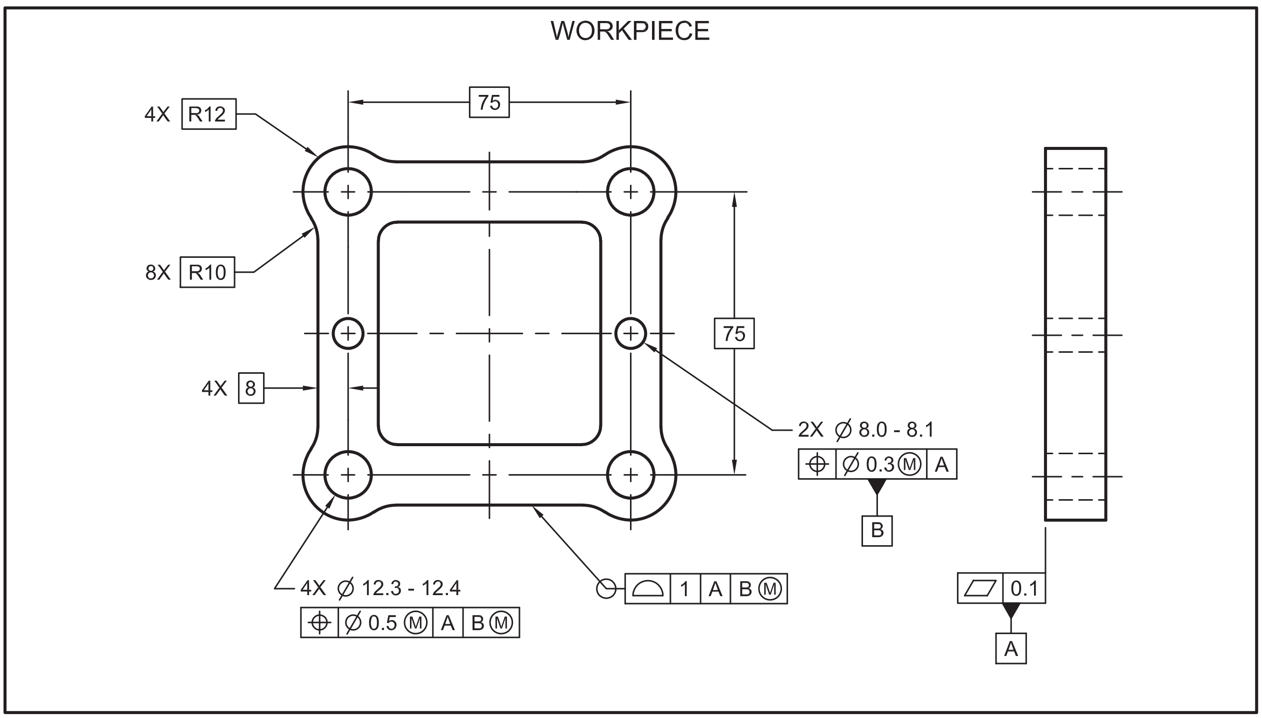


Fig. B-6 Simultaneous Position and Profile Tolerances (Cont'd)

Fig. B-6(a)

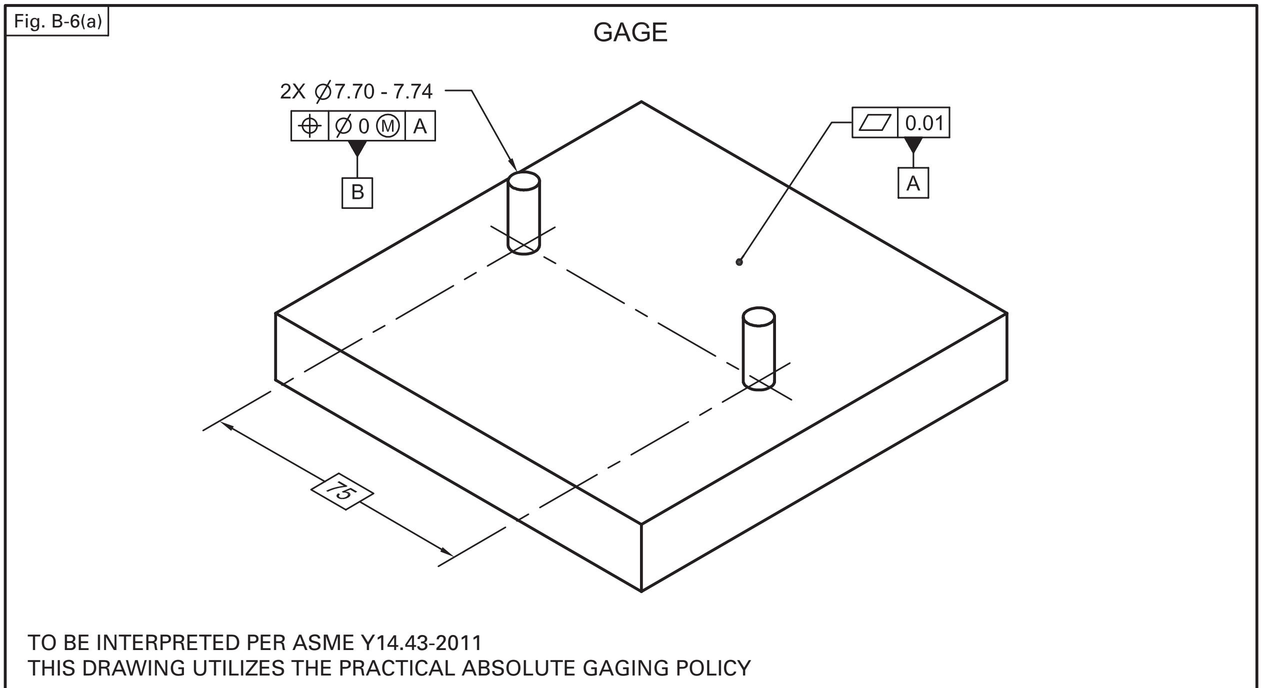


Fig. B-6(b)

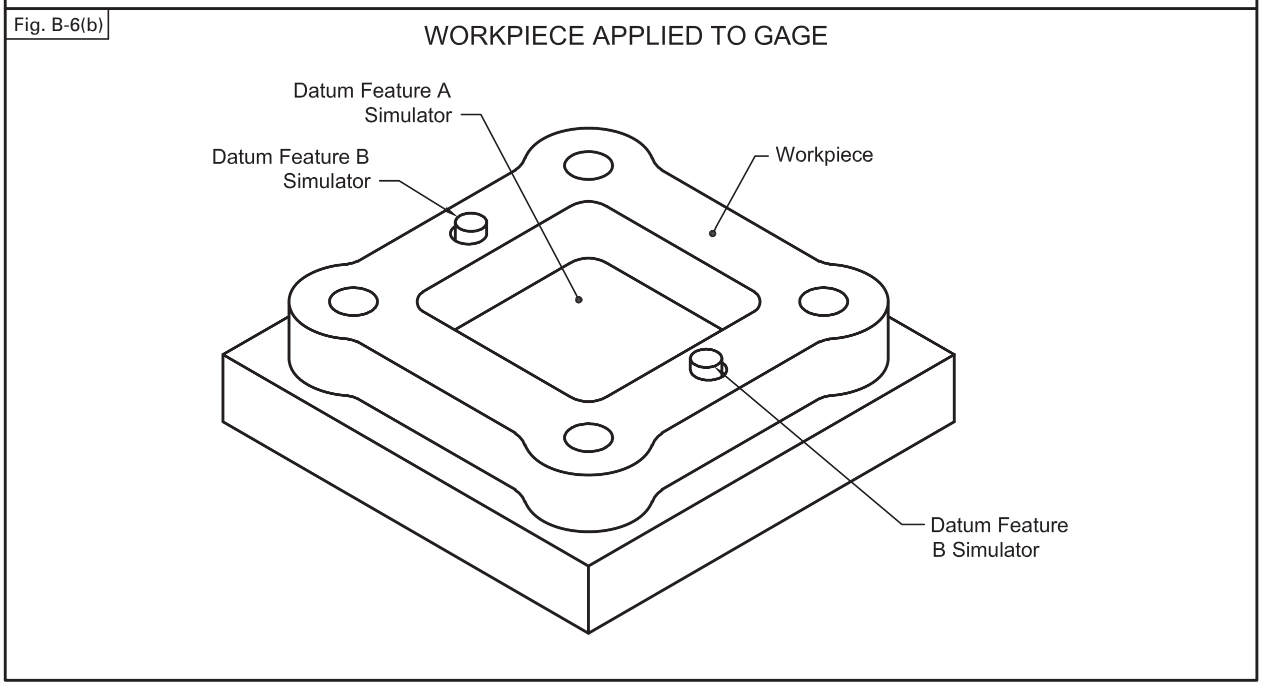
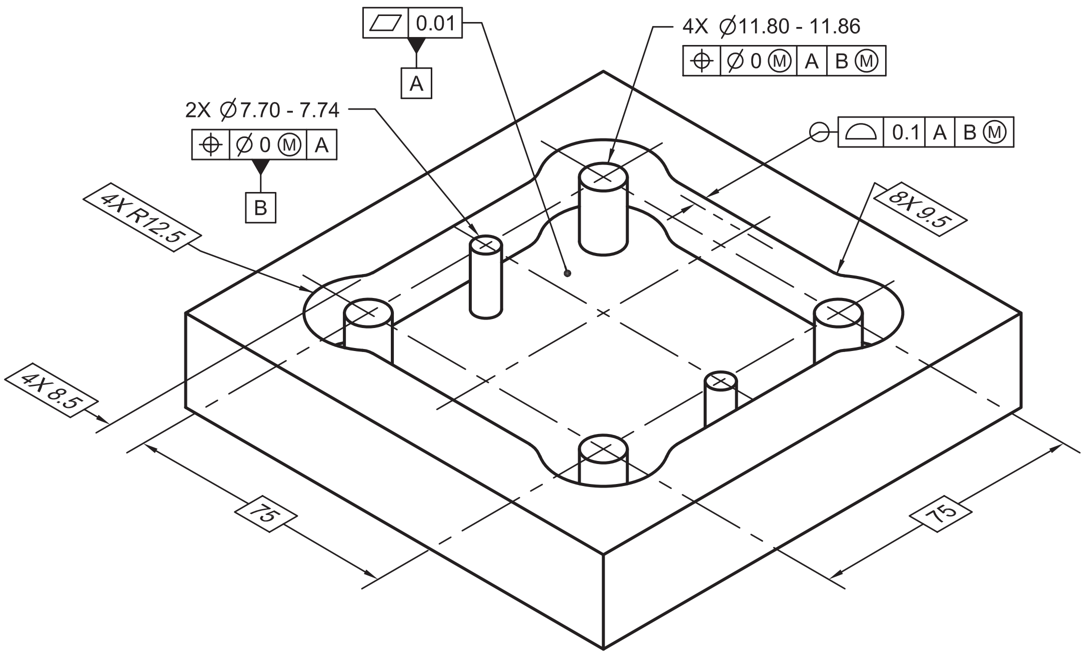


Fig. B-6 Simultaneous Position and Profile Tolerances (Cont'd)

Fig. B-6(c)

GAGE



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NOTE: The nominal profile for the gage is the maximum part profile tolerance boundary. The profile tolerance on the gage is unilaterally in. The gage simultaneously verifies the hole locations and profile outer boundary. It does not verify the profile inner boundary.

Fig. B-6(d)

WORKPIECE APPLIED TO GAGE

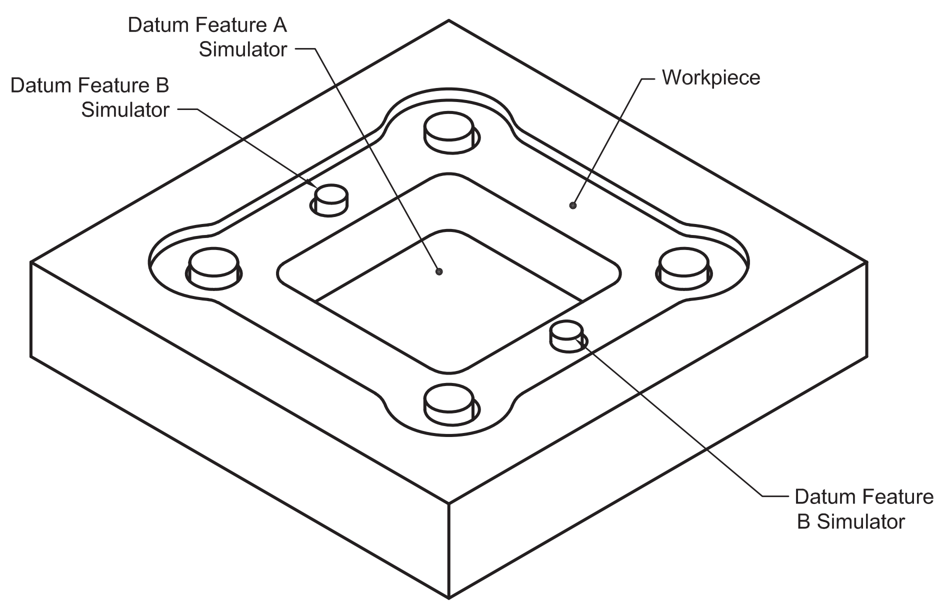

Fig. B-7 Two Rectangular Datum Features of Size at MMB

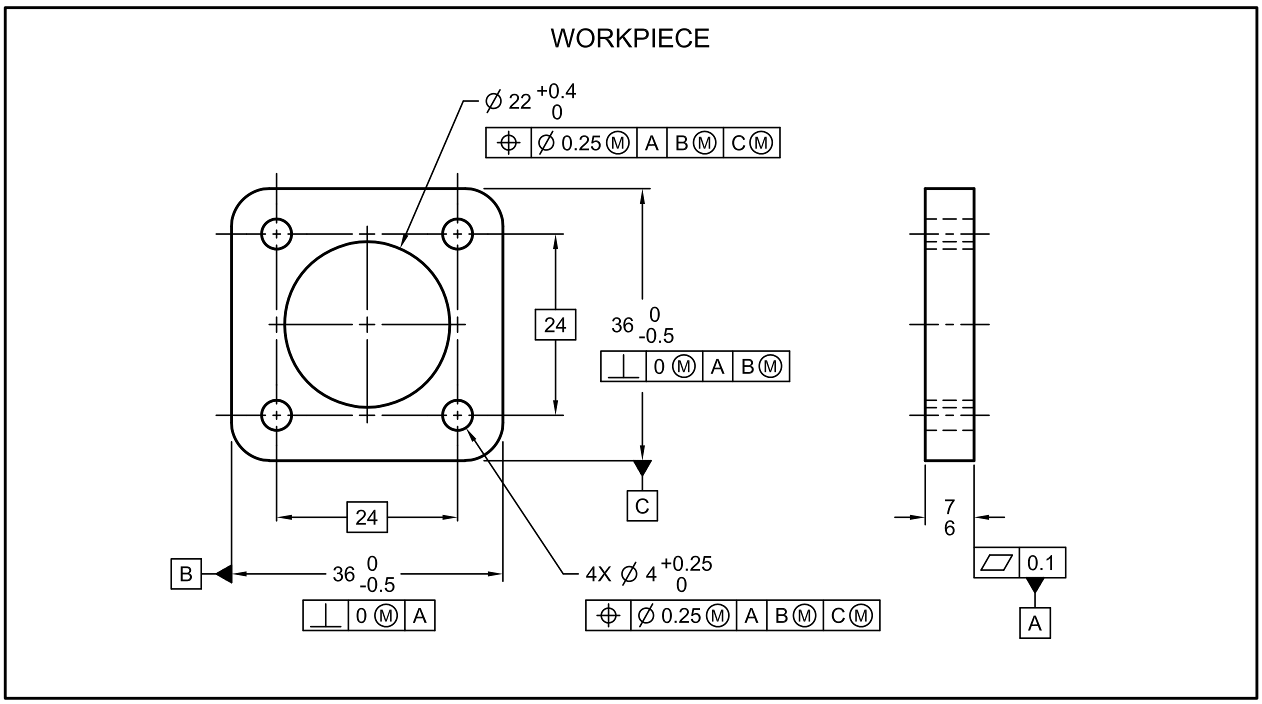

Fig. B-7 Two Rectangular Datum Features of Size at MMB (Cont'd)

Fig. B-7(a)

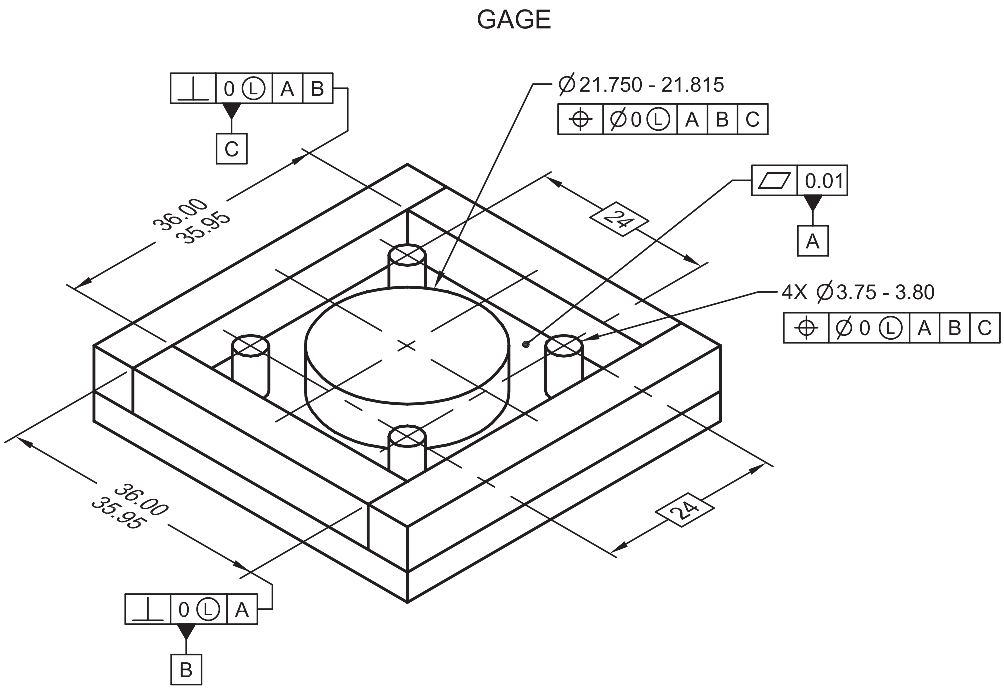

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Fig. B-7(b)

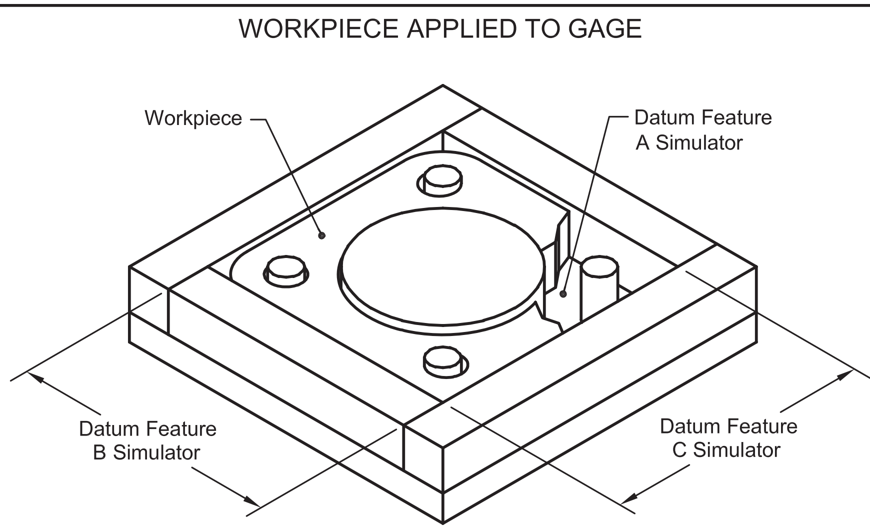

Fig. B-8 Rectangular Feature of Size at MMB

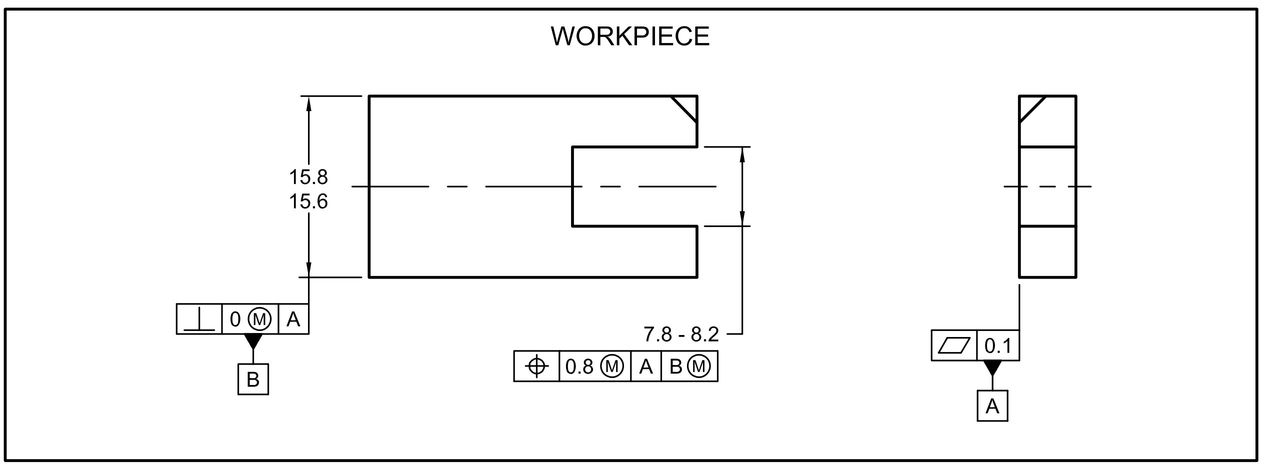

Fig. B-8 Rectangular Feature of Size at MMB (Cont'd)

Fig. B-8(a)

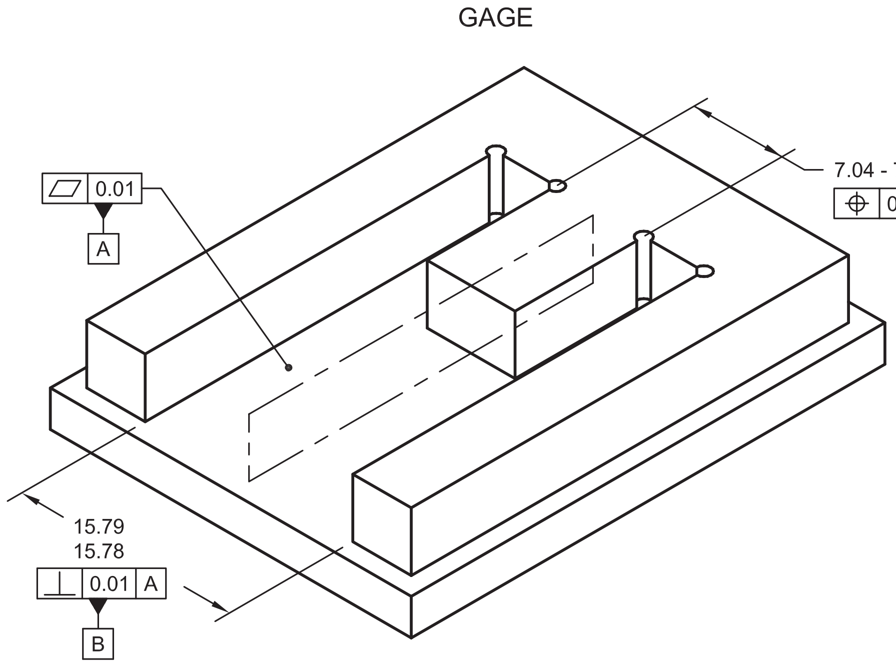

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Fig. B-8(b)

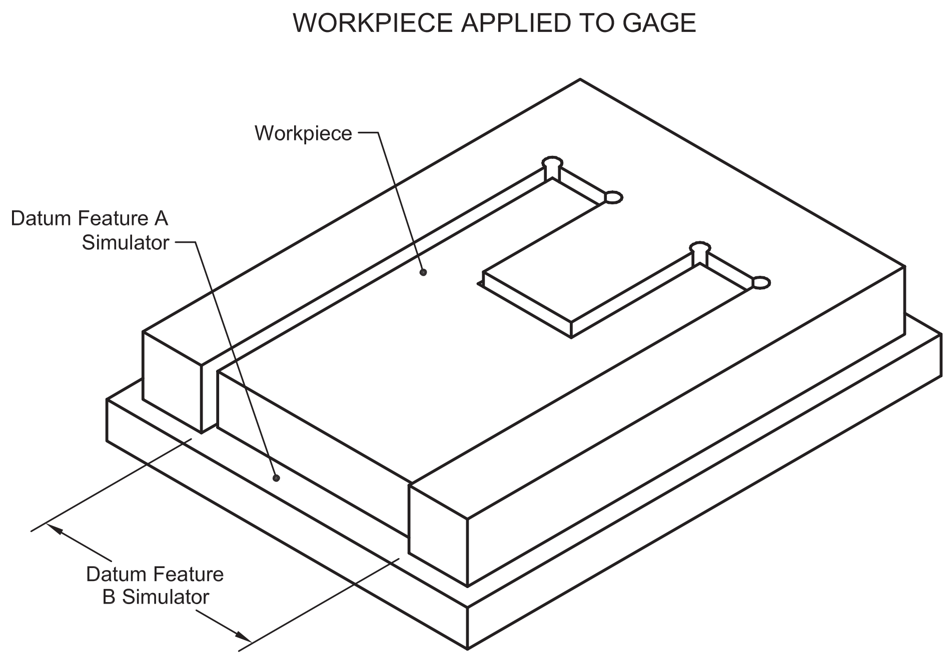


Fig. B-9 Size and Planar Datum Features

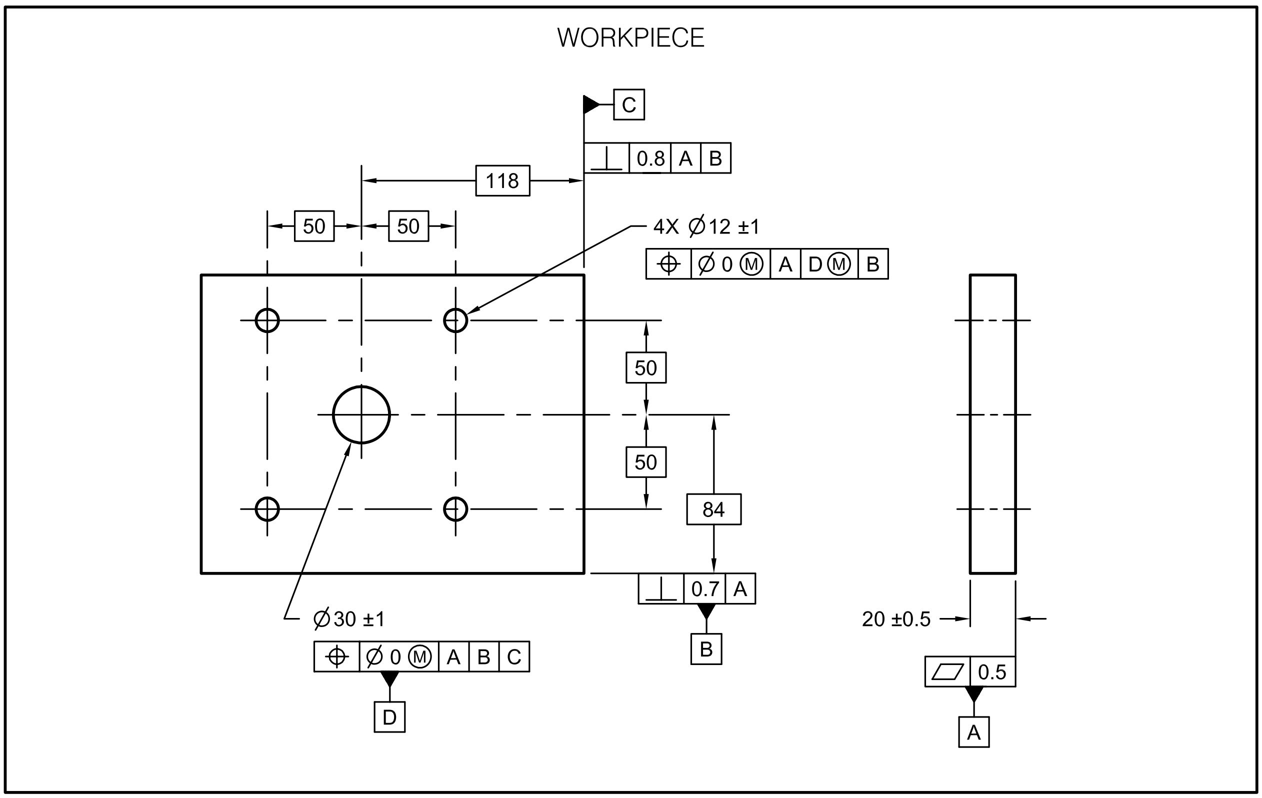


Fig. B-9 Size and Planar Datum Features (Cont'd)

Fig. B-9(a)

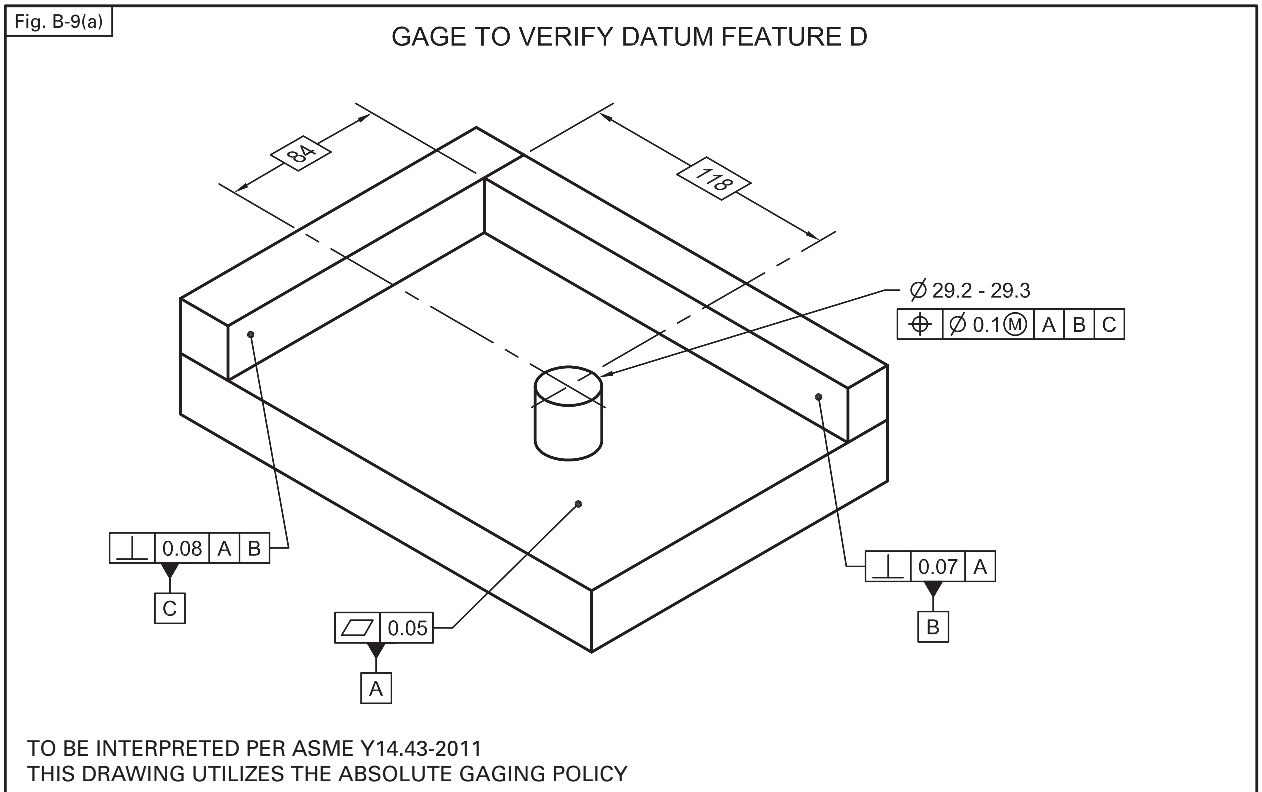


Fig. B-9(b)

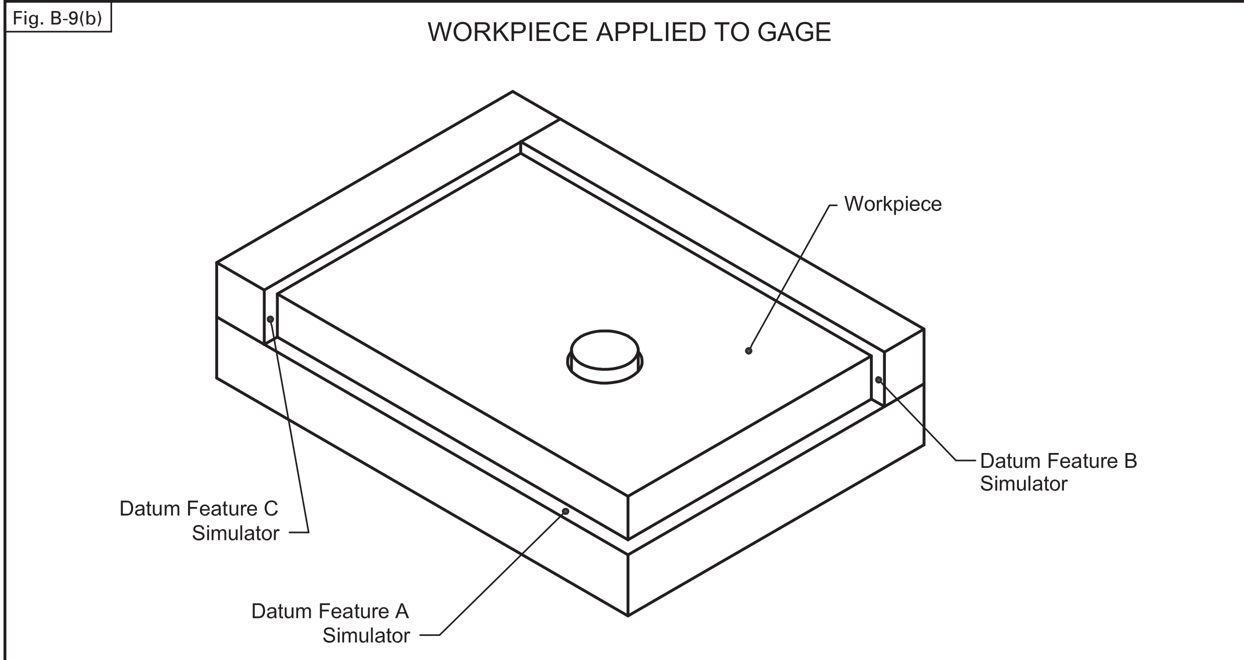


Fig. B-9 Size and Planar Datum Features (Cont'd)

Fig. B-9(c)

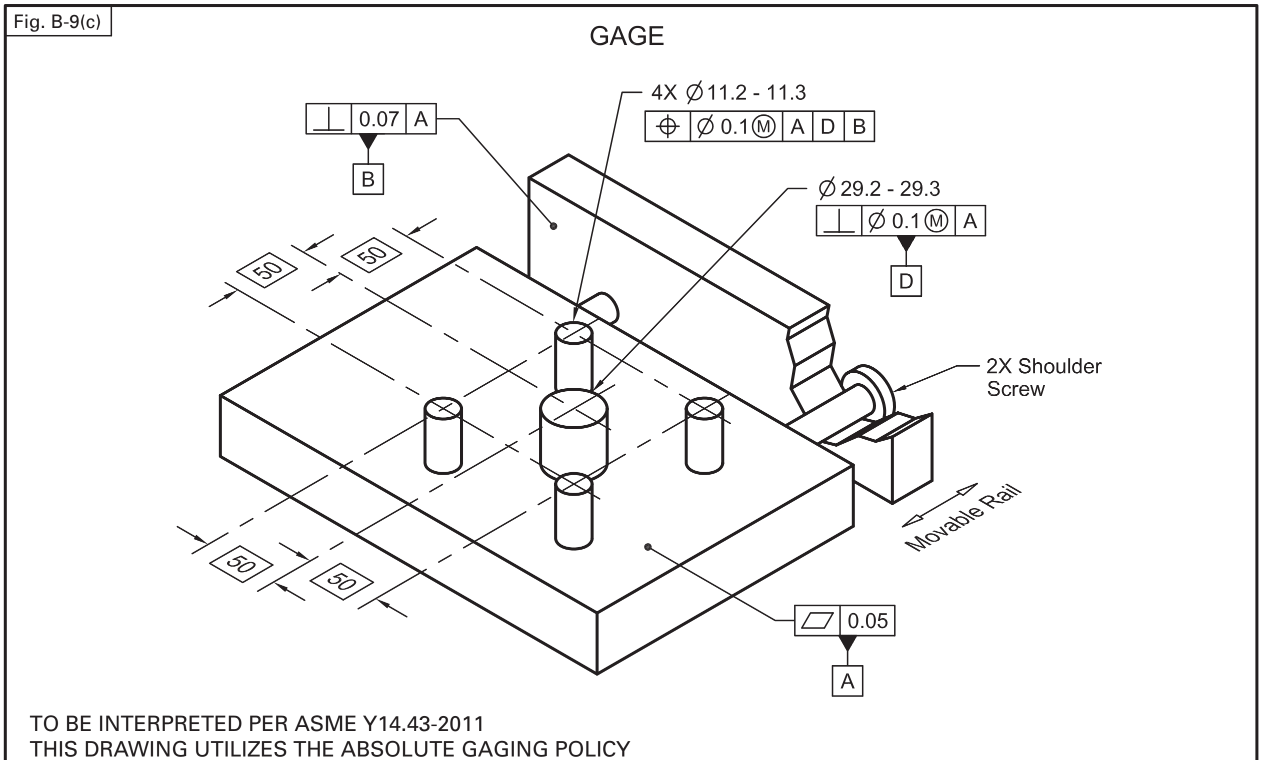


Fig. B-9(d)

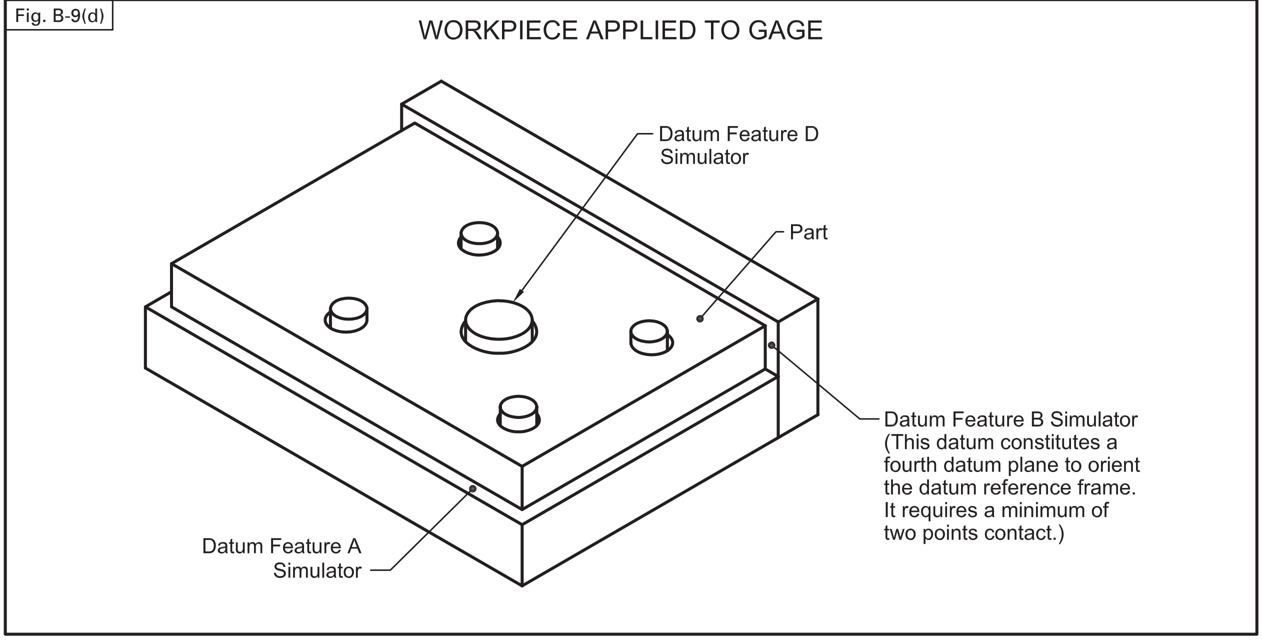


Fig. B-10 Controlling Rotation With Datum Features of Size

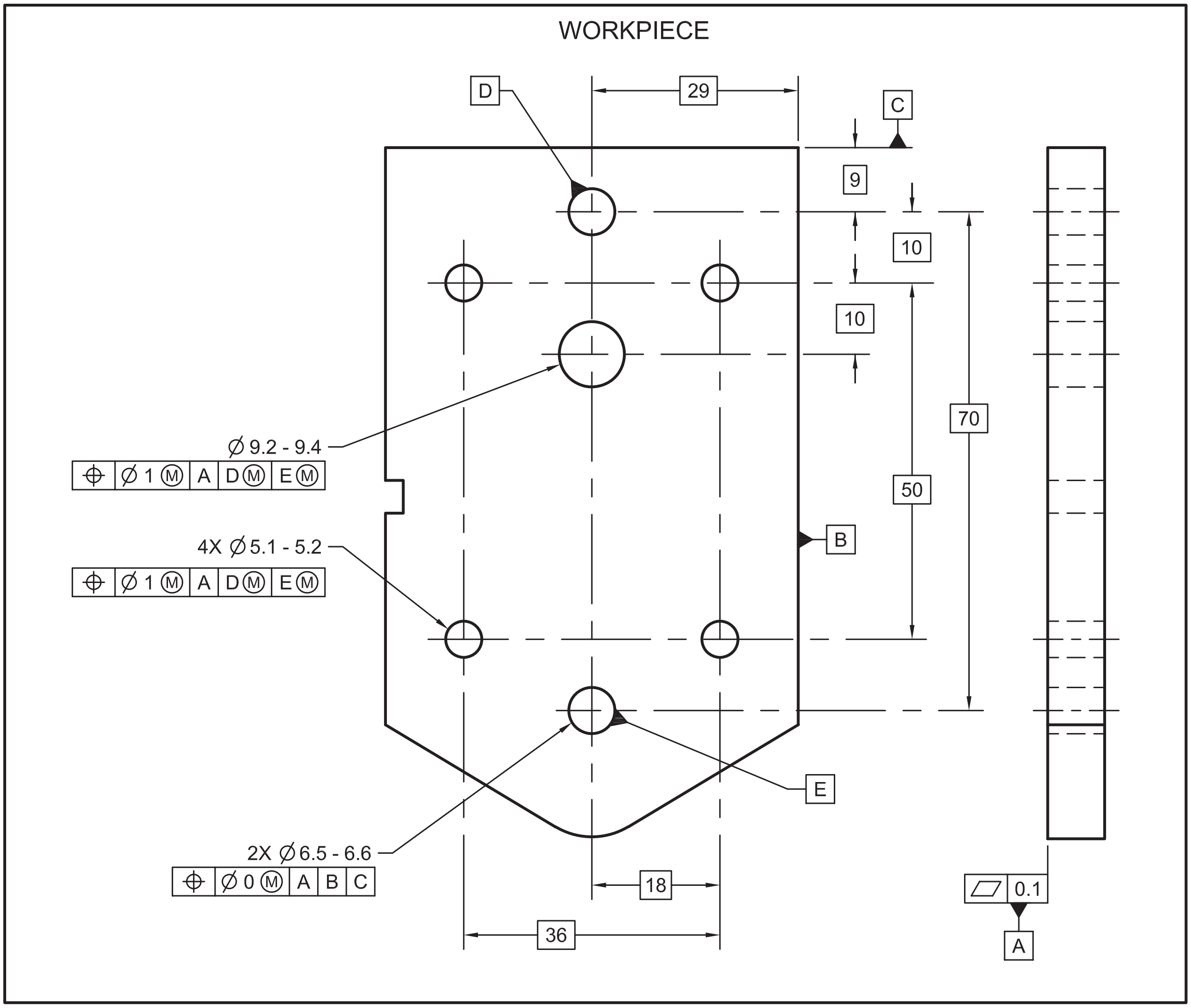


Fig. B-10 Controlling Rotation With Datum Features of Size (Cont'd)

Fig. B-10(a)

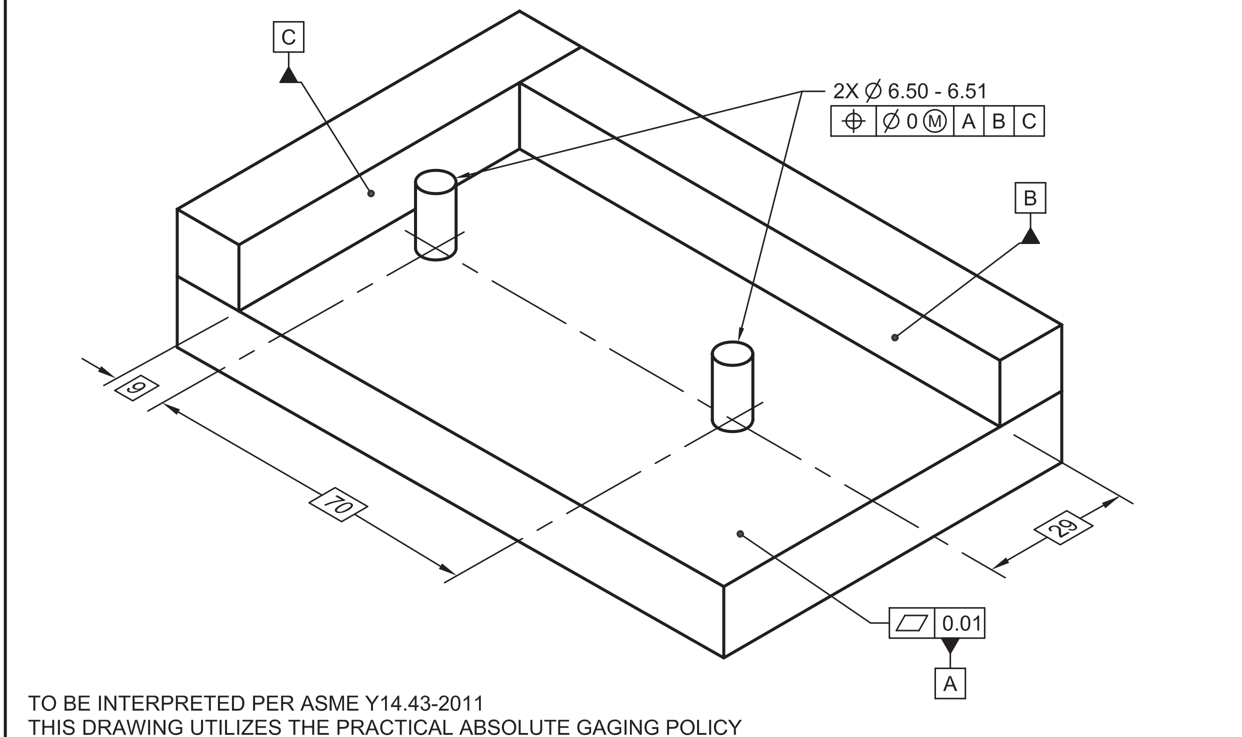


Fig. B-10(b)

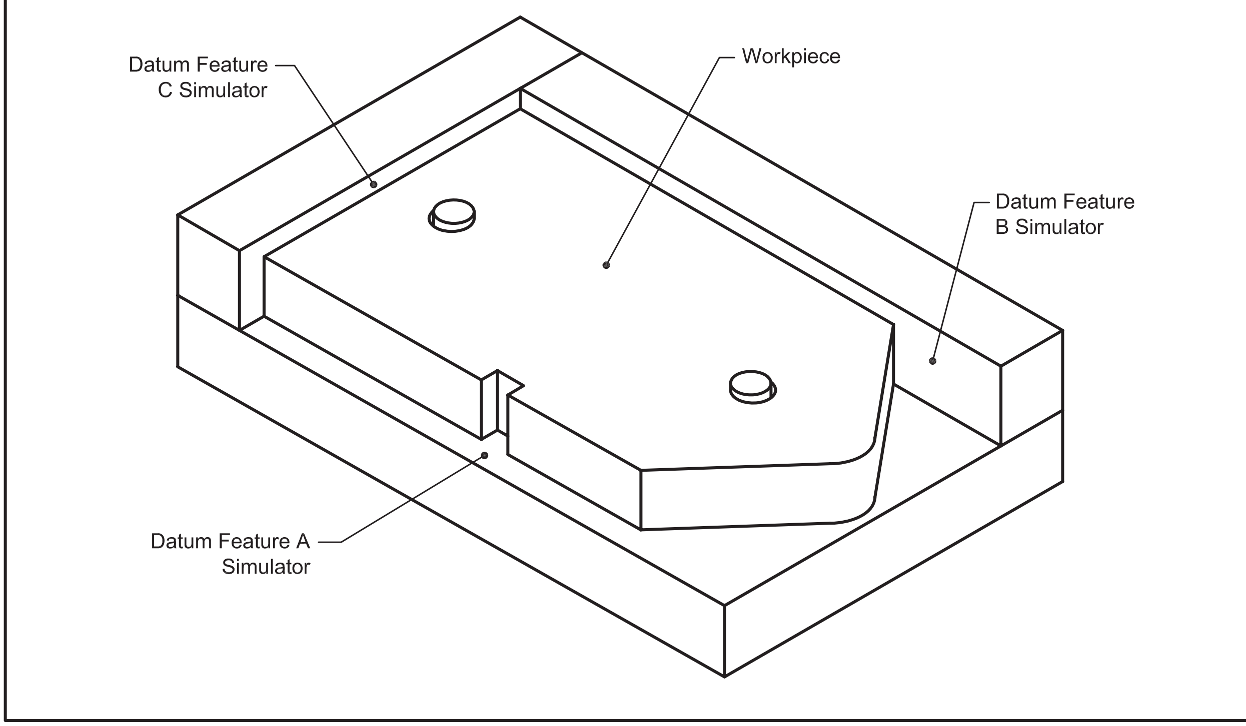
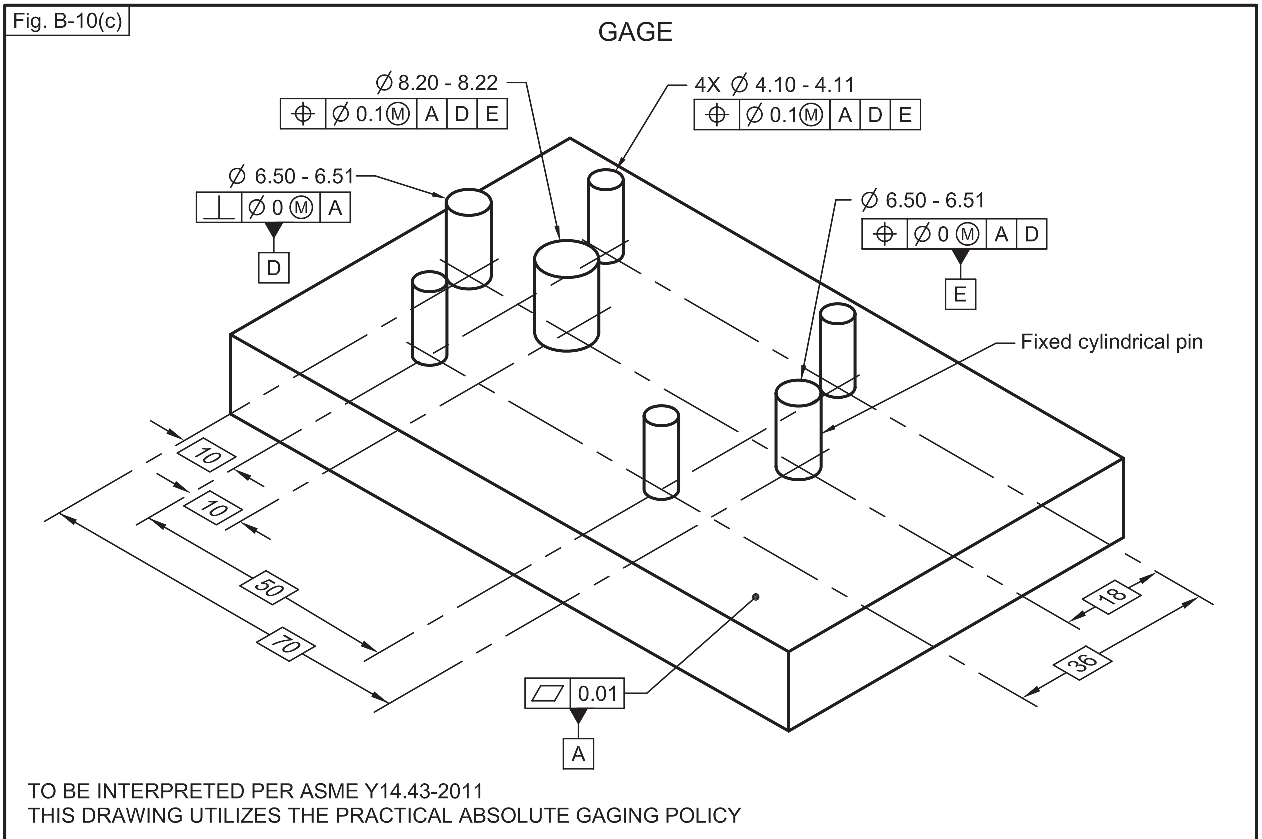


Fig. B-10 Controlling Rotation With Datum Features of Size (Cont'd)



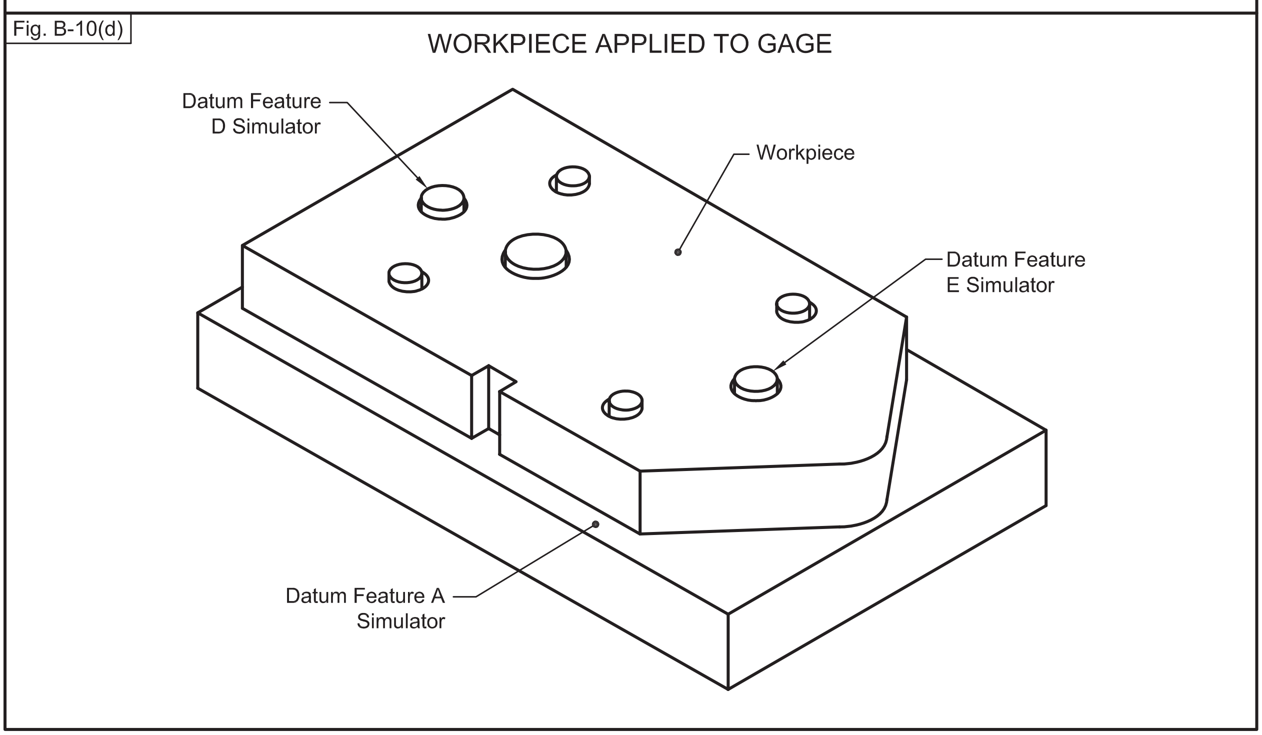


Fig. B-11 Controlling Rotation With Datum Features of Size Using Translation Symbol

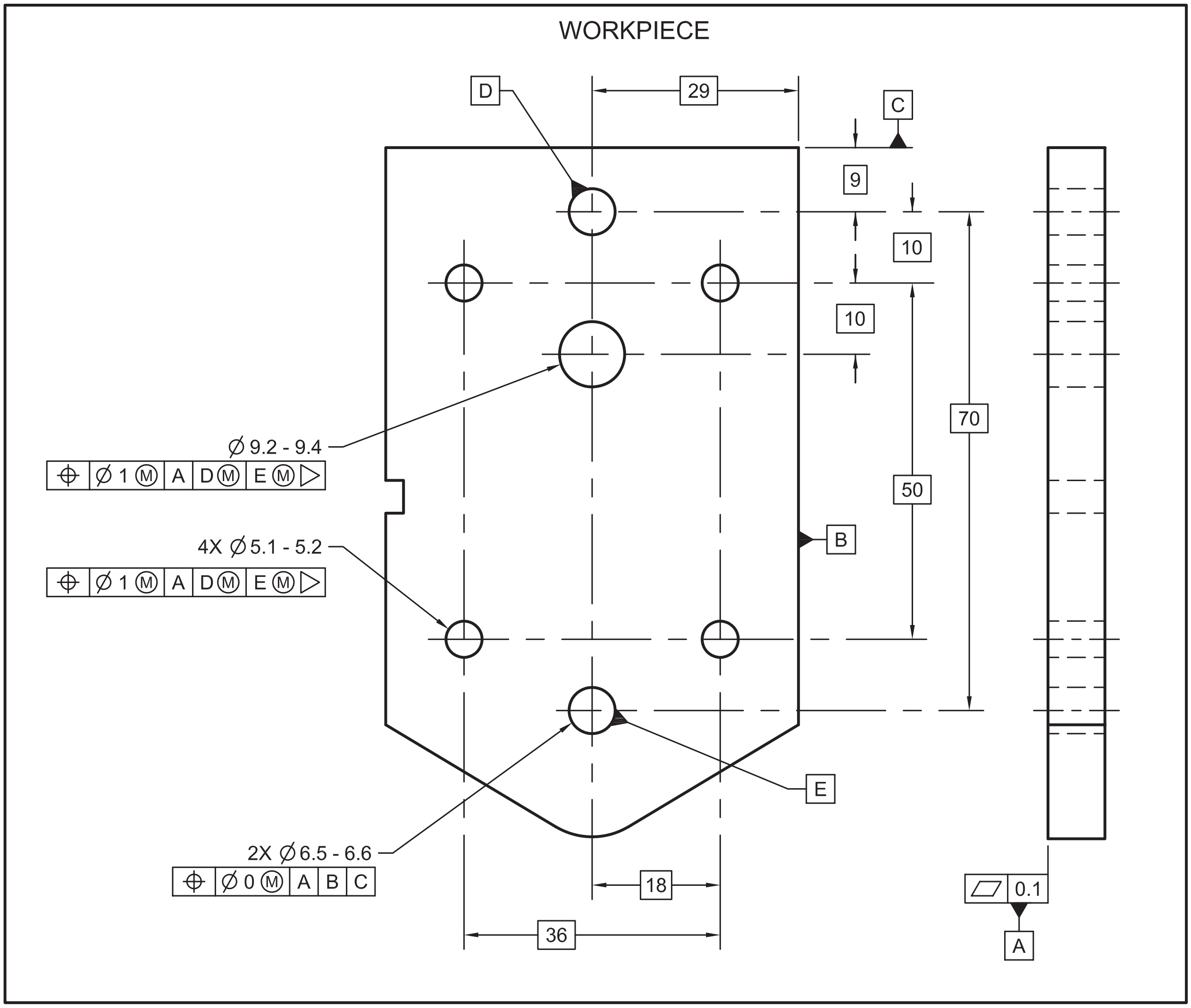


Fig. B-11 Controlling Rotation With Datum Features of Size Using Translation Symbol (Cont'd)

Fig. B-11(a)

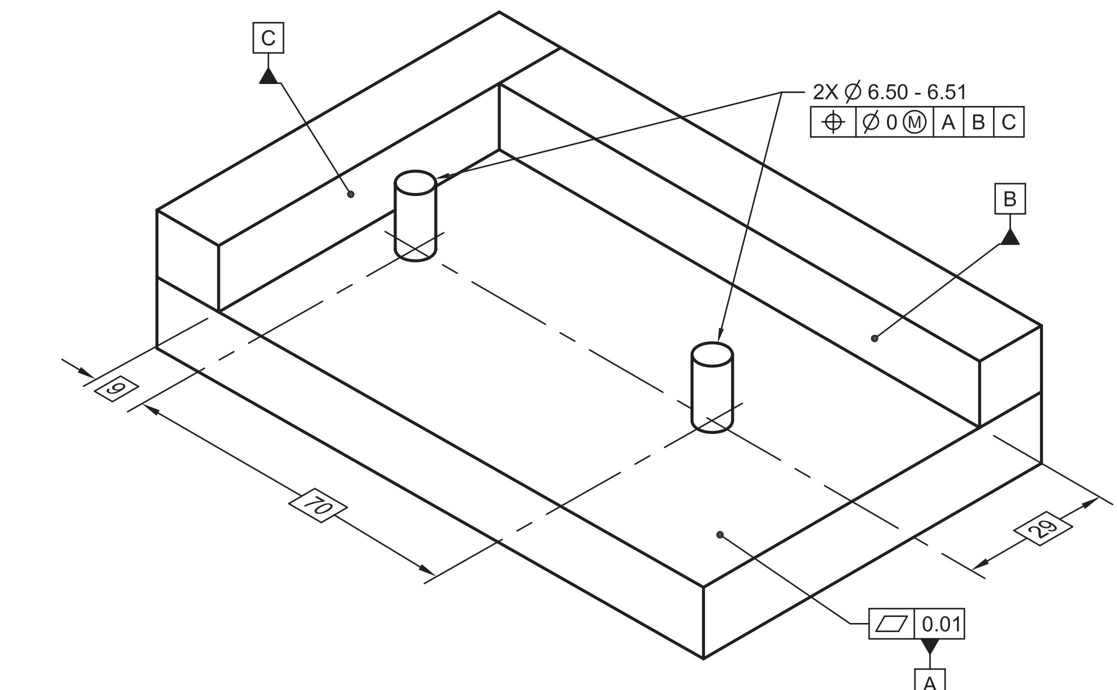


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Fig. B-11(b)

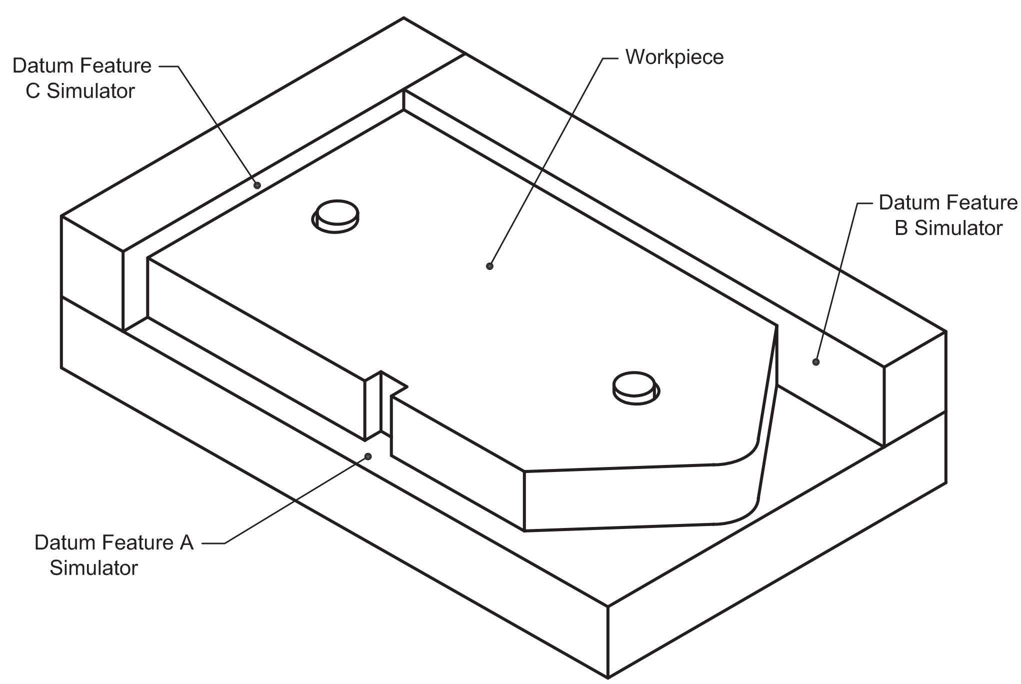


Fig. B-11 Controlling Rotation With Datum Features of Size Using Translation Symbol (Cont'd)

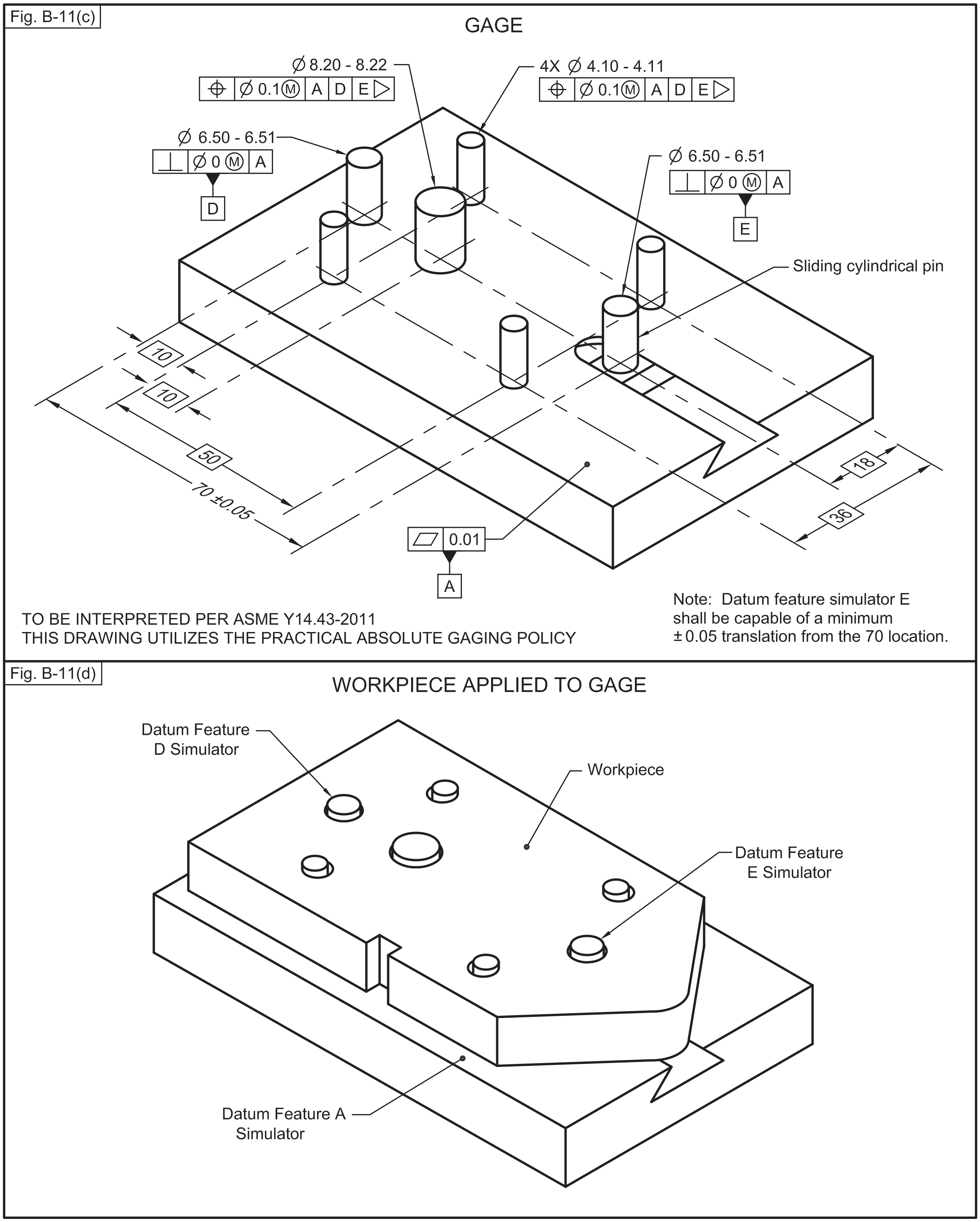


Fig. B-12 Interrelated Datum Reference Frames

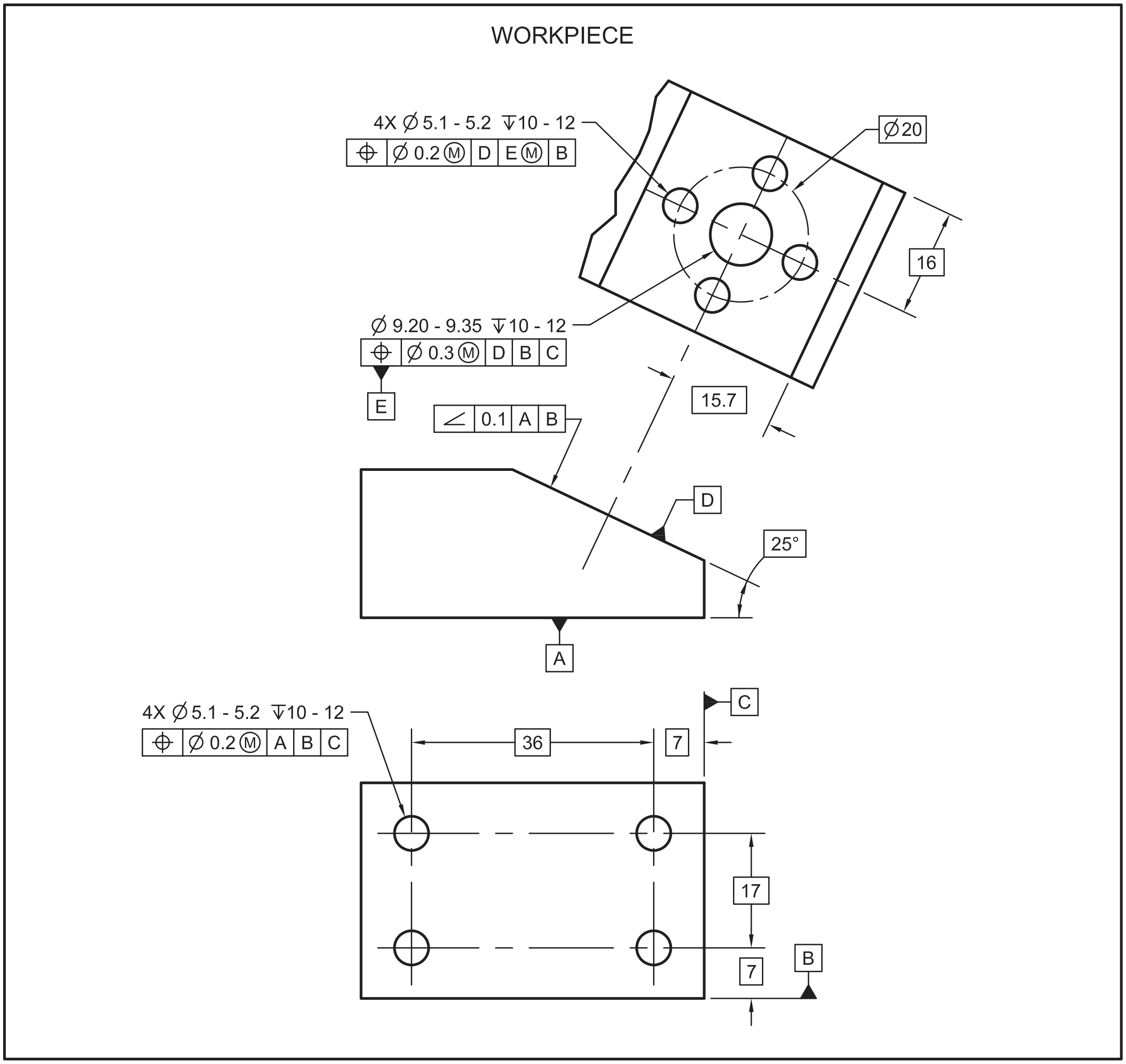


Fig. B-12 Interrelated Datum Reference Frames (Cont'd)

Fig. B-12(a)

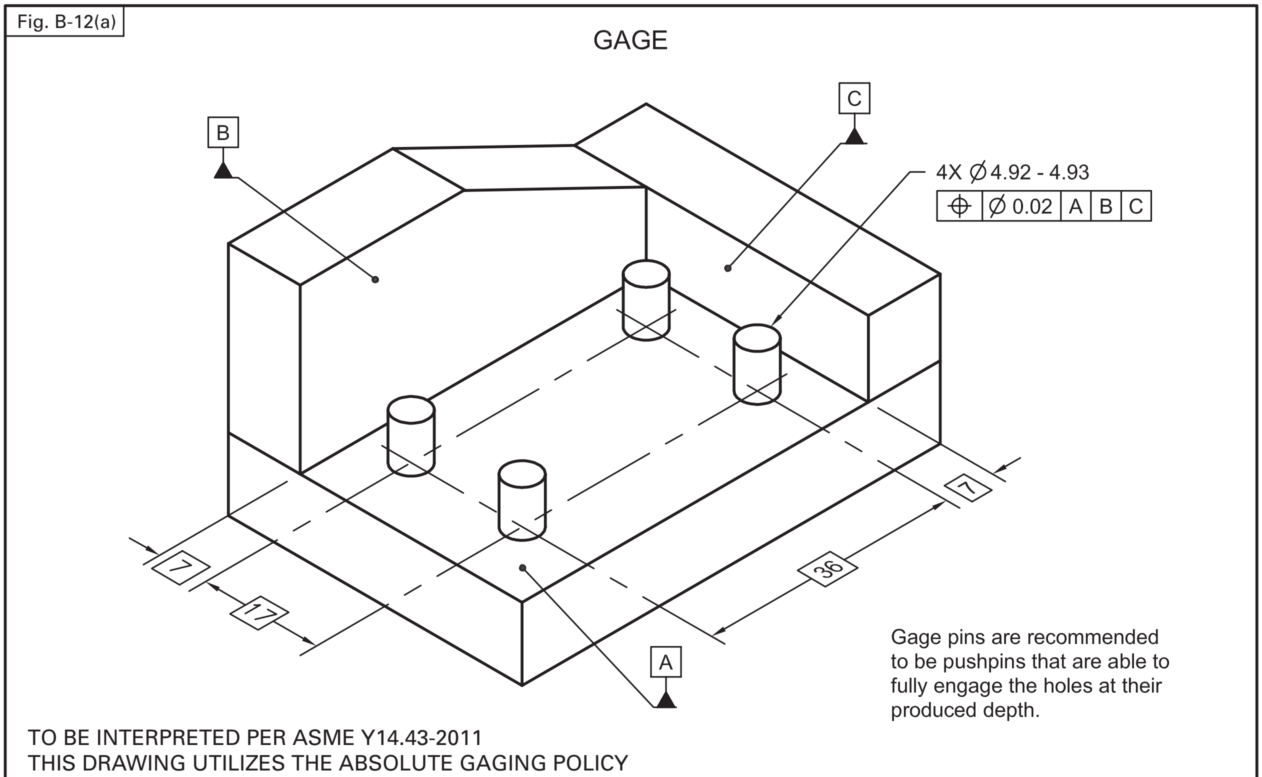


Fig. B-12(b)

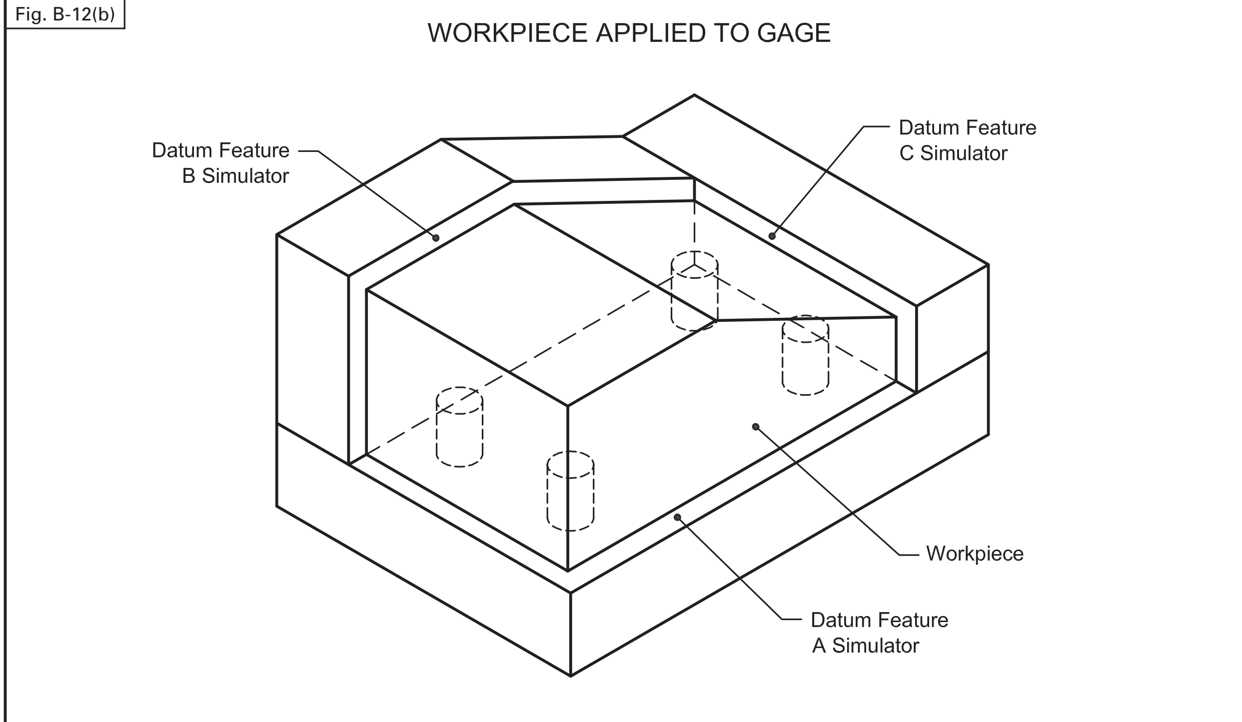
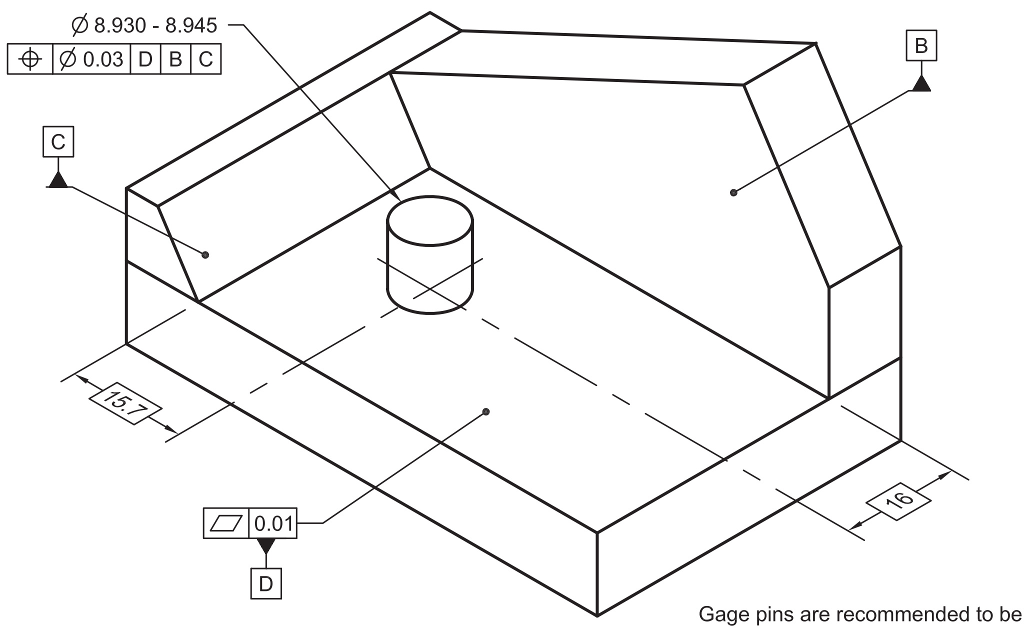


Fig. B-12 Interrelated Datum Reference Frames (Cont'd)

Fig. B-12(c)

GAGE



Gage pins are recommended to be pushpins that are able to fully engage the holes at their produced depth.

TO BE INTERPRETED PER ASME Y14.43-2011
THIS DRAWING UTILIZES THE ABSOLUTE GAGING POLICY

Fig. B-12(d)

WORKPIECE APPLIED TO GAGE

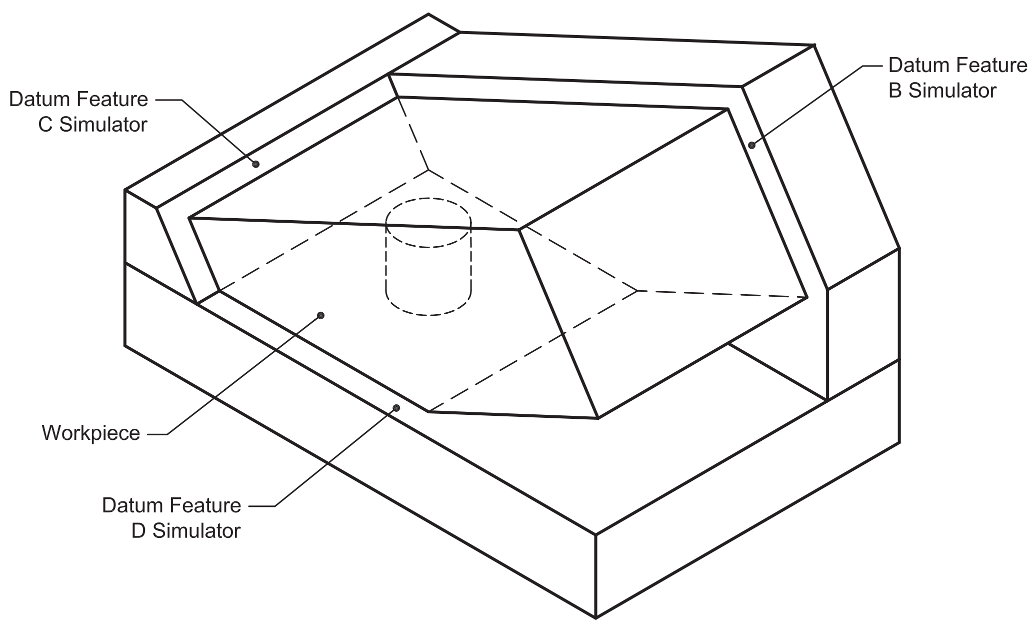


Fig. B-12 Interrelated Datum Reference Frames (Cont'd)

Fig. B-12(e)

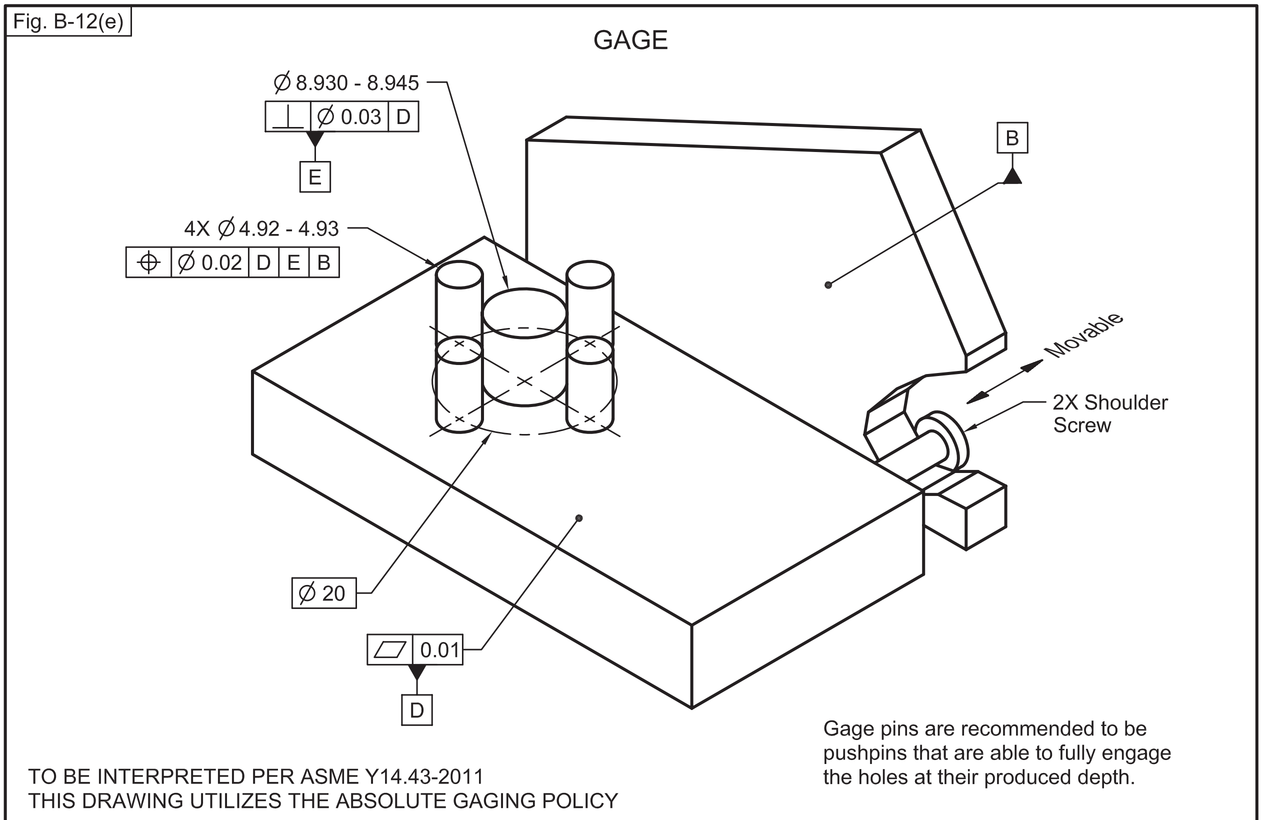


Fig. B-12(f)

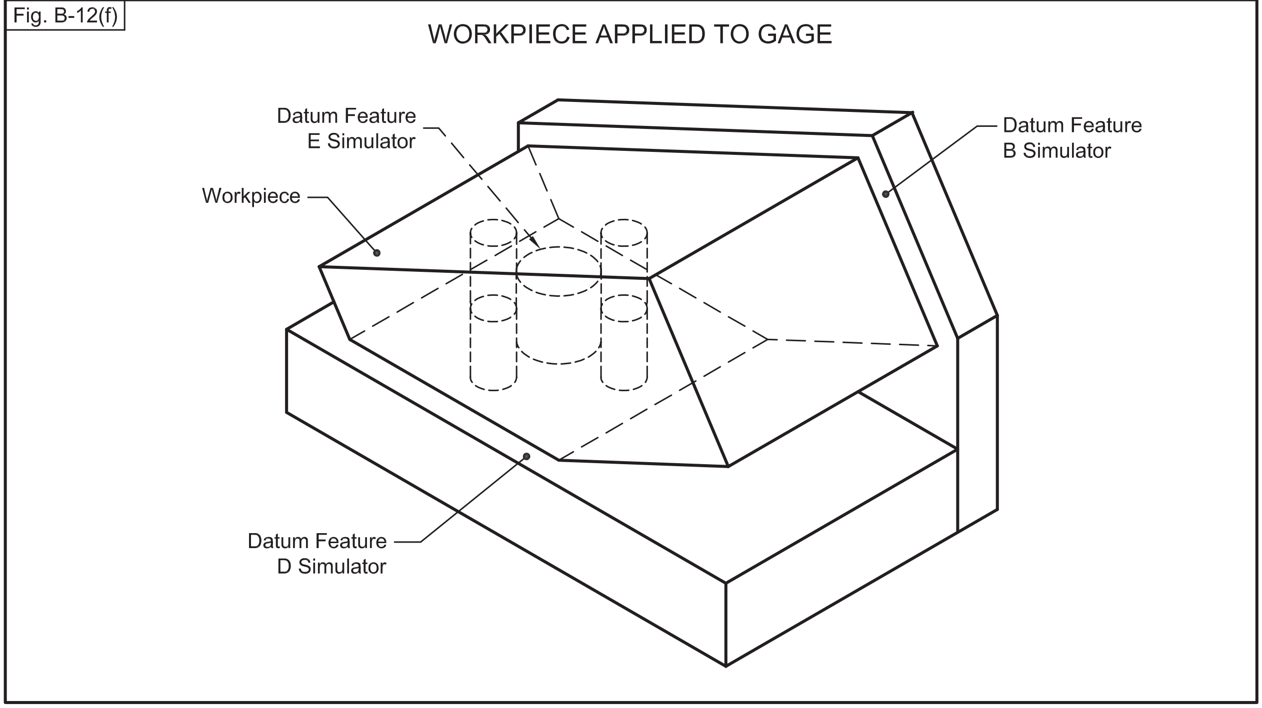


Fig. B-13 Two Datum Features, Single Datum Axis

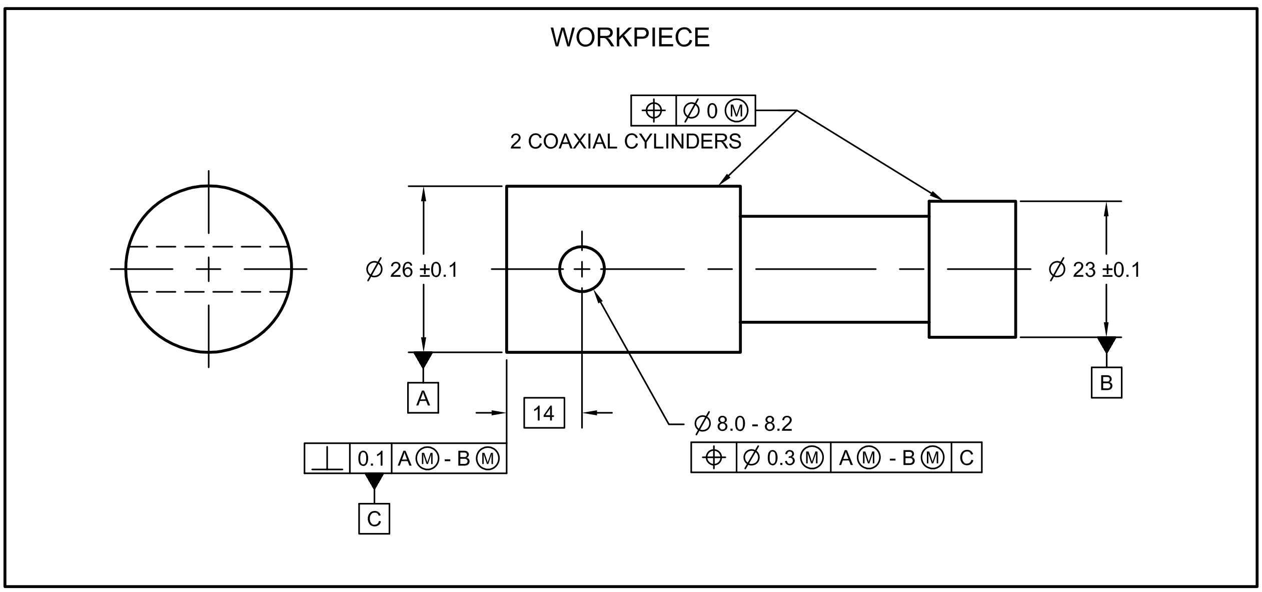
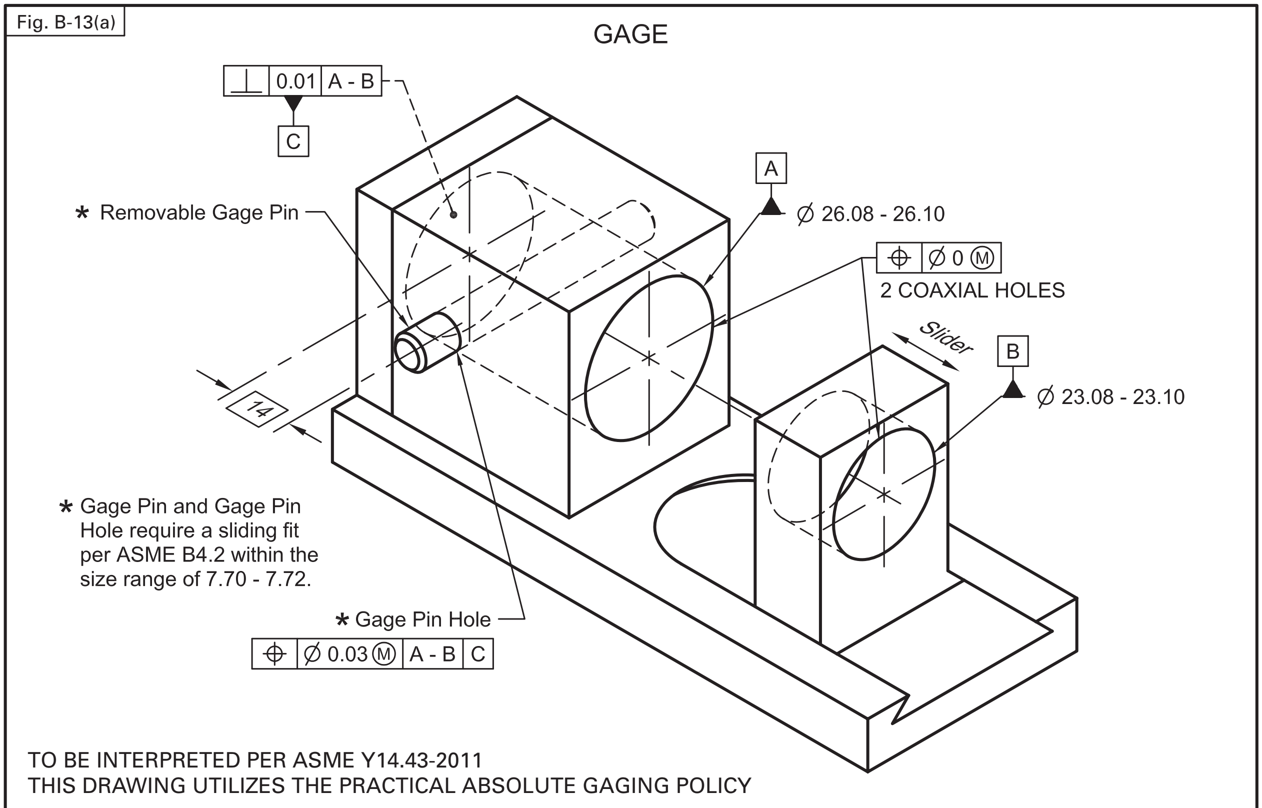


Fig. B-13 Two Datum Features, Single Datum Axis (Cont'd)



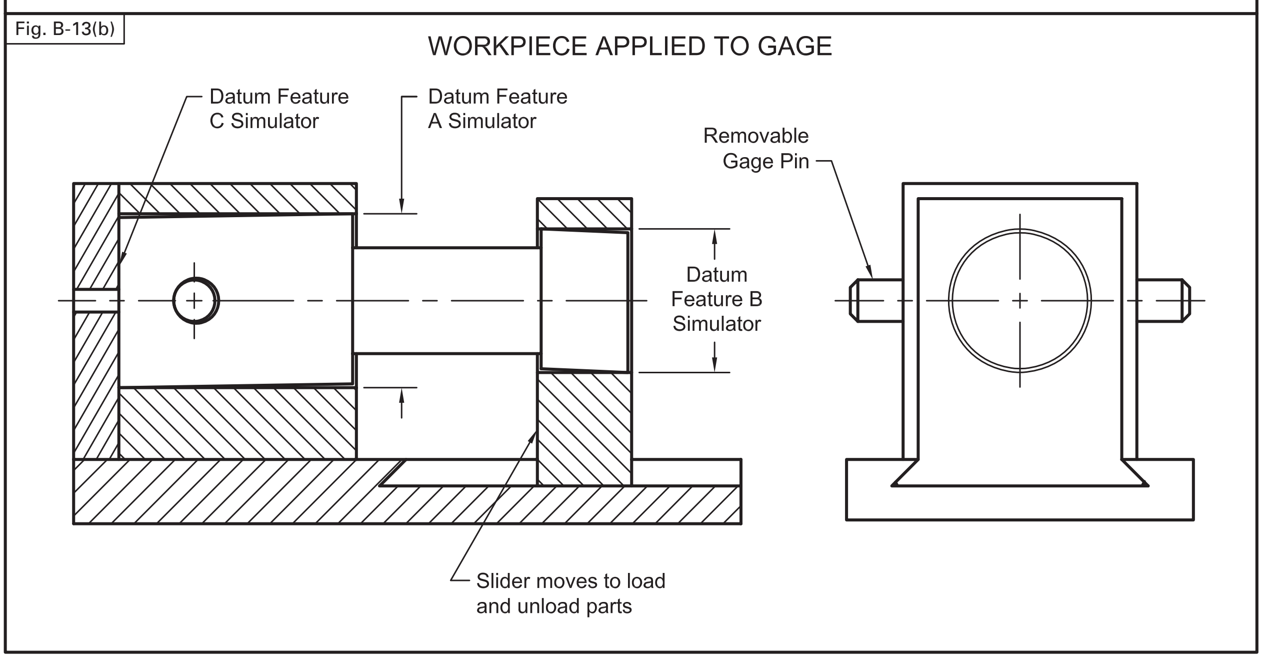


Fig. B-14 Hole Pattern as a Datum

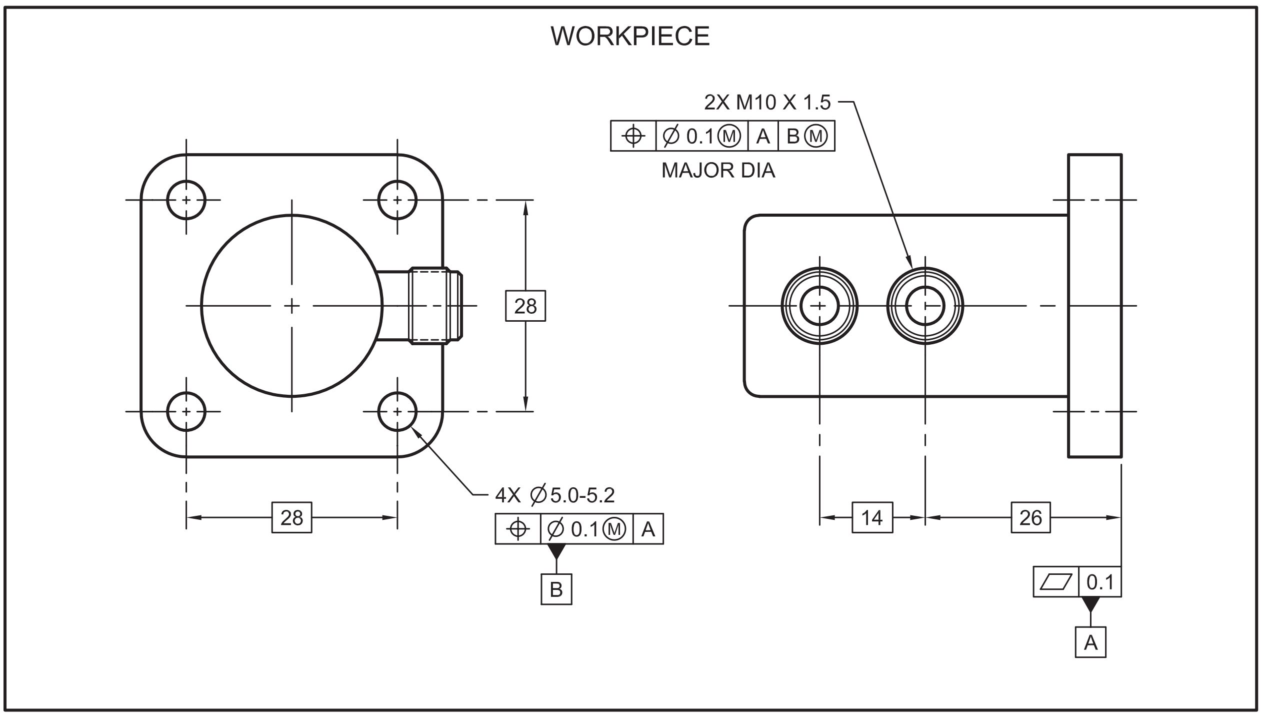


Fig. B-14 Hole Pattern as a Datum (Cont'd)

Fig. B-14(a)

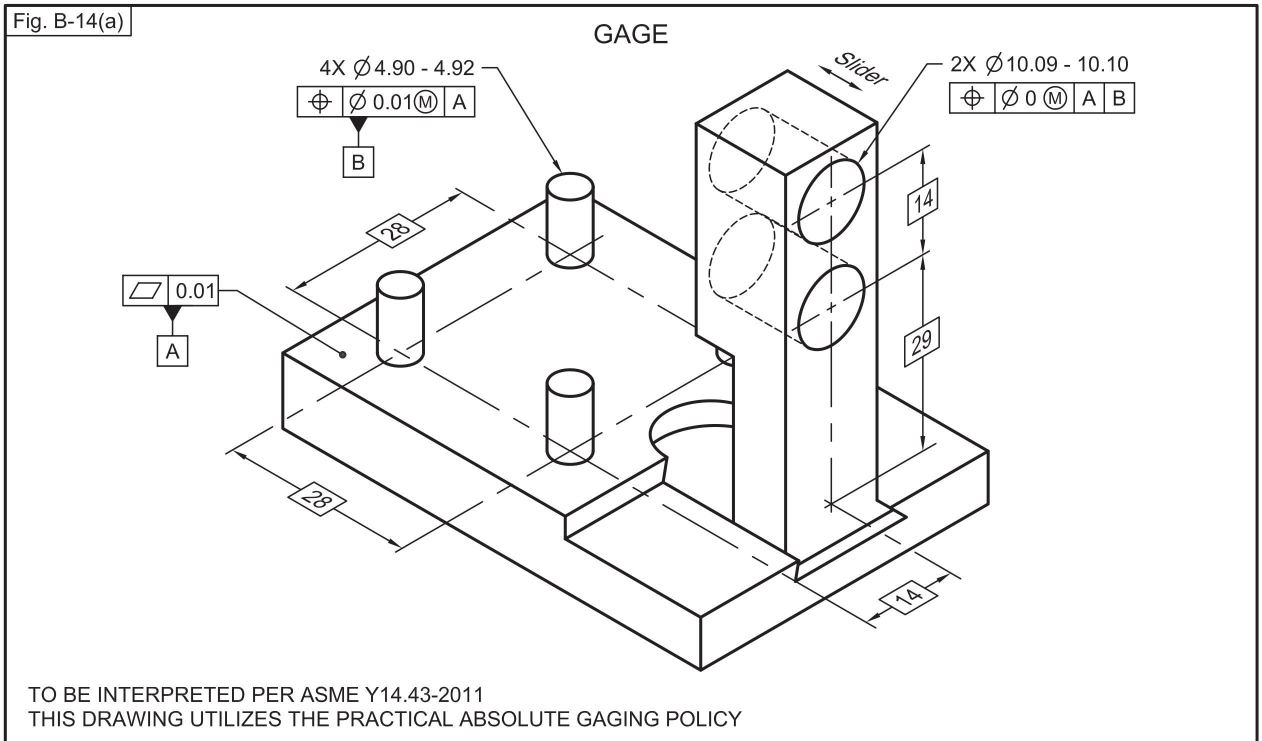


Fig. B-14(b)

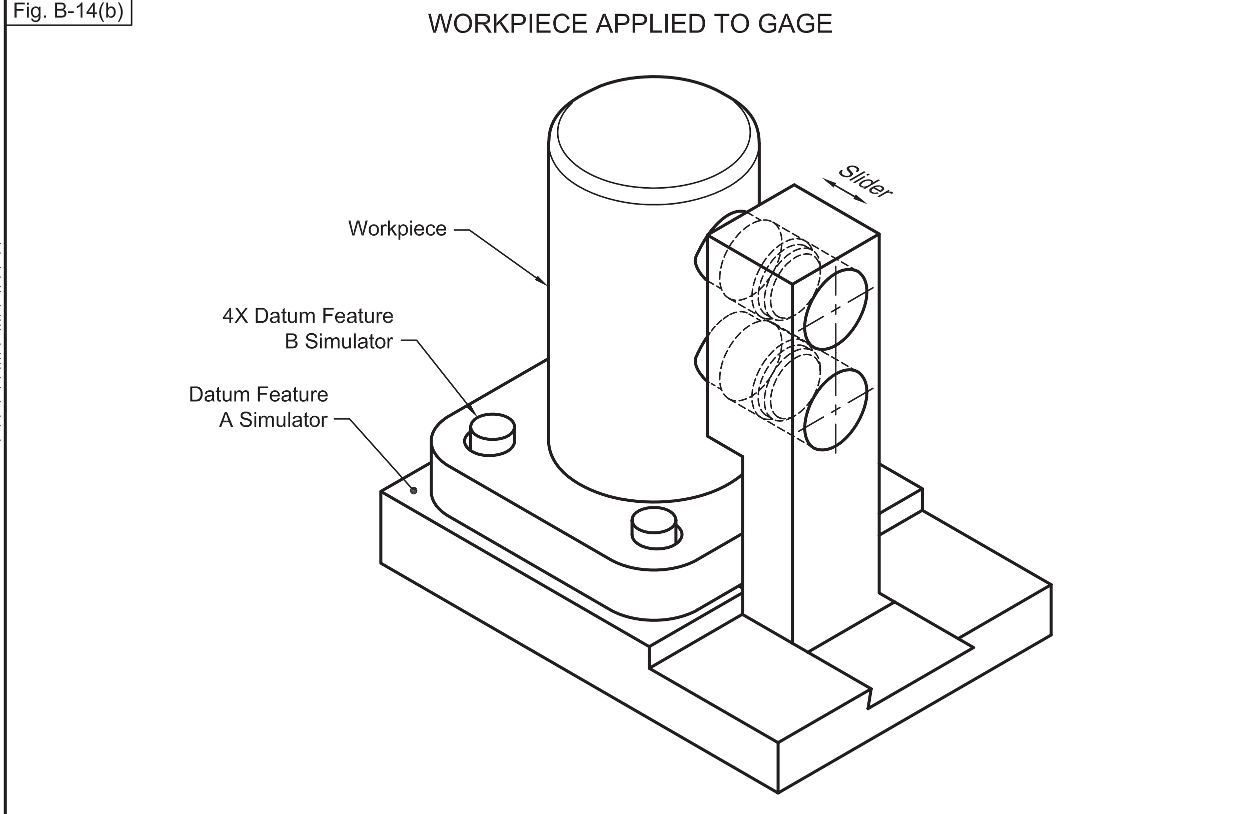


Fig. B-15 Application of Moveable Datum Targets (ASME Y14.5-2009)

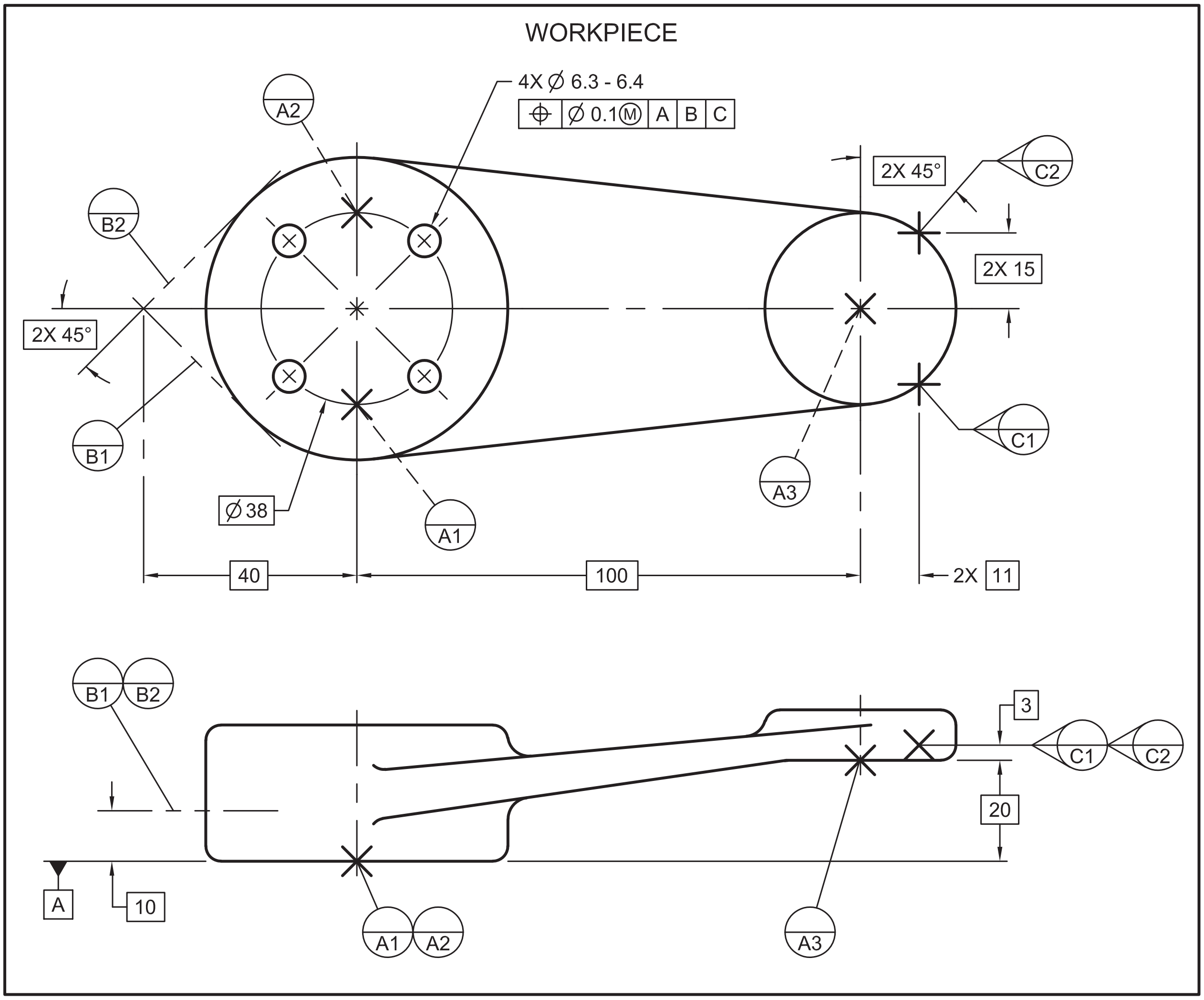
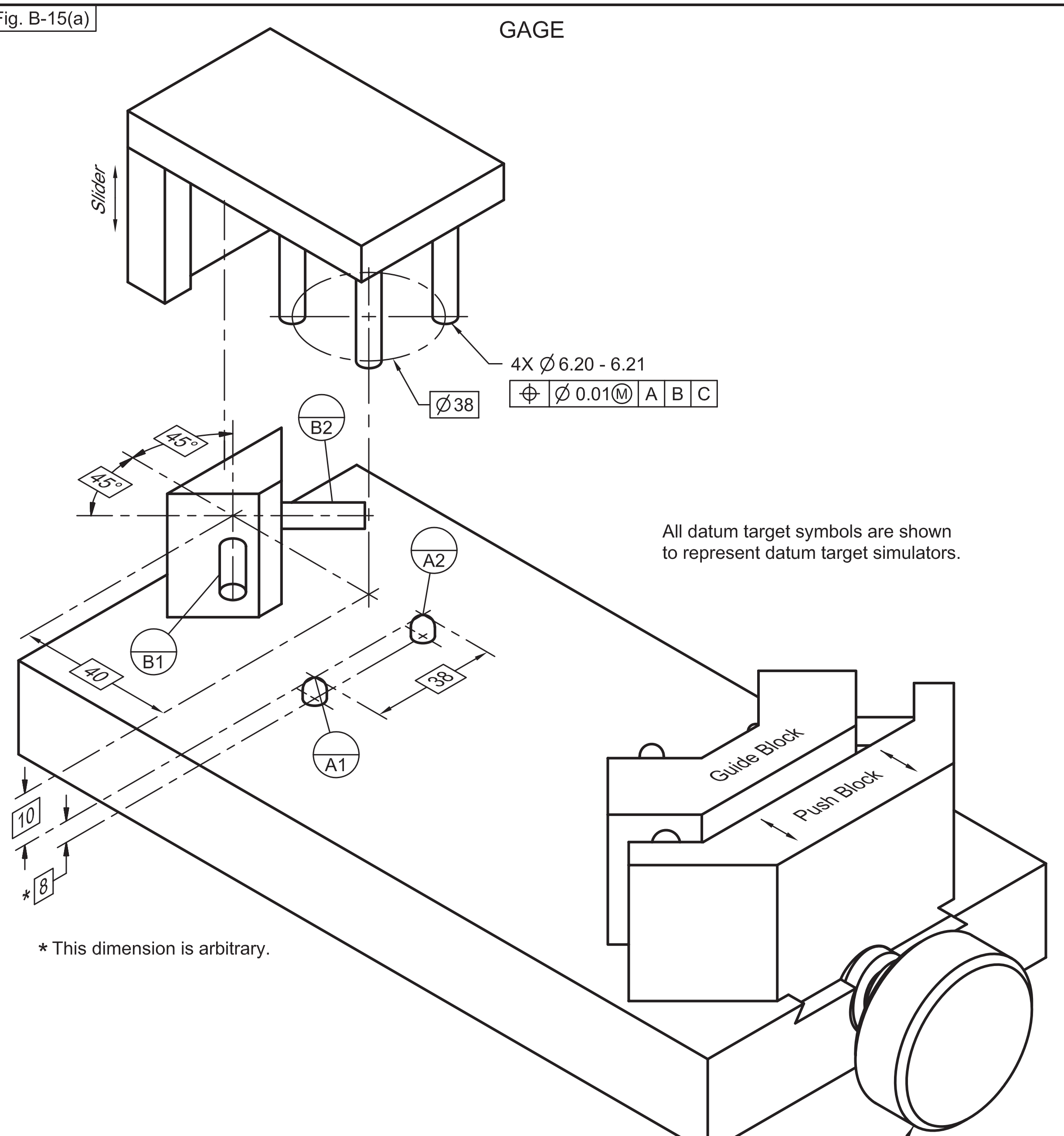


Fig. B-15 Application of Moveable Datum Targets (ASME Y14.5-2009) (Cont'd)

Fig. B-15(a)

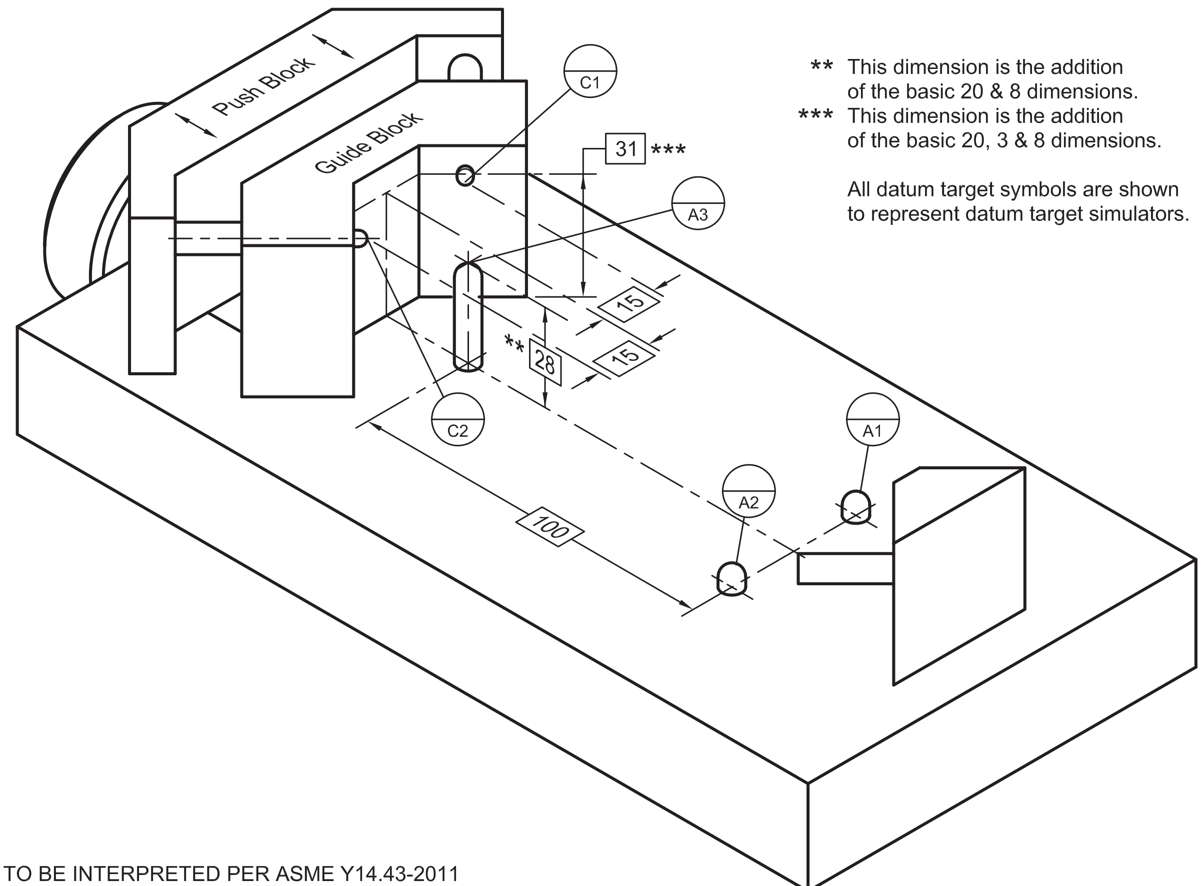


TO BE INTERPRETED PER ASME Y14.43-2011
THIS DRAWING UTILIZES THE PRACTICAL ABSOLUTE GAGING POLICY

Fig. B-15 Application of Moveable Datum Targets (ASME Y14.5-2009) (Cont'd)

Fig. B-15(b)

GAGE



** This dimension is the addition of the basic 20 & 8 dimensions.

*** This dimension is the addition of the basic 20, 3 & 8 dimensions.

All datum target symbols are shown to represent datum target simulators.

TO BE INTERPRETED PER ASME Y14.43-2011
THIS DRAWING UTILIZES THE PRACTICAL ABSOLUTE GAGING POLICY

Fig. B-15 Application of Moveable Datum Targets (ASME Y14.5-2009) (Cont'd)

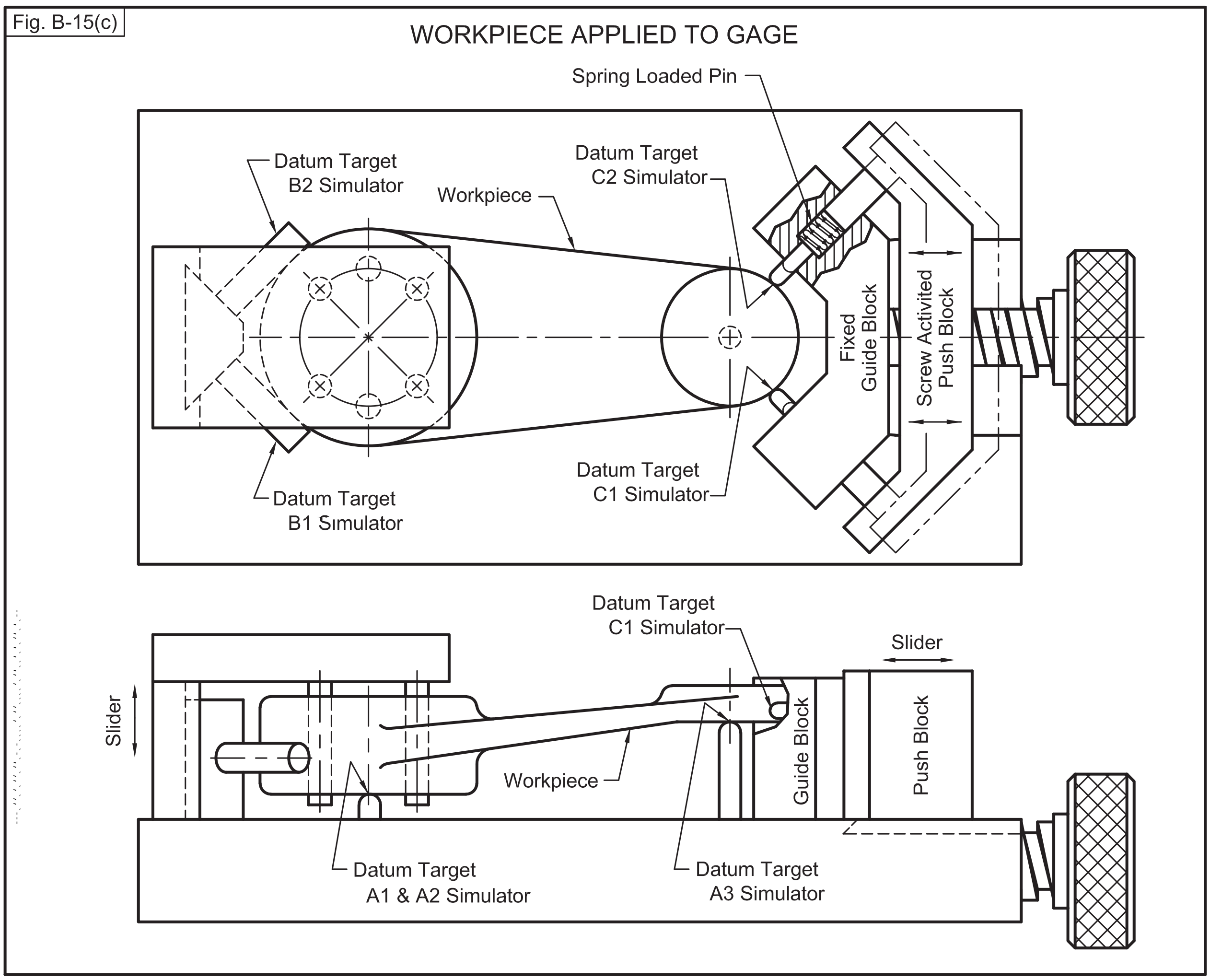


Fig. B-15 Application of Moveable Datum Targets (ASME Y14.5M-1994) (Cont'd)

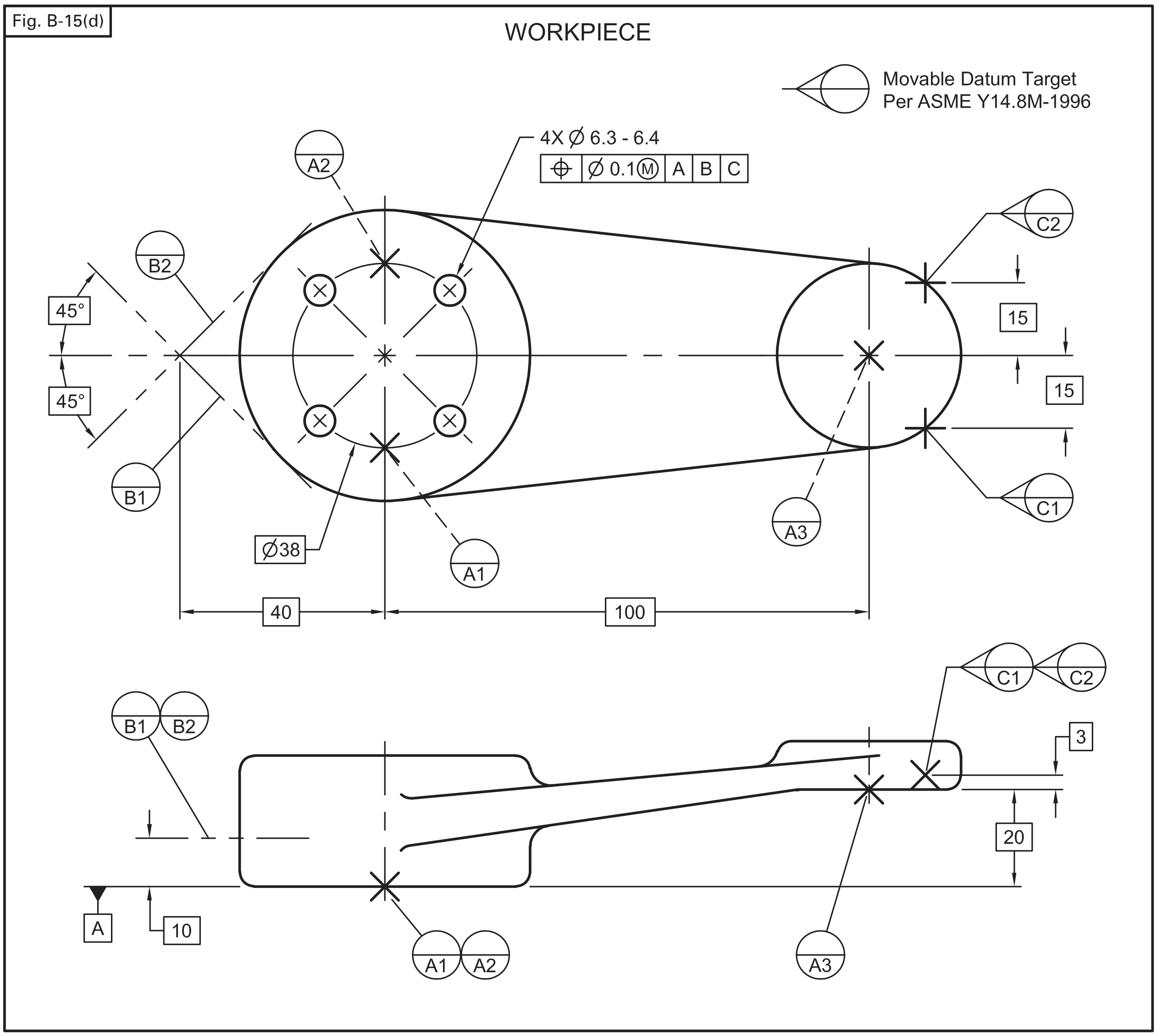


Fig. B-15 Application of Moveable Datum Targets (ASME Y14.5M-1994) (Cont'd)

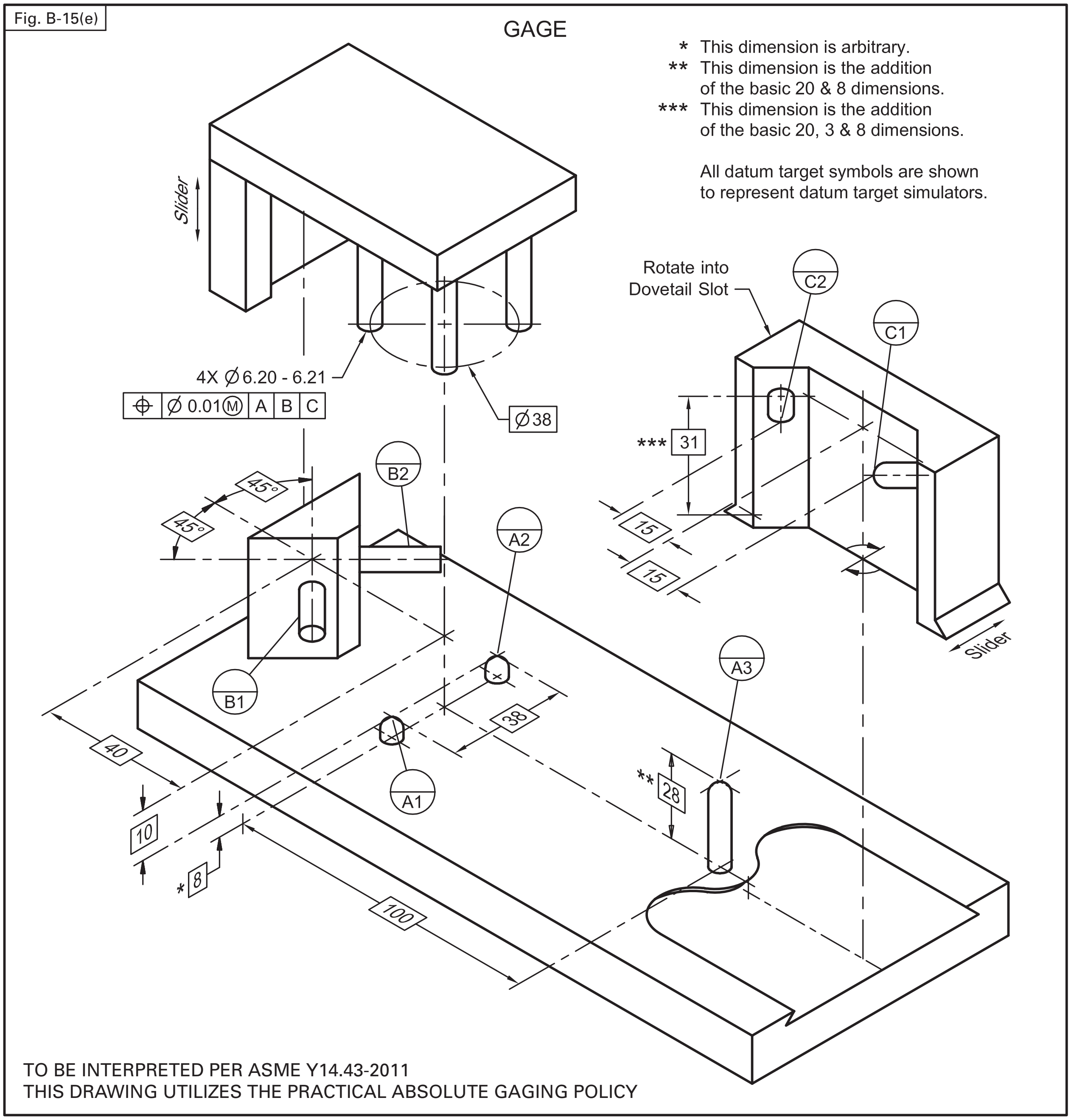


Fig. B-15 Application of Moveable Datum Targets (ASME Y14.5M-1994) (Cont'd)

Fig. B-15(f)

WORKPIECE APPLIED TO GAGE

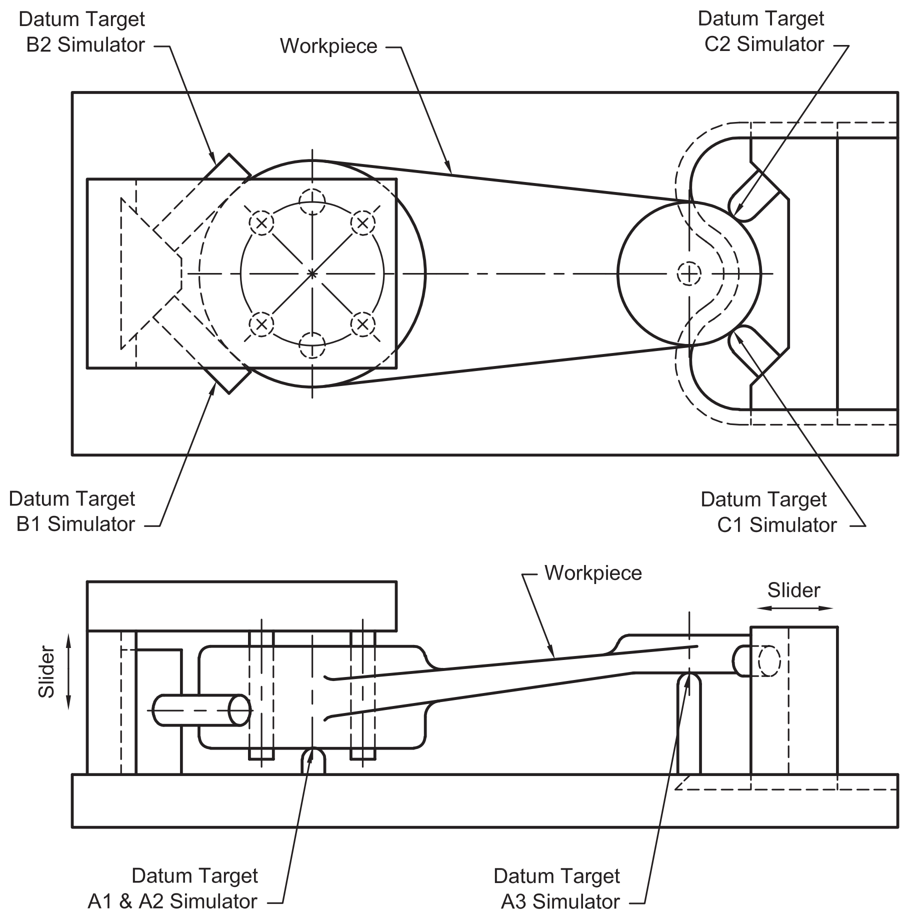


Fig. B-16 Irregular Closed Feature Used as a Datum Feature

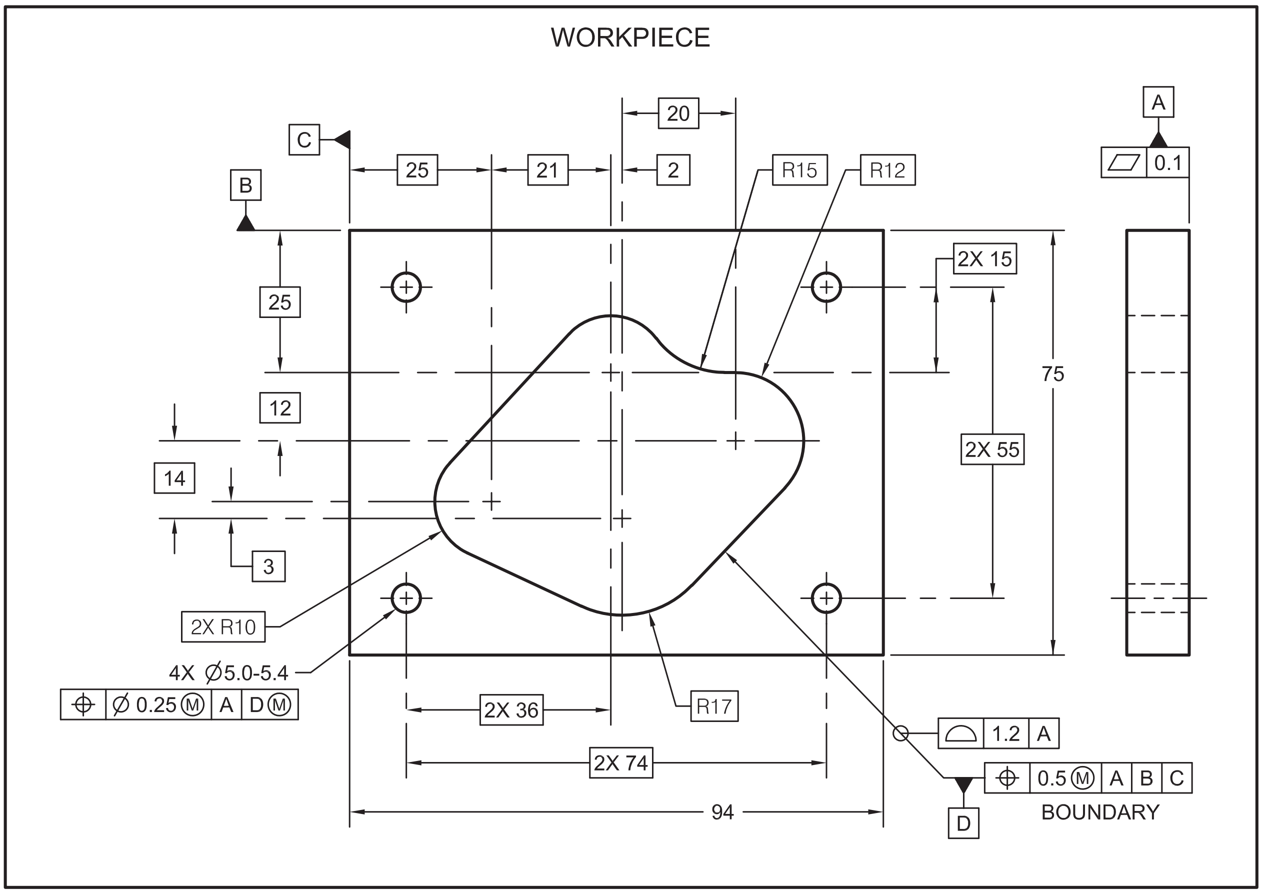


Fig. B-16 Irregular Closed Feature Used as a Datum Feature (Cont'd)

Fig. B-16(a)

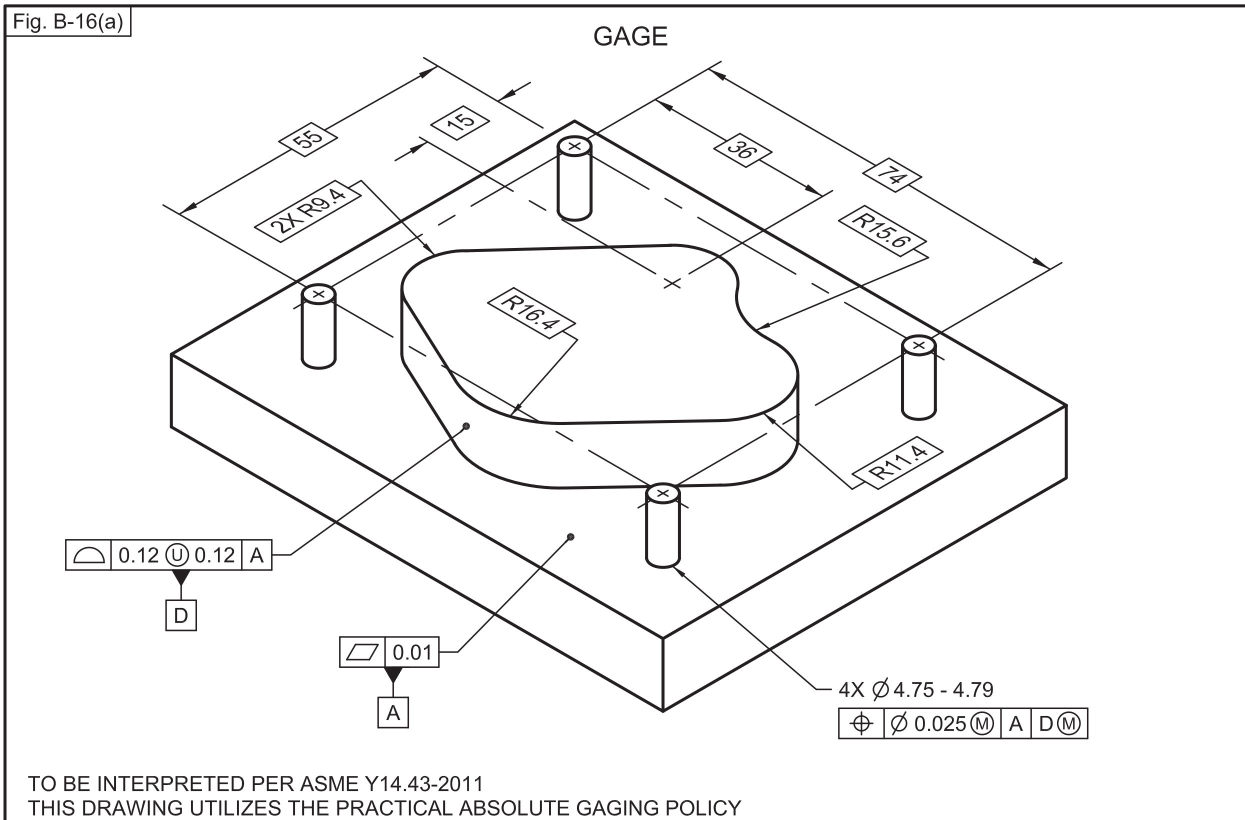


Fig. B-16(b)

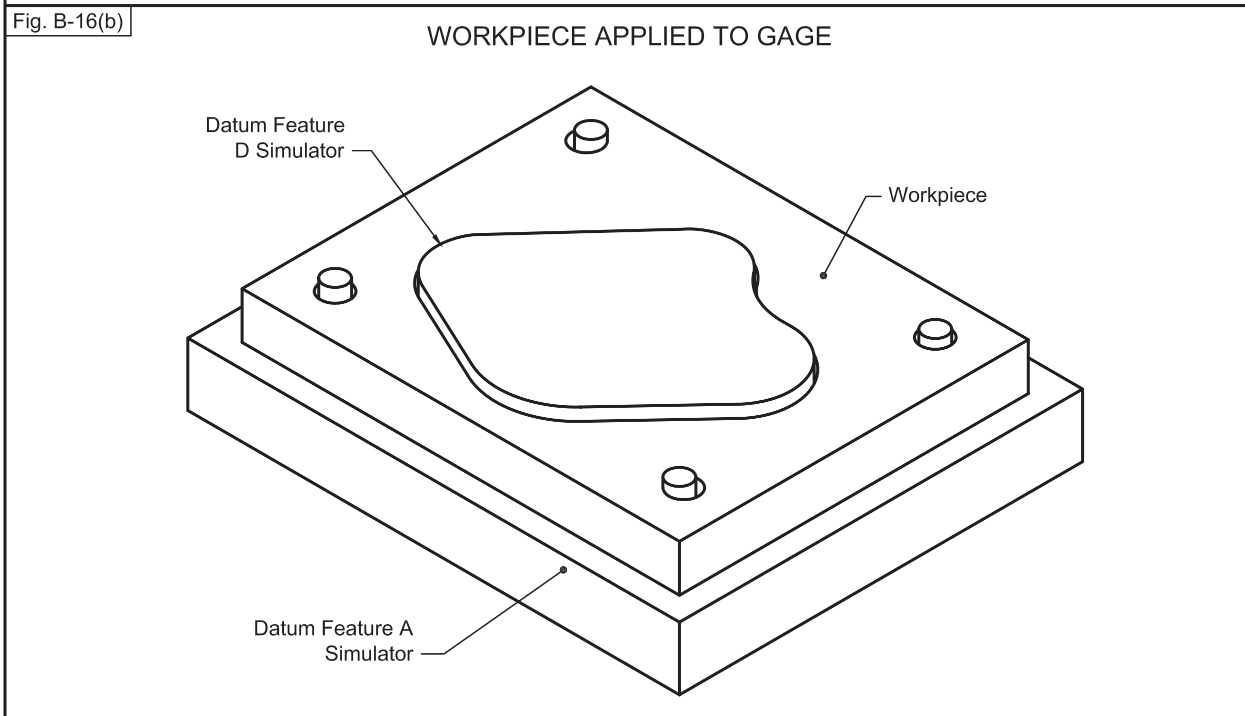


Fig. B-17 Radial Hole Pattern Located by Composite Position

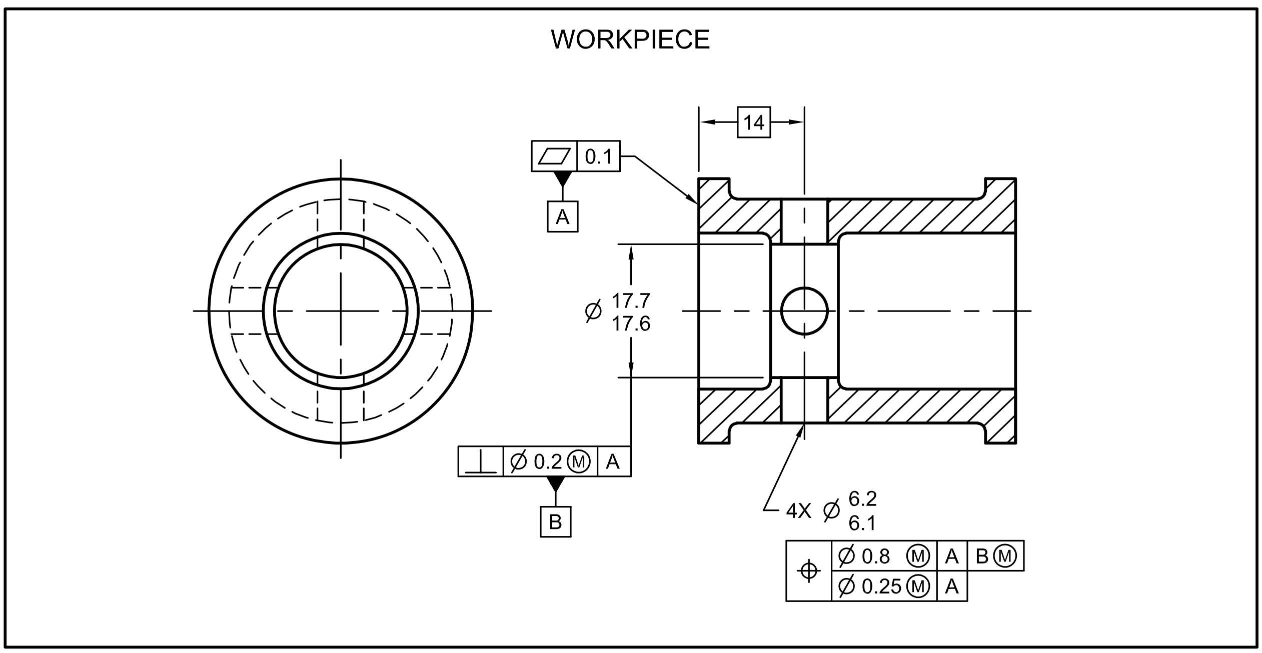
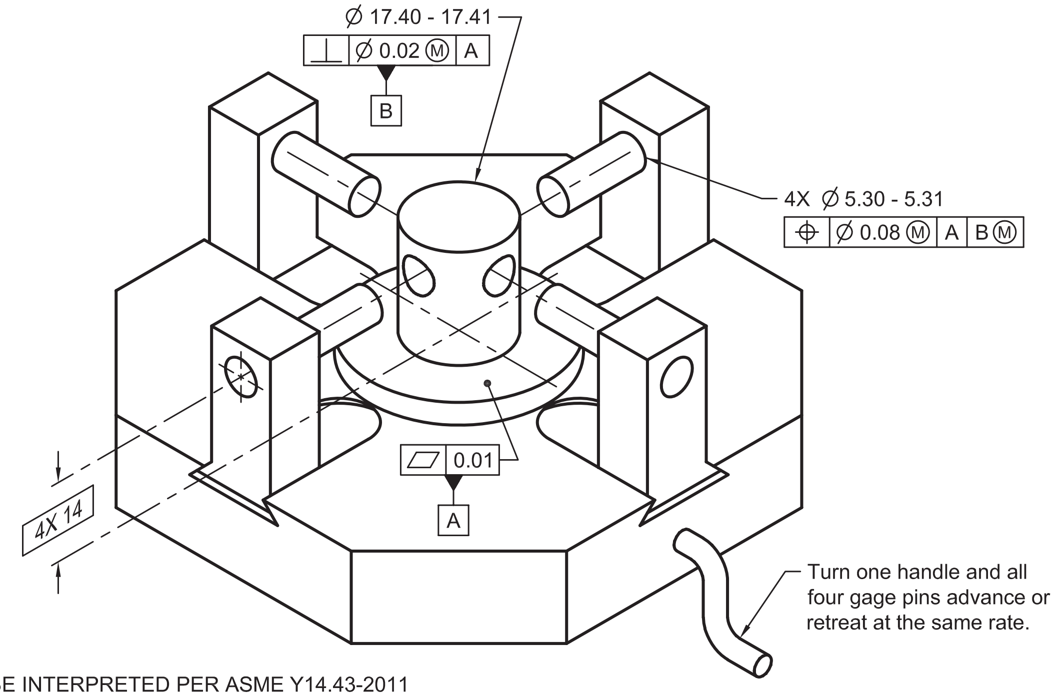


Fig. B-17 Radial Hole Pattern Located by Composite Position (Cont'd)

Fig. B-17(a)

GAGE



TO BE INTERPRETED PER ASME Y14.43-2011
THIS DRAWING UTILIZES THE PRACTICAL ABSOLUTE GAGING POLICY

Fig. B-17(b)

WORKPIECE APPLIED TO GAGE

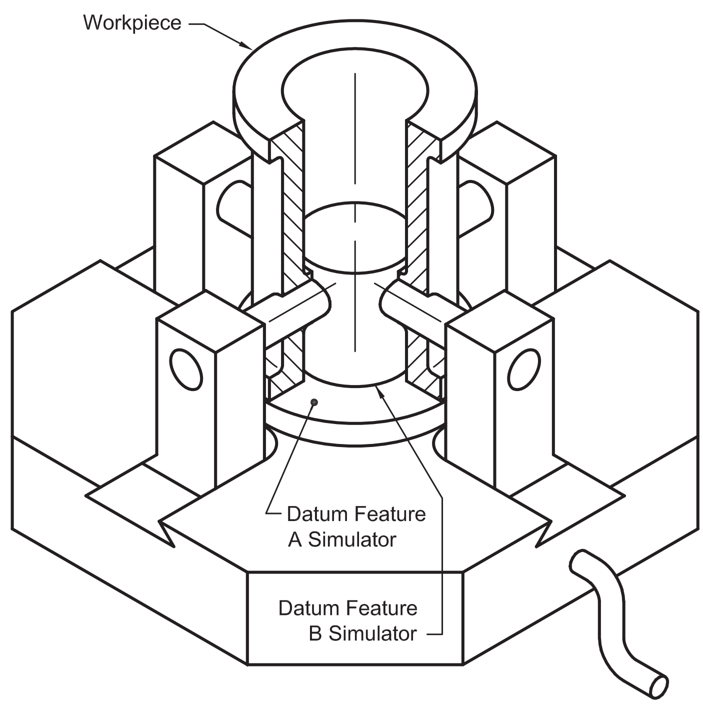
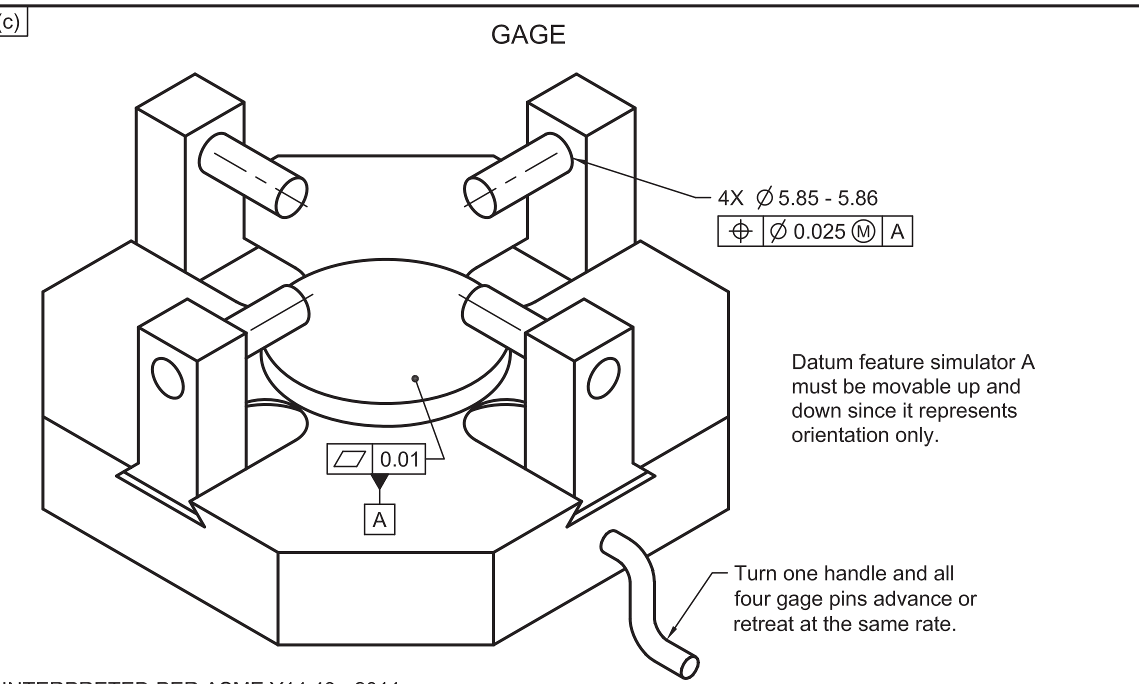


Fig. B-17 Radial Hole Pattern Located by Composite Position (Cont'd)

Fig. B-17(c)



TO BE INTERPRETED PER ASME Y14.43 - 2011
THIS DRAWING UTILIZES THE PRACTICAL ABSOLUTE GAGING POLICY

Fig. B-17(d)

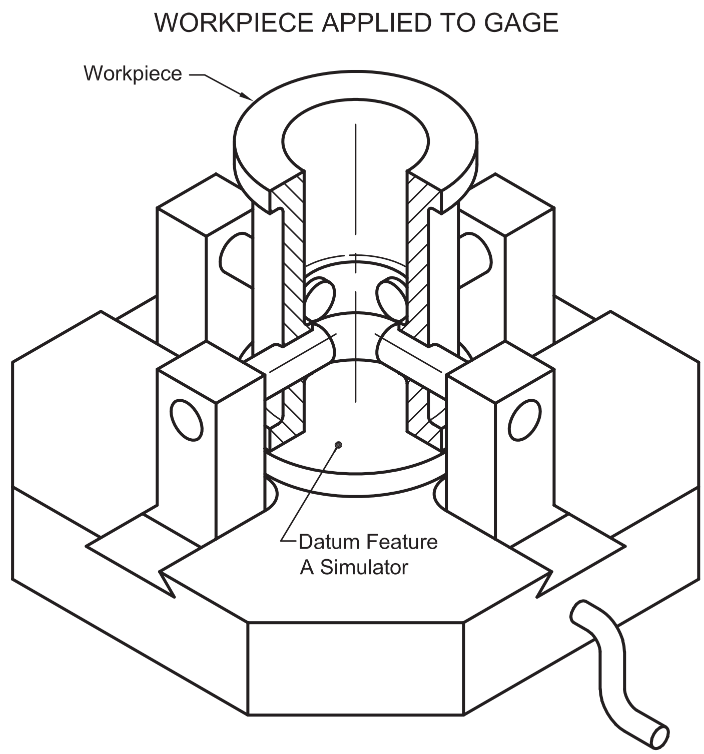


Fig. B-18 Datum Targets on a Complex Part

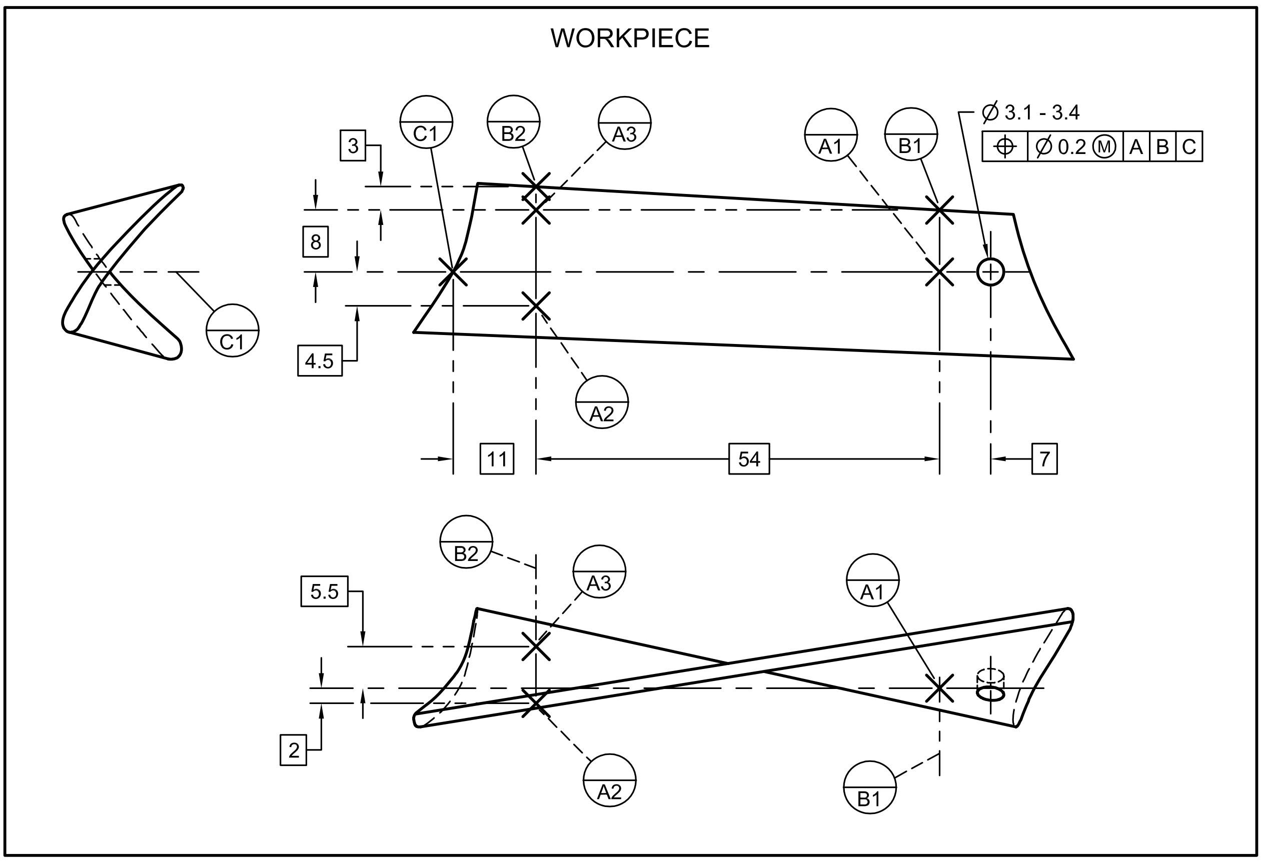


Fig. B-18 Datum Targets on a Complex Part (Cont'd)

Fig. B-18(a)

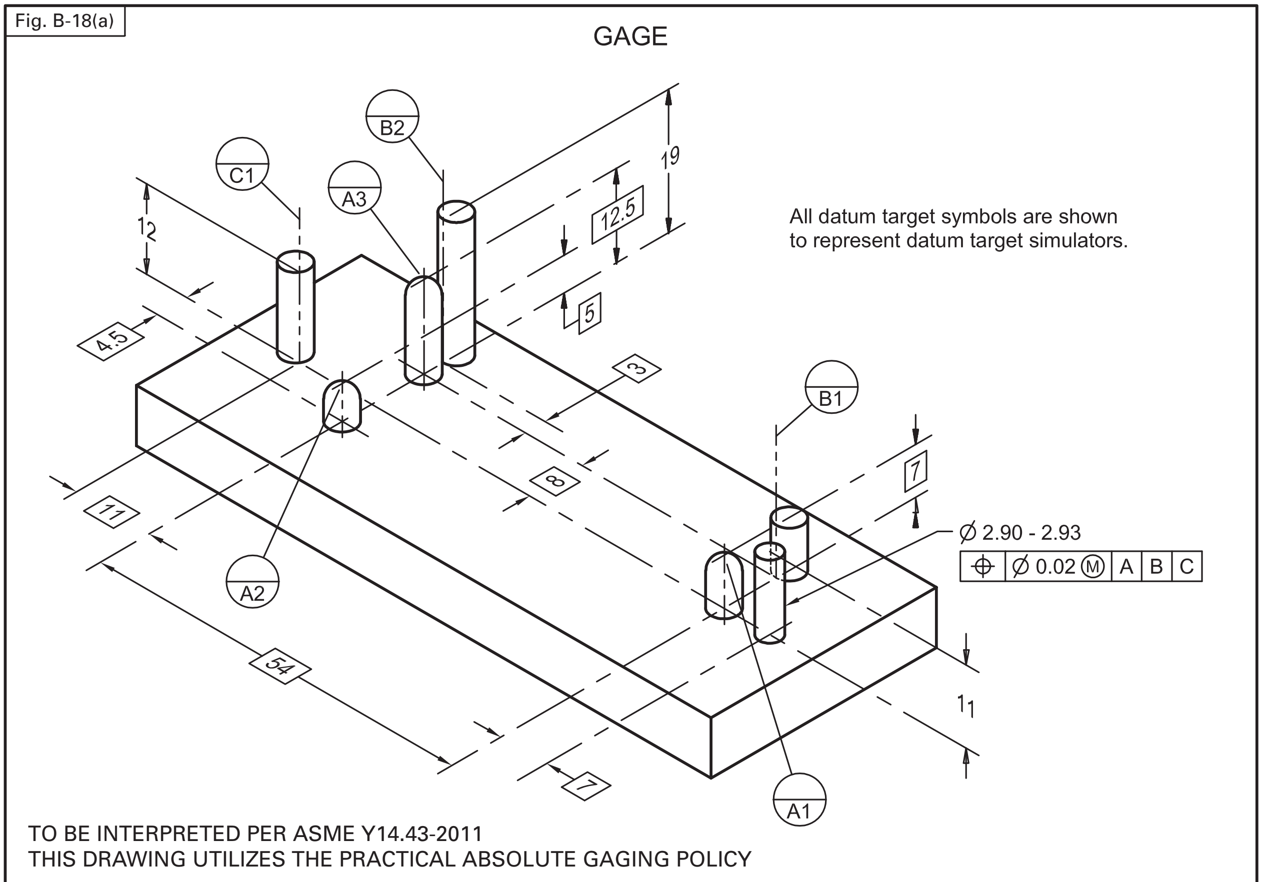


Fig. B-18(b)

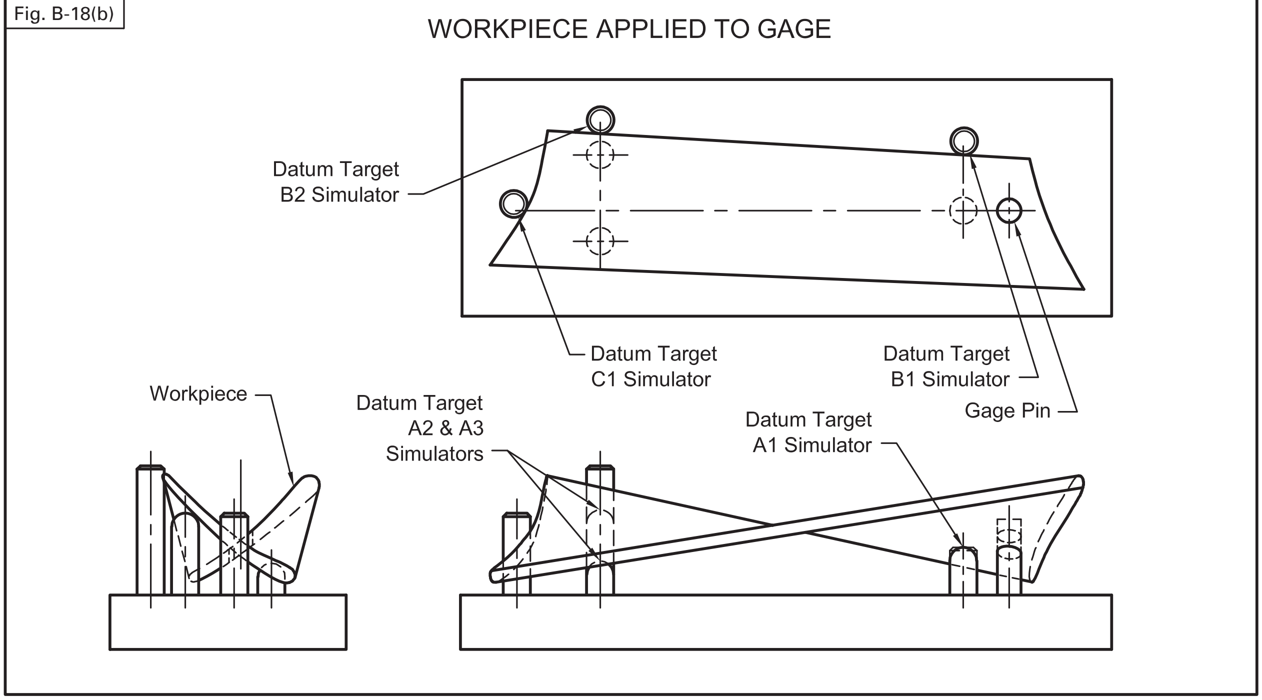


Fig. B-19 Push Pin Gages for Part With Clearance Holes

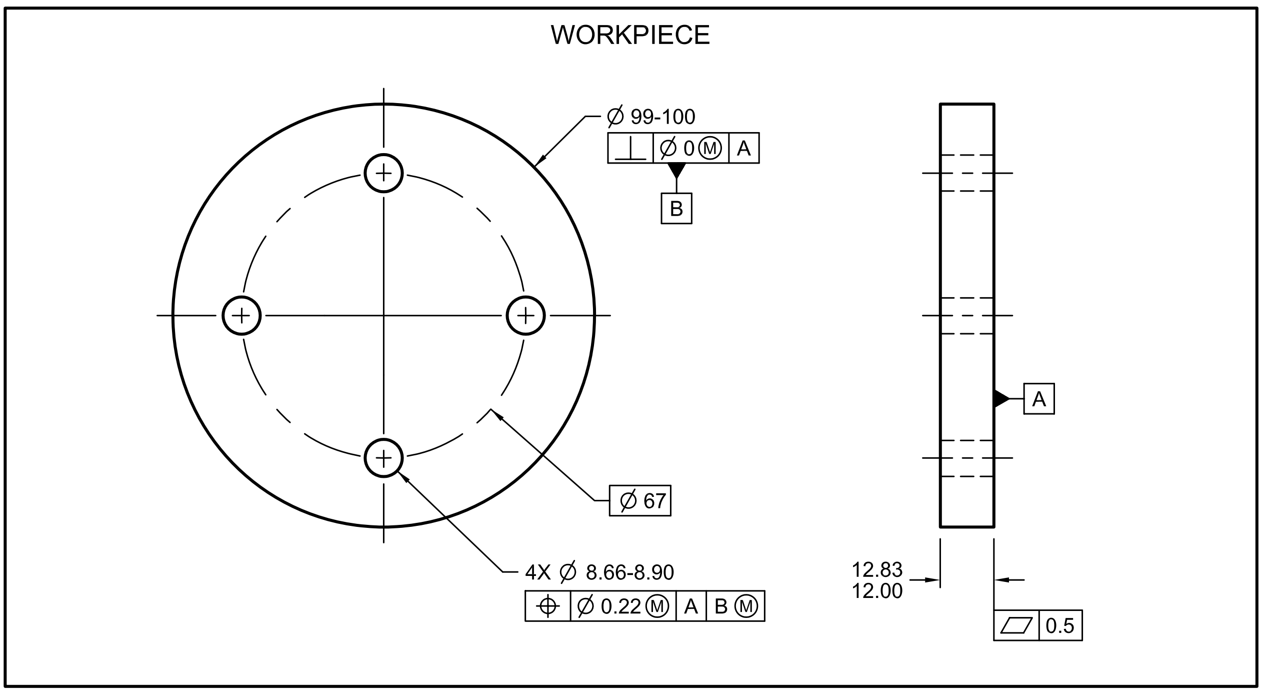


Fig. B-19 Push Pin Gages for Part With Clearance Holes (Cont'd)

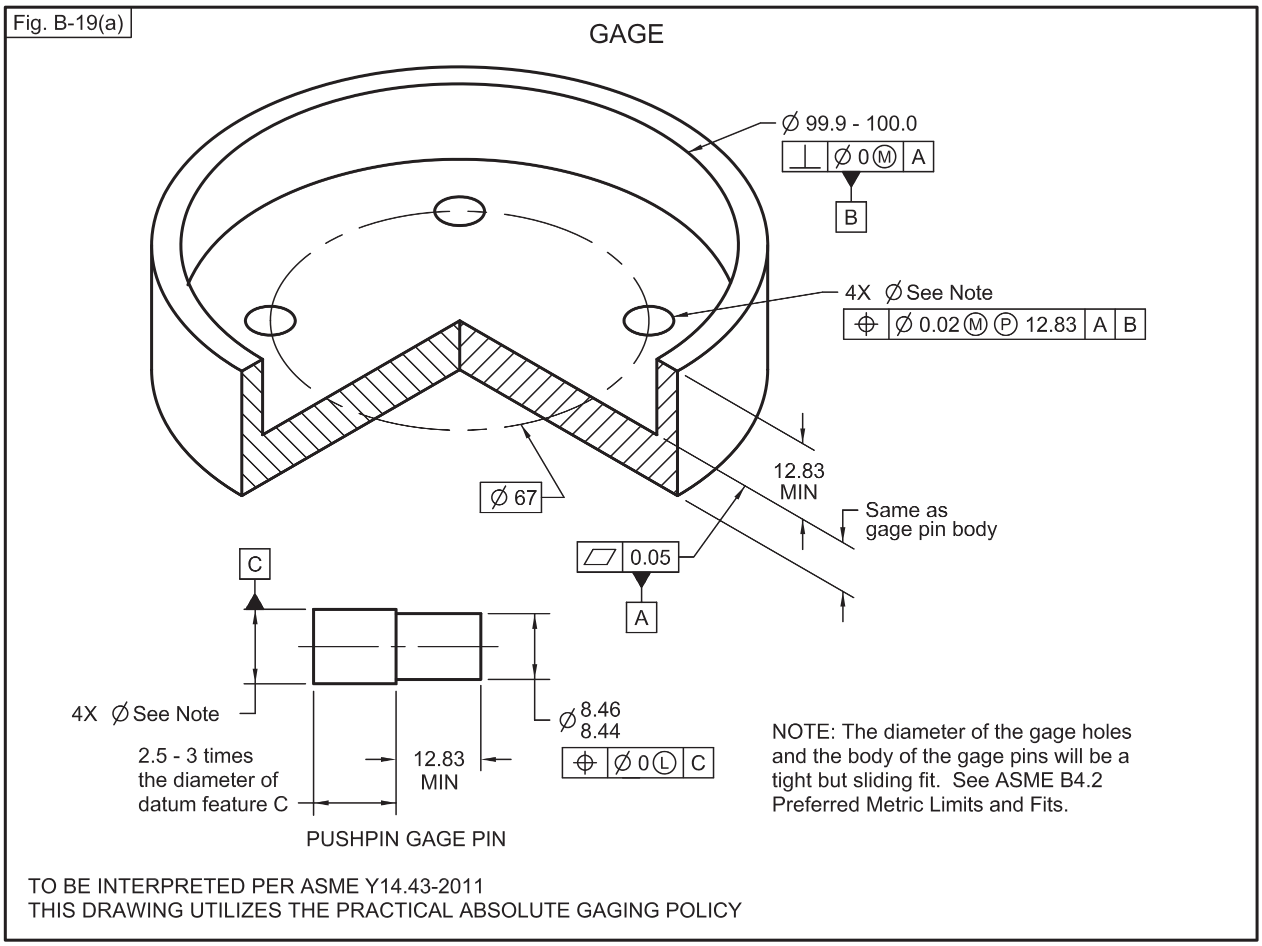


Fig. B-20 Push Pin Gages for Part With Threaded Holes

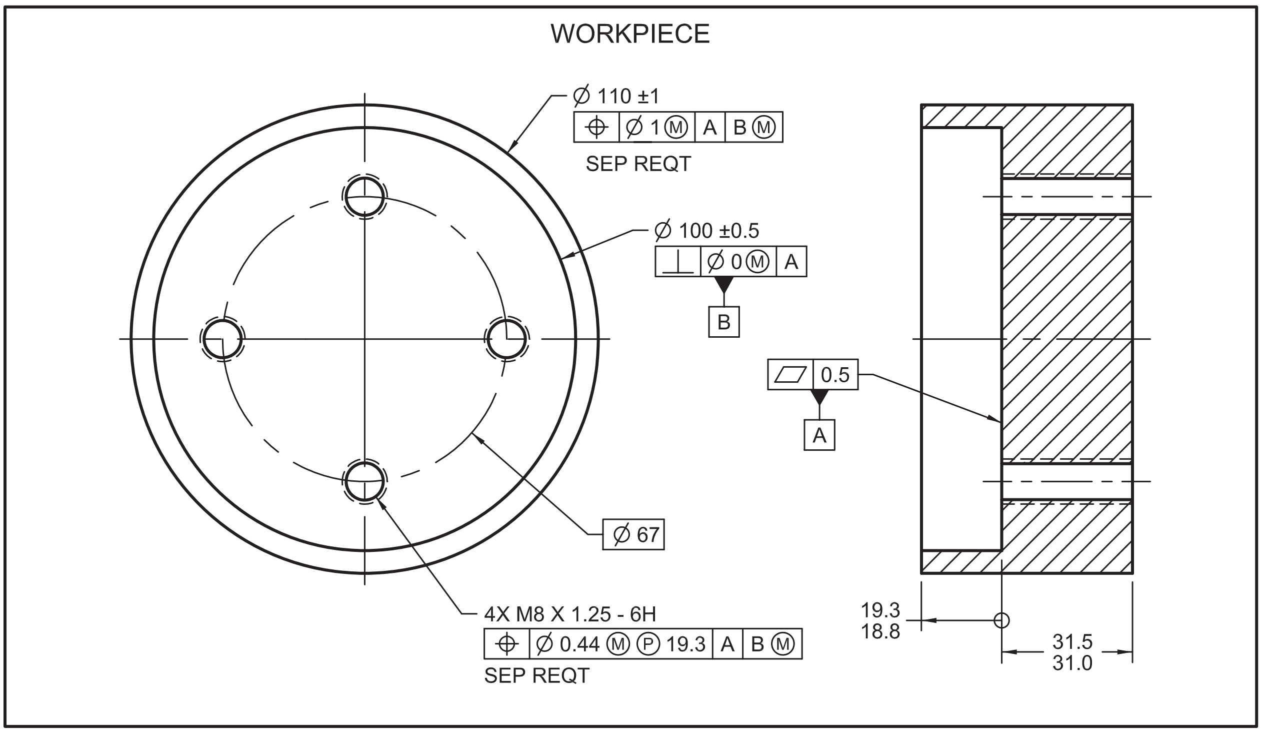


Fig. B-20 Push Pin Gages for Part With Threaded Holes (Cont'd)

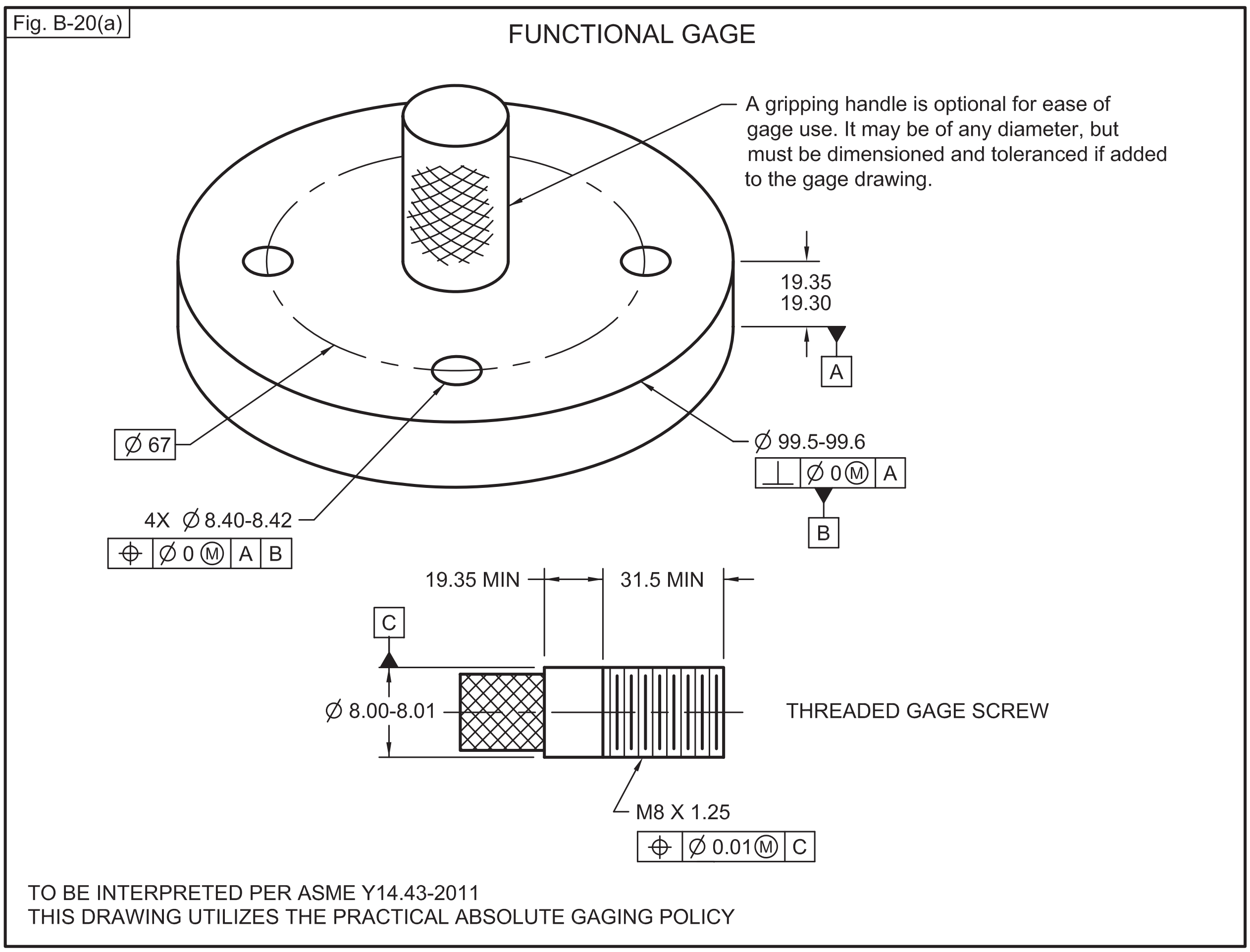
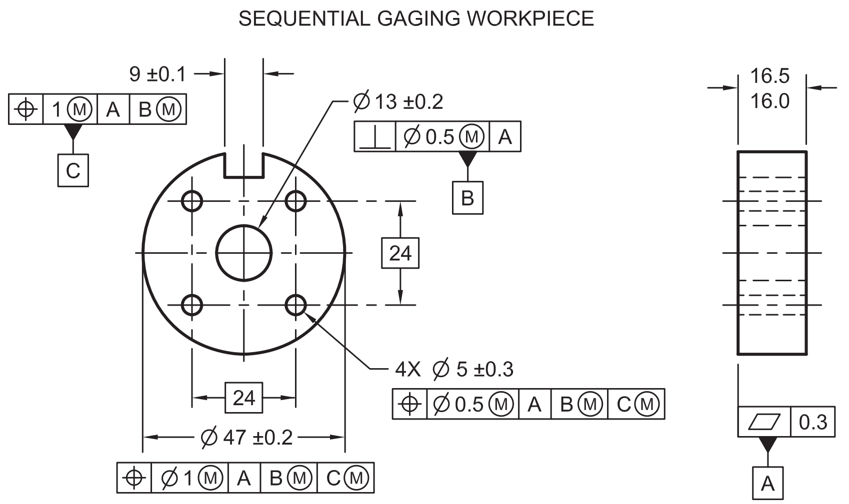


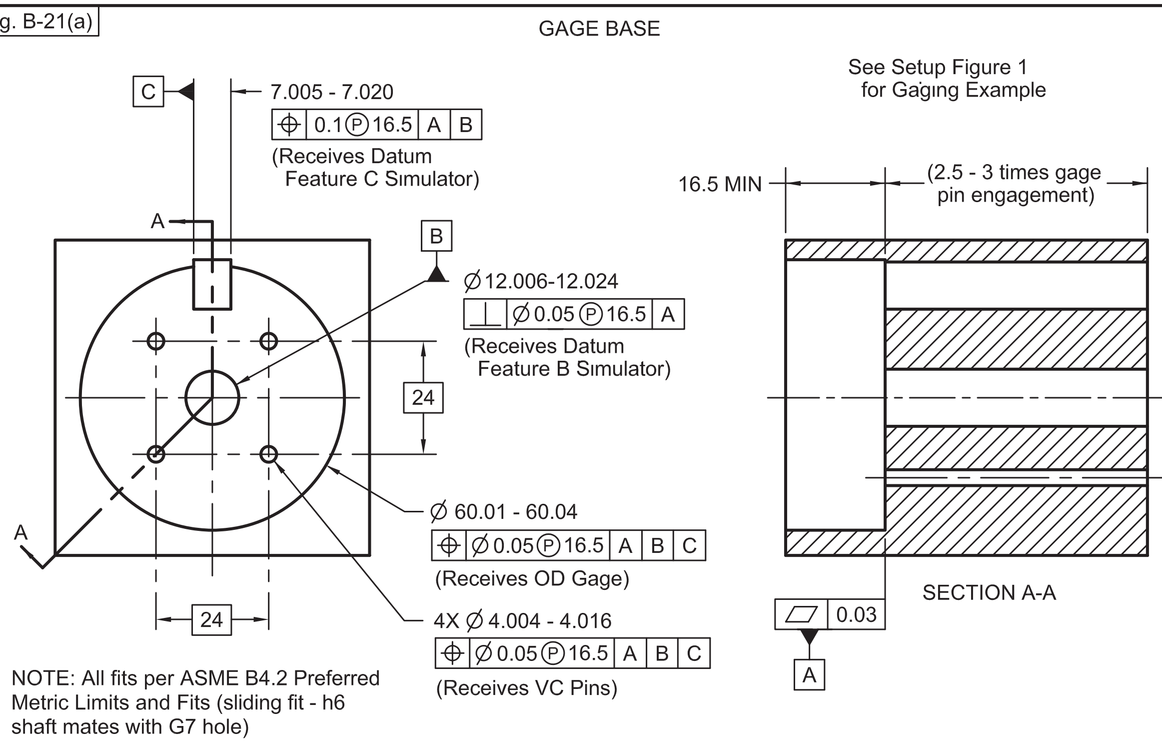
Fig. B-21 Sequential Gaging



The Primary Datum Feature is a flat surface, the Secondary Datum Feature is a cylindrical feature of size, and the Tertiary Datum Feature is a width feature of size. In this example the keyway is used as Datum Feature C. The part is staged against Datum Feature Simulator A and over Datum Feature Simulators B & C. The holes are checked using Virtual Condition pins, and the outside diameter is checked using a Virtual Condition cylinder relative to Datums A, B at MMB and C at MMB.

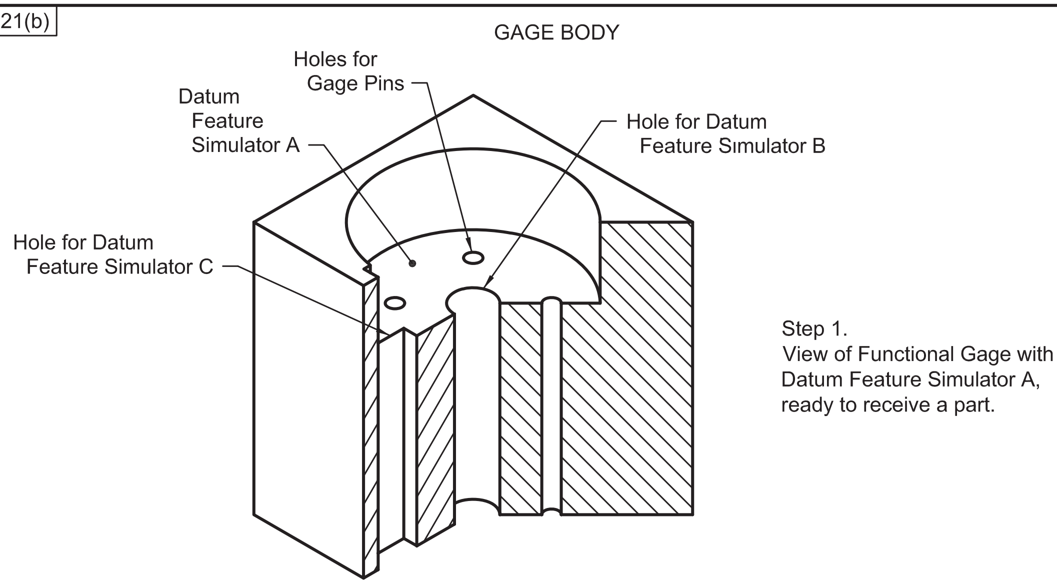
Fig. B-21 Sequential Gaging (Cont'd)

Fig. B-21(a)



Datum Feature A on the Gage is the simulator for Datum Feature A on the part. The Gage also contains receivers (holes and slots) for pins that simulate Datum Features B and C on the part as well as receivers for the Virtual Condition pins and OD Gage. Gage feature tolerances are 10% of the associated part feature tolerances.

Fig. B-21(b)

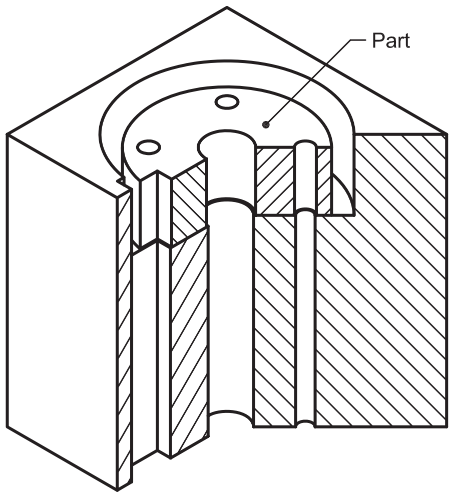


Step 1.
View of Functional Gage with
Datum Feature Simulator A,
ready to receive a part.

Fig. B-21 Sequential Gaging (Cont'd)

Fig. B-21(c)

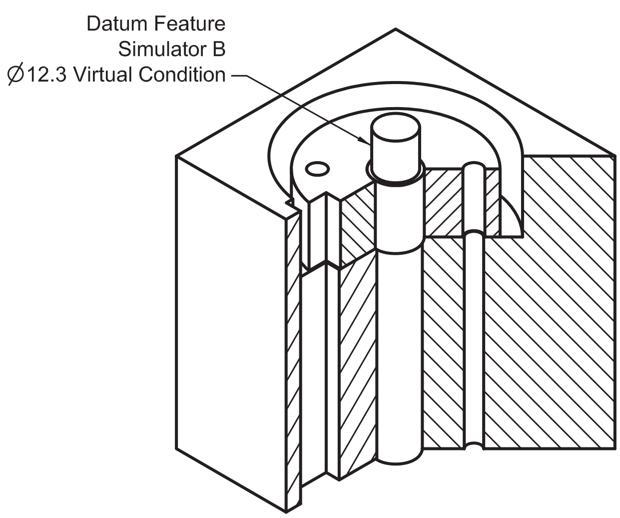
WORKPIECE APPLIED TO GAGE



Step 2.
The part is staged on the Functional Gage against Primary Datum Feature Simulator A. This establishes the orientation of the part to the Datum Reference Frame.

Fig. B-21(d)

WORKPIECE APPLIED TO GAGE

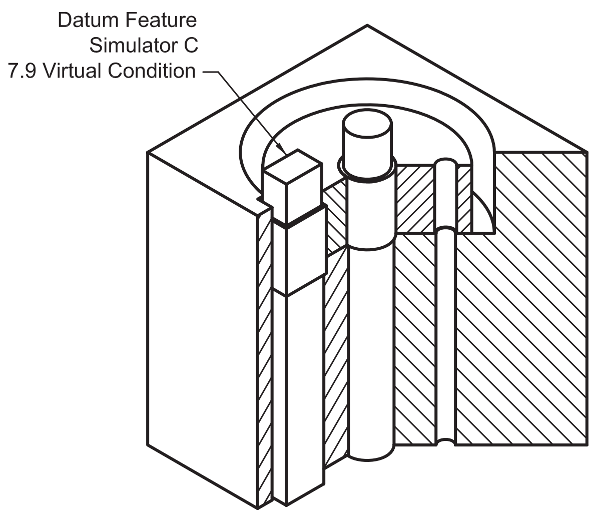


Step 3.
The Secondary Datum Feature Simulator B is inserted into the Gage, locating the part within the Datum Reference Frame. While maintaining contact with Datum Feature Simulator A, the part is free to shift slightly and rotate freely about Datum Feature Simulator B in the XY plane. The amount the part may shift is equivalent to the clearance between Datum Feature B and its ∅12.3 Virtual Condition Simulator.

Fig. B-21 Sequential Gaging (Cont'd)

Fig. B-21(e)

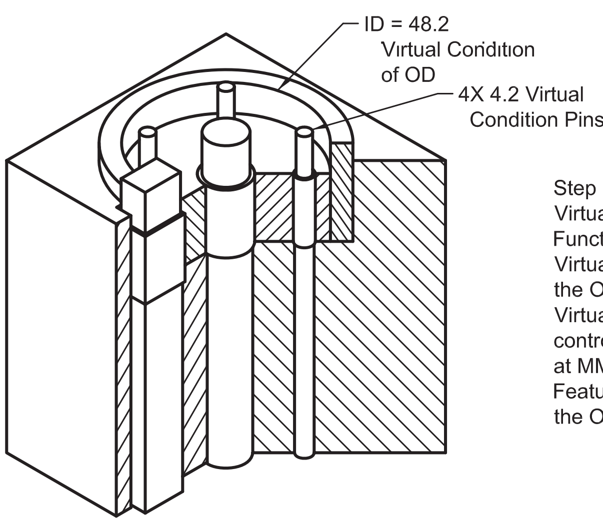
WORKPIECE APPLIED TO GAGE



Step 4.
The Tertiary Datum Feature Simulator C is inserted into the Gage which restricts the rotation of the part about Datum Feature Simulator B. The amount the part may rotate is equivalent to the clearance between Datum Features B and C and their 12.3 and 7.9 Virtual Condition Simulators, respectively.

Fig. B-21(f)

WORKPIECE APPLIED TO GAGE

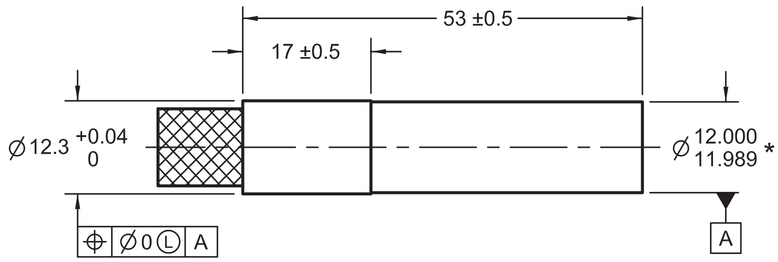


Step 5.
Virtual Condition pins are inserted into the Functional Gage to verify hole locations and a Virtual Condition cylinder is inserted to verify the OD location. The OD must be within its Virtual Condition with all pins inserted since all controlled features are related to Datums A, B at MMB, and C at MMB. The size of Datum Feature B, Datum Feature C, the holes, and the OD must be verified separately.

Fig. B-21 Sequential Gaging (Cont'd)

Fig. B-21(g)

DATUM FEATURE B SIMULATOR

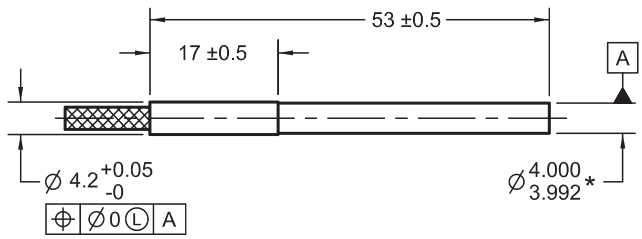


The Ø12.3 cylinder is the Virtual Condition Simulator for Datum Feature B of the part.

See Fig. B21(d) for application.

Fig. B-21(h)

HOLE GAGE PINS

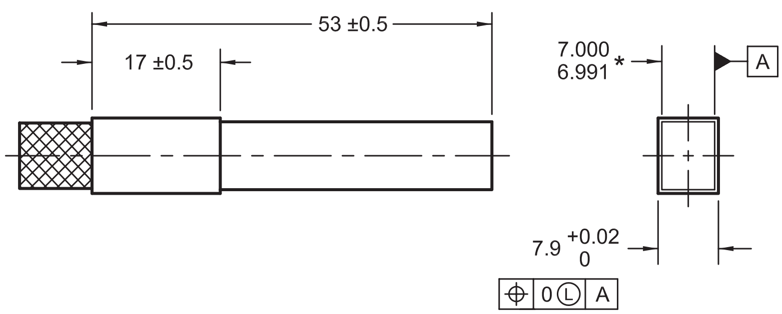


The Ø4.2 cylinder is the Virtual Condition Simulator for the 4X Ø4 ±0.3 holes on the part.

See Fig. B21(f) for application.

Fig. B-21(i)

DATUM FEATURE C SIMULATOR

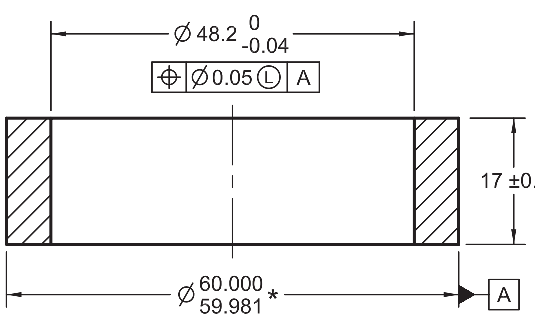


The 7.9 width is the Virtual Condition Simulator for Datum Feature C of the part.

See Fig. B21(e) for application.

Fig. B-21(j)

OUTSIDE DIAMETER GAGE



The Ø48.2 cylinder is the Virtual Condition Simulator for the outside diameter of the part.

See Fig. B21(f) for application.

*From ASME B4.2 Preferred Metric Limits and Fits (sliding fit - h6 shaft mates with G7 hole)

Fig. B-22 Curved Surface as a Datum Feature

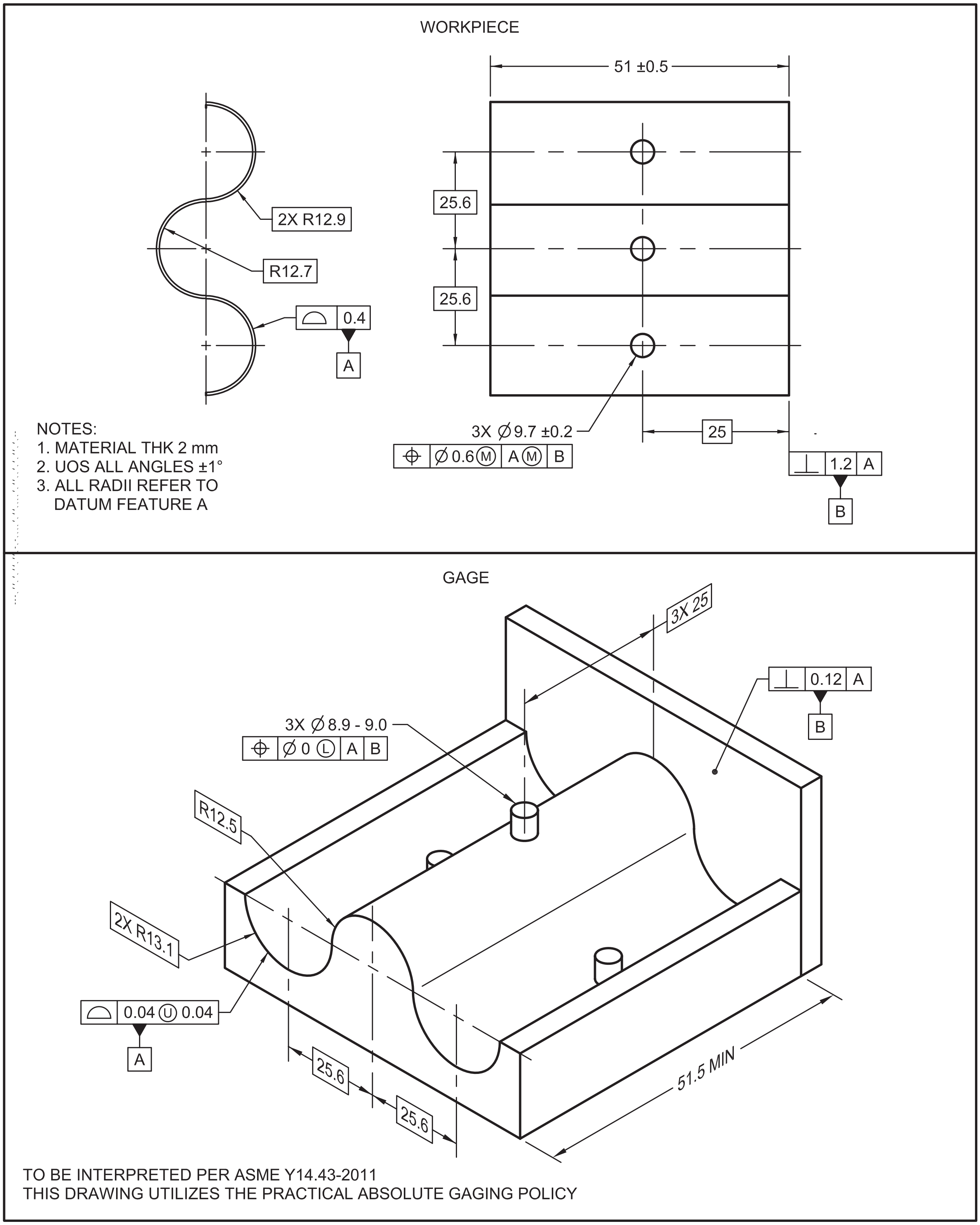


Fig. B-23 Outer Boundary of a Pattern of Pins Applied at MMB

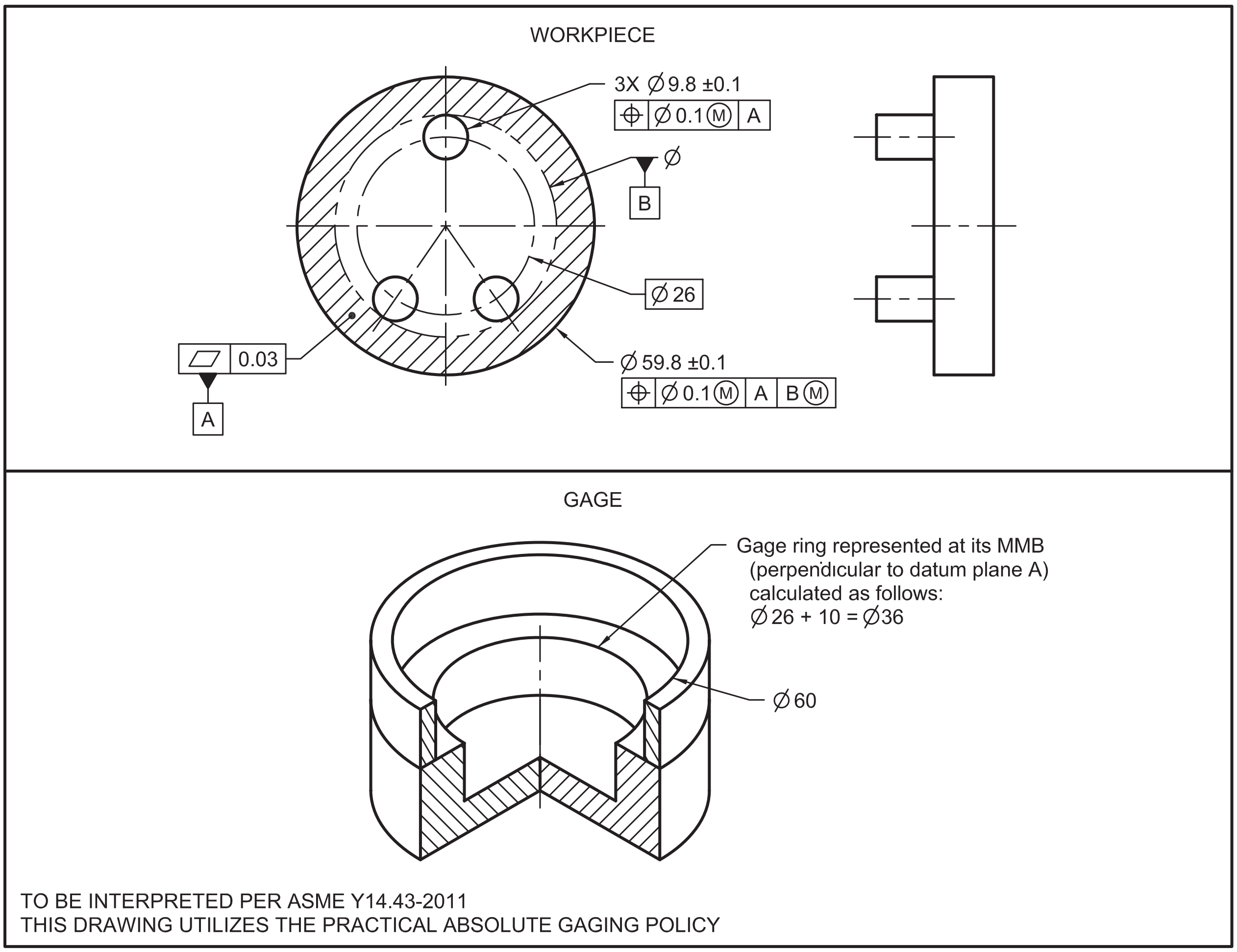


Fig. B-24 Customized Datum Reference Frame

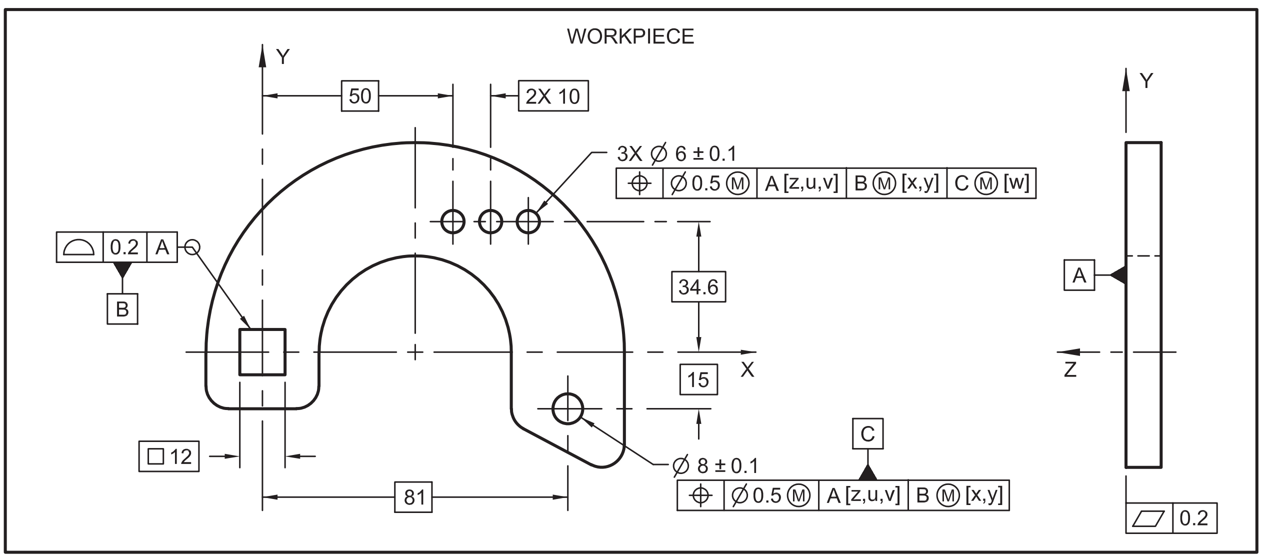
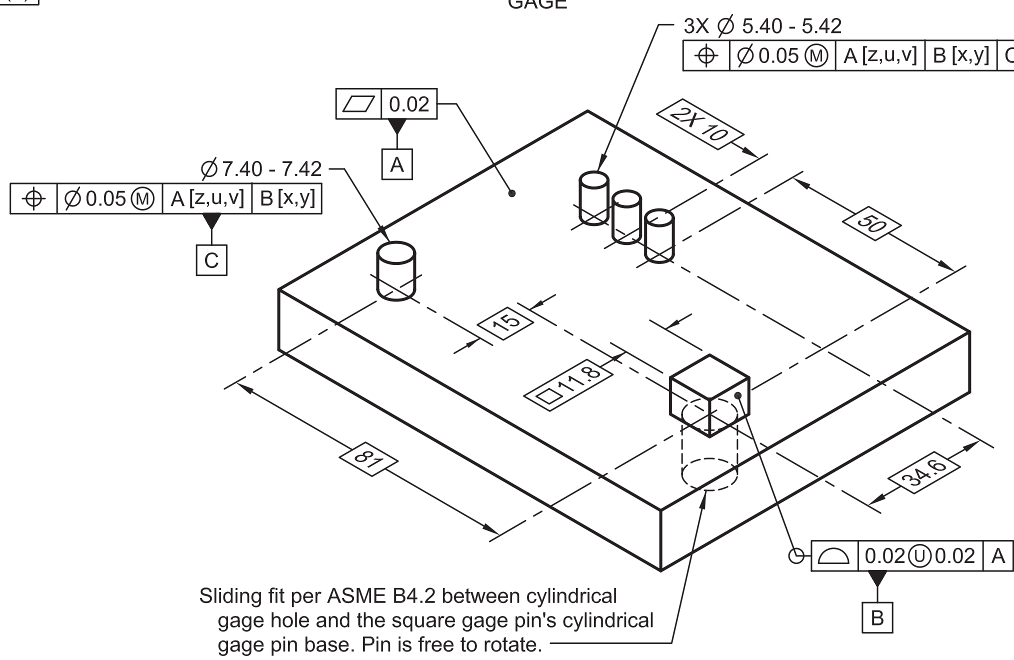


Fig. B-24 Customized Datum Reference Frame (Cont'd)

Fig. B-24(a)



TO BE INTERPRETED PER ASME Y14.43-2011
THIS DRAWING UTILIZES THE PRACTICAL ABSOLUTE GAGING POLICY

Fig. B-24(b)

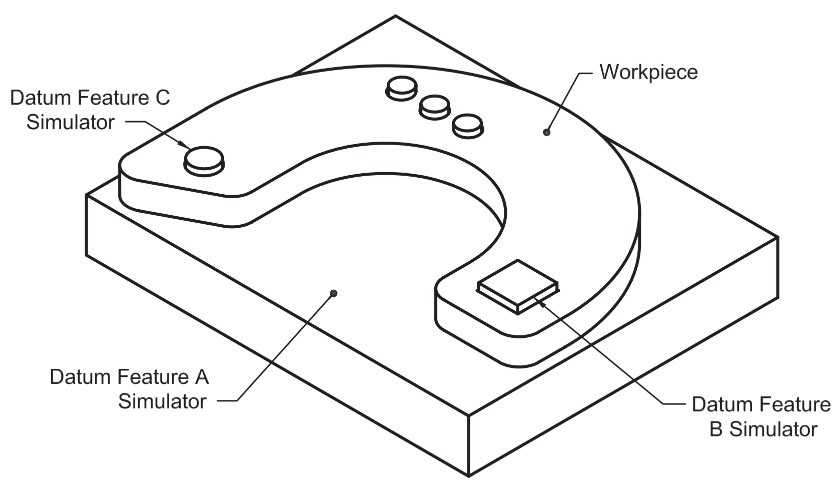


Fig. B-25 Basic Location of Angular Orientation Planar Datum Feature Simulator

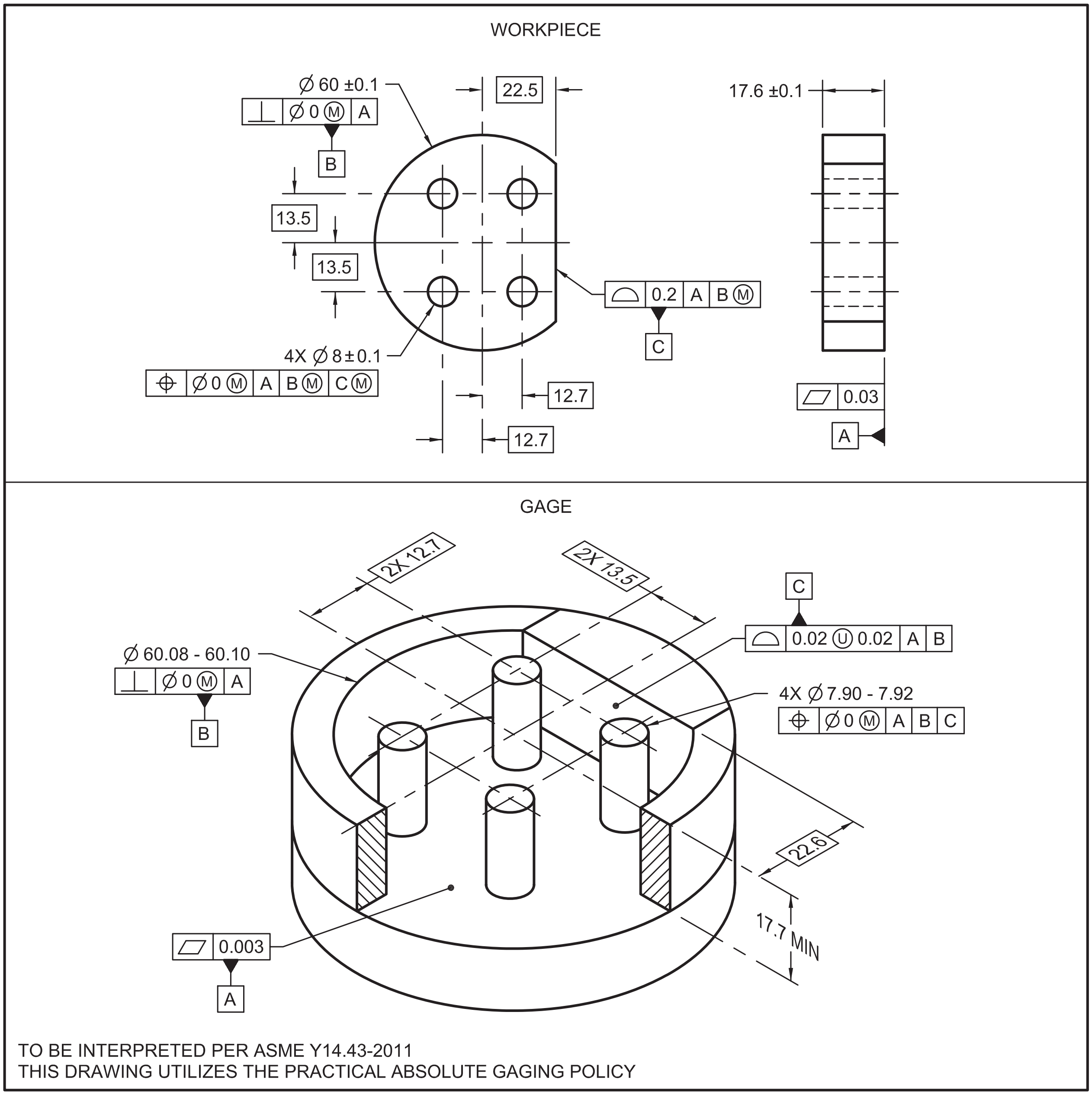


Fig. B-26 Basic Location of Angular Orientation Curved Datum Feature Simulator

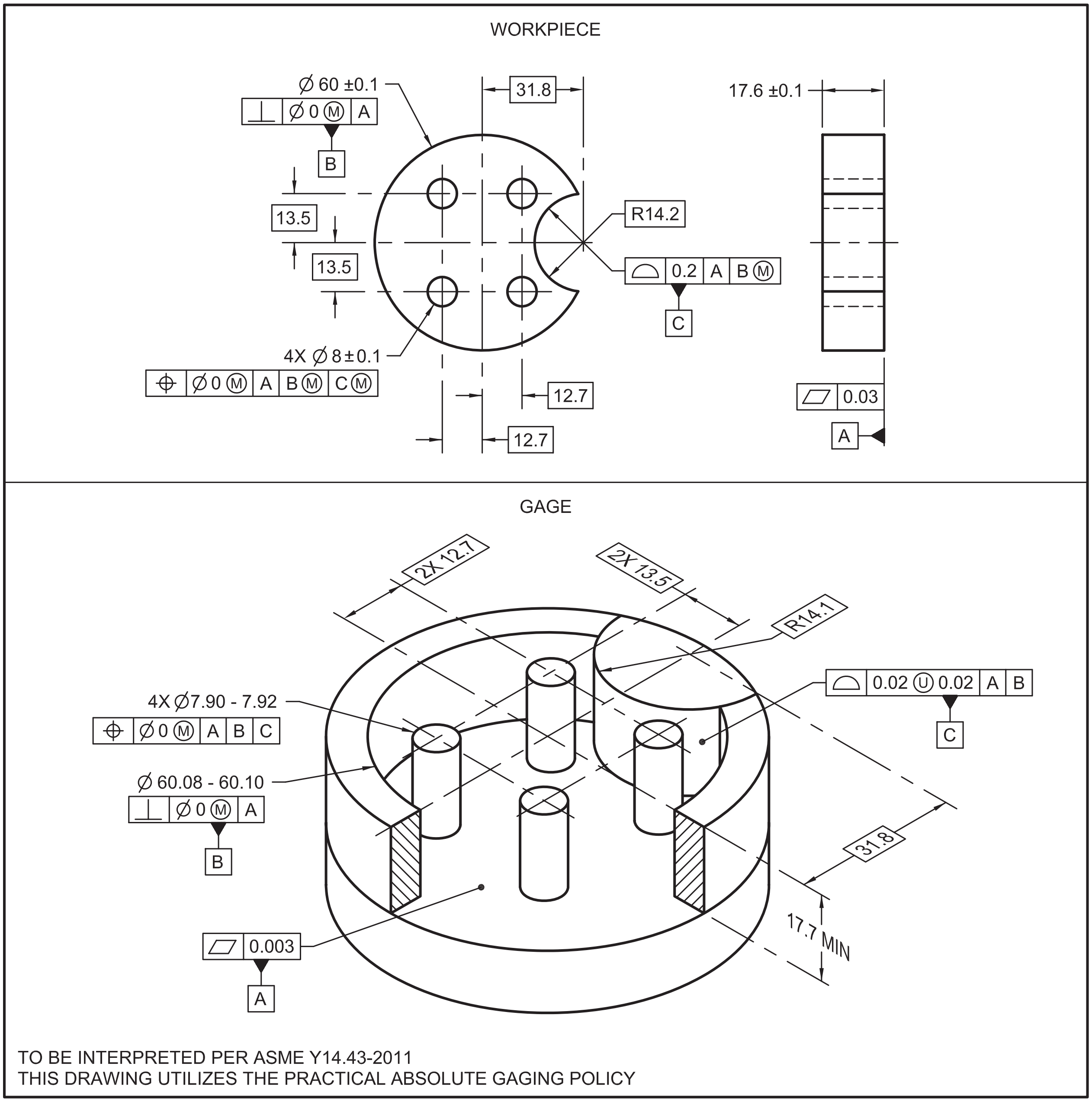


Fig. B-27 Datum Feature Referenced at MMB

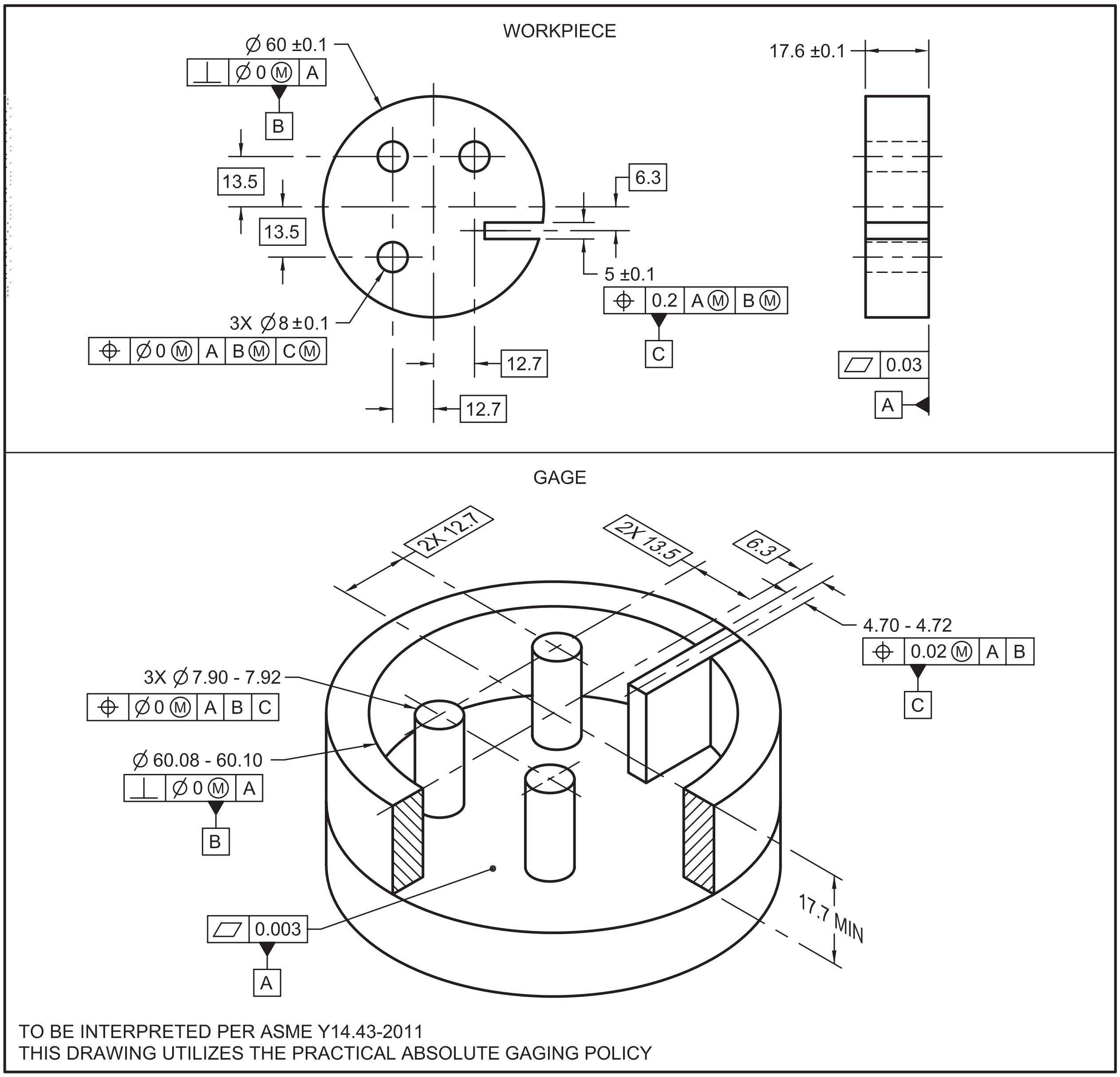


Fig. B-28 Planar Datum Feature Referenced at MMB

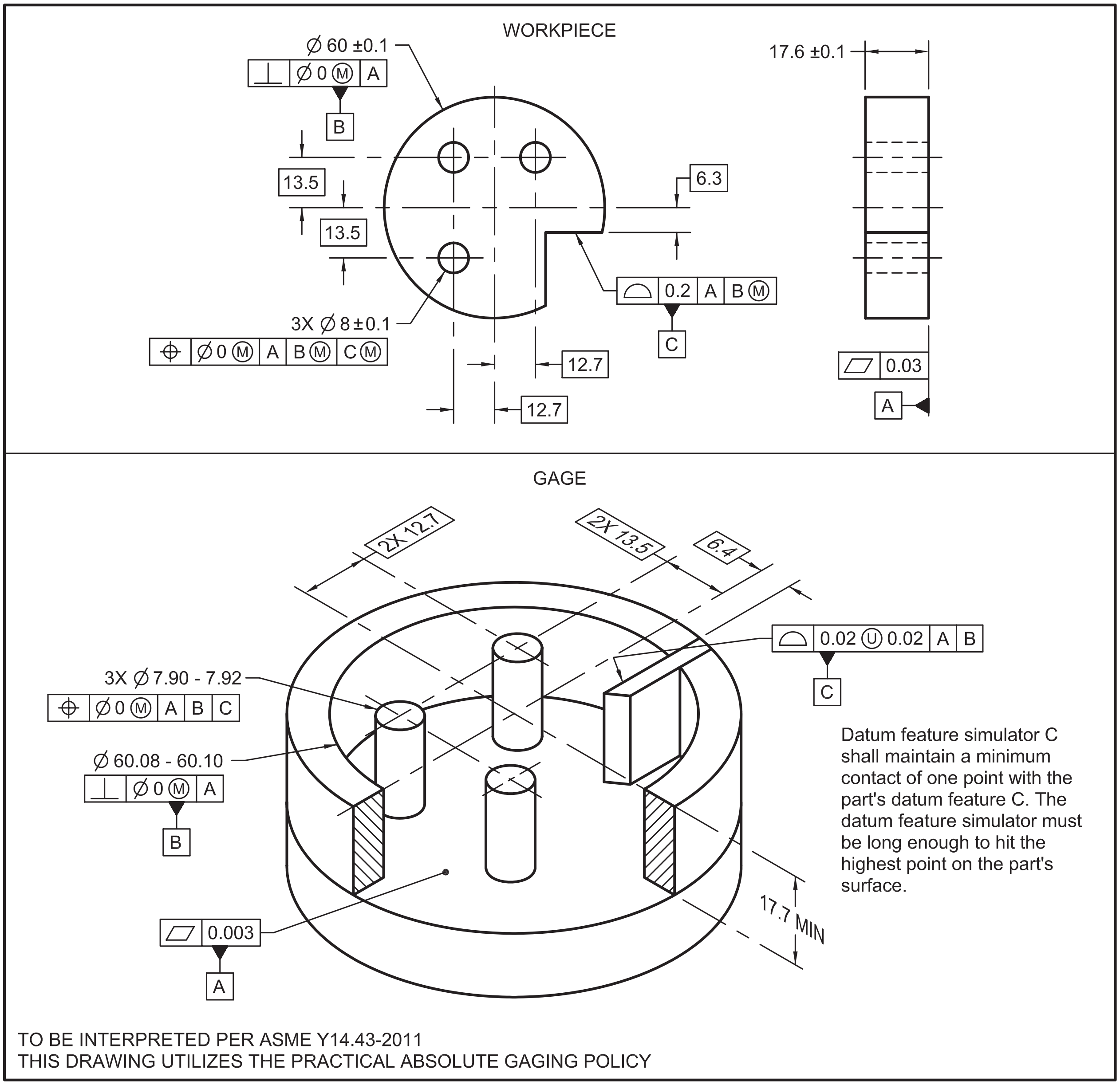
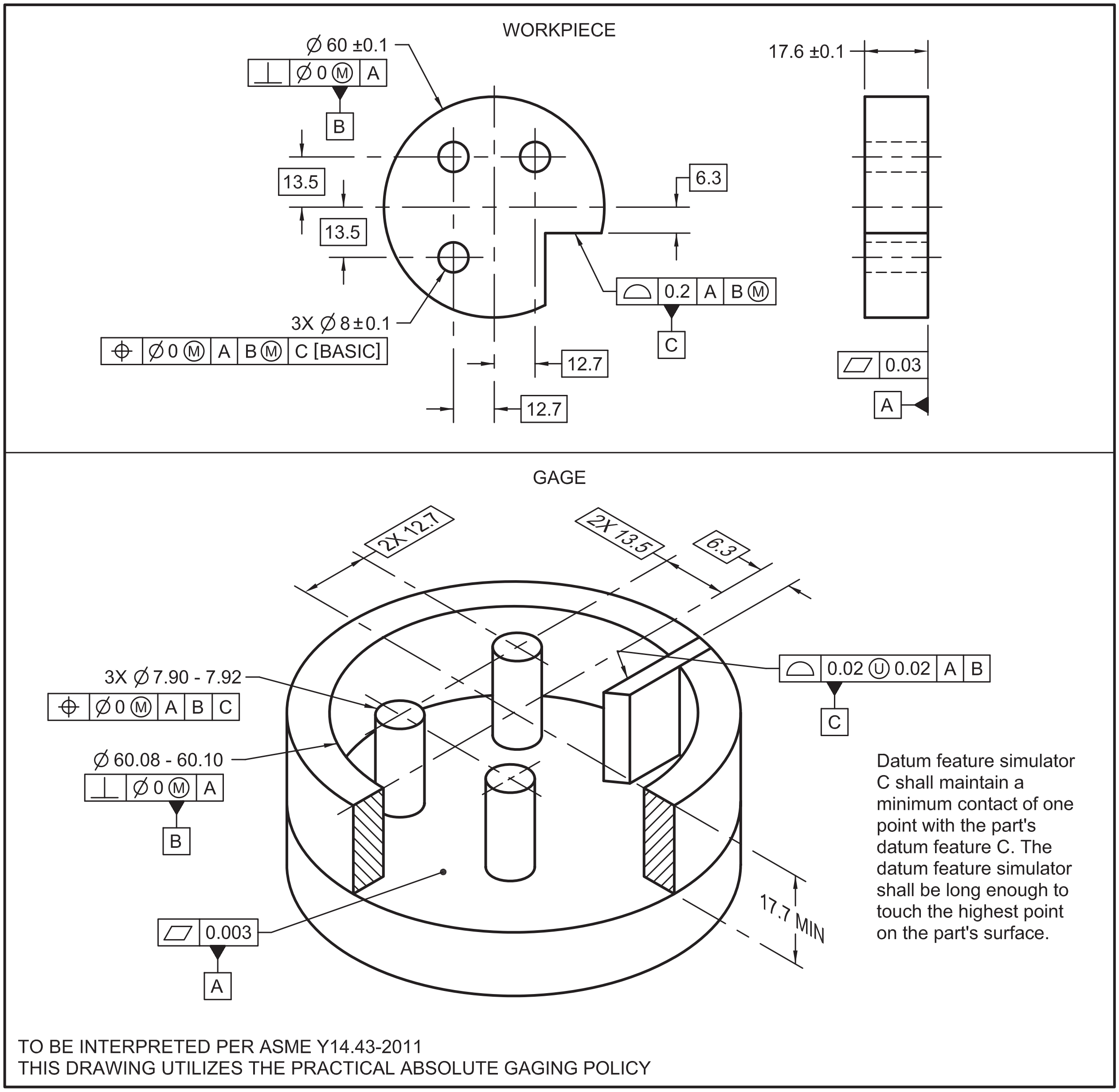


Fig. B-29 Planar Datum Feature Referenced at Basic



NONMANDATORY APPENDIX C
REGARDLESS OF FEATURE SIZE (RFS) AND REGARDLESS OF MATERIAL BOUNDARY (RMB)

C-1 RFS AND RMB GAGING

Regardless of feature size (RFS) is a term used to indicate that a geometric tolerance applies at any increment of the feature size within its size tolerance. Regardless of material boundary (RMB) is a term used to indicate that a geometric tolerance applies at any increment of the datum feature boundary. As such, the geometric tolerance is independent of the finished size of the feature and the datum feature. RMB can be applied to the datum features and RFS to other features whose axes or center planes are controlled by geometric tolerances.

With this concept, the actual axis of a part datum feature shall be used for inspection regardless of the finished size of the feature. Therefore, this type of inspection equipment usually is characterized by expanding devices, tapered locators, V-blocks, spring-loaded devices, or other units capable of locating the axis or center plane of the feature and the datum feature. Fixed-size elements are not appropriate for ascertaining the compliance of geometrically controlled features. Therefore, when a geometric tolerance is independent of feature size, the design frequently uses dial indicators or other devices capable of variables data collection.

Inspection equipment designs of this nature apply to situations in which the callout for positional tolerance directly states the RFS or RMB requirement. When no modifier is specified after the geometric tolerance, the RFS condition applies. When no modifier is specified after the datum feature, the RMB condition applies.

The basic advantage of the RFS and RMB type of inspection equipment design is its ability to perform a measurement accurately and independently of feature size and geometry variations. In some cases, RFS and RMB measurements are the only functional inspection method. Gage designs for these callouts often employ dial indicators that provide easy recalibration. Wear adjustments are an inherent part of the design. This ease of recalibration also provides a means of compensating for revisions in product size or tolerance requirements quickly. When dial indicators or similar units are incorporated into the design, RFS and RMB inspection equipment can determine not only whether the product is within specified limits, but also the magnitude and support phase of the life cycle, in which the product rebuild design may provide for adjustment to compensate for wear. Under these circumstances, RFS and RMB can be a desirable tolerancing concept.

The disadvantage of the RFS and RMB concepts is that the cost of the required inspection equipment is generally higher, as is the level of operator skill needed. Also, if expanding and contracting gage elements are not used, an infinite range of gage element sizes would be required to gage a part dimensioned with RFS and RMB modifiers, as this modifier does not allow use of fixed-size gaging elements.

(a) Gage Example With Both RMB and MMC References (See Fig. C-1). This example shows a workpiece that has two rectangular size datum features referenced at RMB, with round considered features referenced at MMC. While the gage has a complex datum feature simulator for the RMB references, it has a conventional set of fixed-size gage elements for the holes at MMC. This gage represents a combination of hole pattern alignment to the datums, while the pattern takes advantage of MMC for assemblability of the feature relationship. Figures C-1(a) and C-1(b) show the gage and describe its features.

(b) Gage Example With All RFS and RMB References [See Fig. C-2 (Fig. 5-60 of ASME Y14.5-2009)]. This example shows a workpiece that has a single-size datum feature referenced at RMB and a considered feature referenced at RFS. While the workpiece appears to be simple, the gage required to inspect the requirements is complex. A description for the use of the gage follows:

(1) Figure C-2(b) shows the workpiece restrained to simulated datum features as specified by the workpiece shown in Fig. C-2.

The guide block and three pins are shown assembled over guide rail 1. The guide block and three pins have been omitted over guide rail 2 for illustration clarity. The complete gage is shown in Fig. C-2(a).

Datum A feature of the workpiece makes contact on the datum A simulator. Clockwise rotation of the crank causes guide rails 1 and 2 to move inward simultaneously to simulate datum feature B center plane of the workpiece.

The workpiece is brought into contact with the pin or pins indicated as ③. See Fig. C-2(f).

The expanding block is inserted into the slot of the workpiece and is expanded to contact the sides of the slot.

The base block is shown with three fixed pins that pass through holes in the guide block.

The guide blocks are capable of up and down adjustment to allow for the variable thickness of the workpiece. This is necessary because the tolerance projects through the thickness of the workpiece.

A dial indicator is used to check the location and orientation of the slot.

(2) The cross sections shown in Figs. C-2(c) and C-2(d) were taken from the gage shown in Fig. C-2(b). The dial indicator shall be set to zero using the calibration gage shown in Fig. C-2(e) prior to taking any measurements.

Figure C-2(c) shows the slot at near ideal location and orientation. Figure C-2(d) shows the slot with orientation and location error. There is one set of four inspection bores at the forward position of the slot and four more inspection bores at the aft end of the slot. The instructions that follow are for one set of four inspection bores. This process is repeated for the other set of four inspection bores.

The dial indicator is shown inserted into each inspection bore to show how the gage is used. Only one dial indicator is needed to inspect the slot for location and orientation. The expanding block is shown inserted into the slot of the workpiece. A dog-legged inspection probe is shown in each of the inspection bores. These probes remain in the bores as part of the gage. The dog-legged inspection probes contact the expanding block with the knife edge of the probe on the same plane as datum feature A simulator. The dial indicator is used to probe position 1 and the reading is recorded. Next, the dial indicator is used to probe position 2 and the reading is recorded and compared for deviation against the reading for position 1. The deviation shall be equal to or less than the stated positional tolerance.

The guide block for position 3 is brought into contact with the surface of the workpiece. The dial indicator is inserted into the inspection bore and the dog-legged inspection probe contacts the expanding block with the knife edge of the probe on the same plane as the contact surface of the workpiece. The dial indicator reading for position 3 is recorded. The guide block for position 4 is brought into contact with the surface of the workpiece. The dial indicator is inserted into the inspection bore and the dog-legged inspection probe contacts the expanding block with the knife edge of the probe on the same plane as the contact surface of the workpiece. The dial indicator reading for position 4 is recorded and the deviation between positions 3 and 4 shall be equal to or less than the stated positional tolerance.

(3) Figure C-2(f) shows the workpiece with relevant features of the gage to describe the inspection method for the location and orientation error of the slot. The length of the slot is a variable and the slot can be longer or shorter as specified by the plus or minus tolerance shown on Fig. C-2. Checking the various lengths of the slots adds more complexity to the gage. With the plus or minus tolerance on the length, there is a certain portion of the slot that is unusable, and in the case shown in Fig. C-2(f), the gage is designed to check only the functional length of the slot. The workpiece is brought into contact with one of the two pins and the aft upper and lower dog-legged inspection probes contact the expanding block at the points indicated as A and B.

(c) Figure C-3 shows an example of an inner boundary of a pattern of pins referenced at RMB.

(d) Figure C-4 shows an example of a truncated cone as a datum feature RMB.

(e) Figure C-5 shows an example of a pattern of datum features referenced at RMB for an irregular profile and a slot position.

(f) Figure C-6 shows an example of secondary and tertiary datum features referenced at RMB.

Fig. C-1 Two Rectangular Size Datum Features at MMC and RFS/RMB

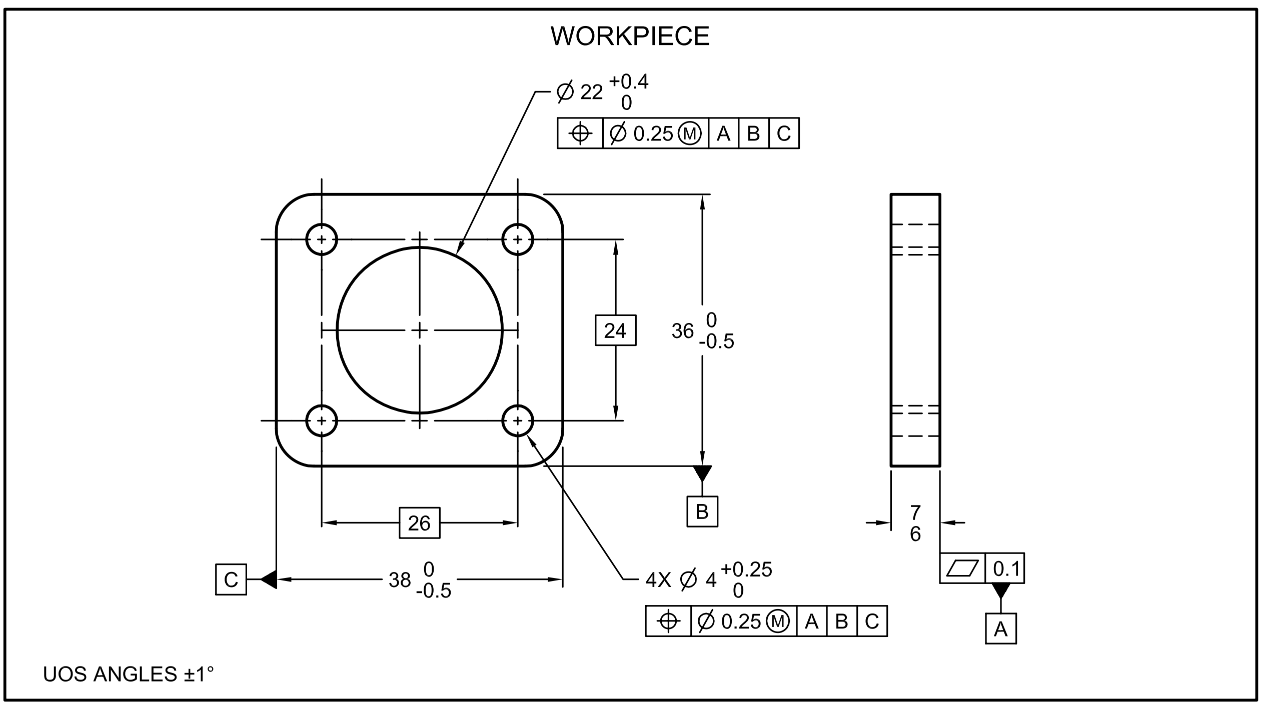
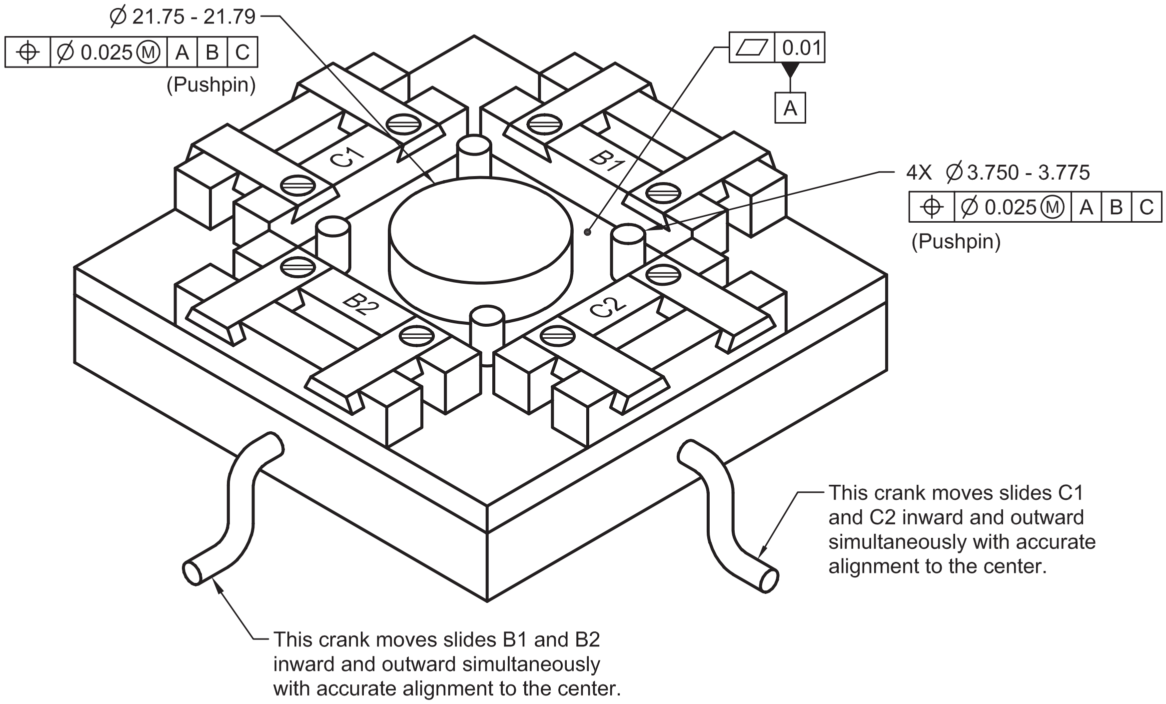


Fig. C-1 Two Rectangular Size Datum Features at MMC and RFS/RMB (Cont'd)

Fig. C-1(a)

GAGE WITH PUSHPINS INSERTED



TO BE INTERPRETED PER ASME Y14.43-2011
THIS DRAWING UTILIZES THE PRACTICAL ABSOLUTE GAGING POLICY

Fig. C-1(b)

WORKPIECE APPLIED TO GAGE

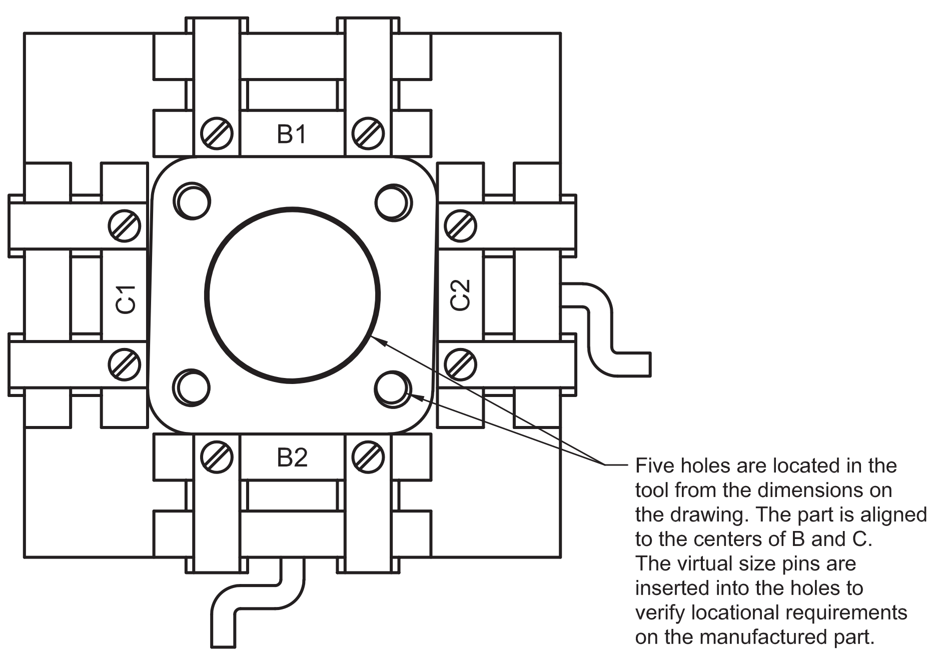


Fig. C-2 Rectangular Size Feature RFS/RMB

WORKPIECE

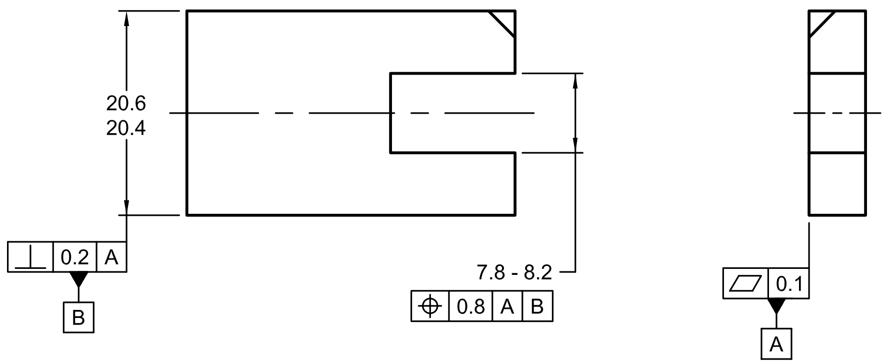


Fig. C2(a)

This Figure illustrates the complete gaging fixture for the workpiece shown above.
It is the basis for Figs. C2(b), (c), (d), (e), and (f) that describe the gaging details.

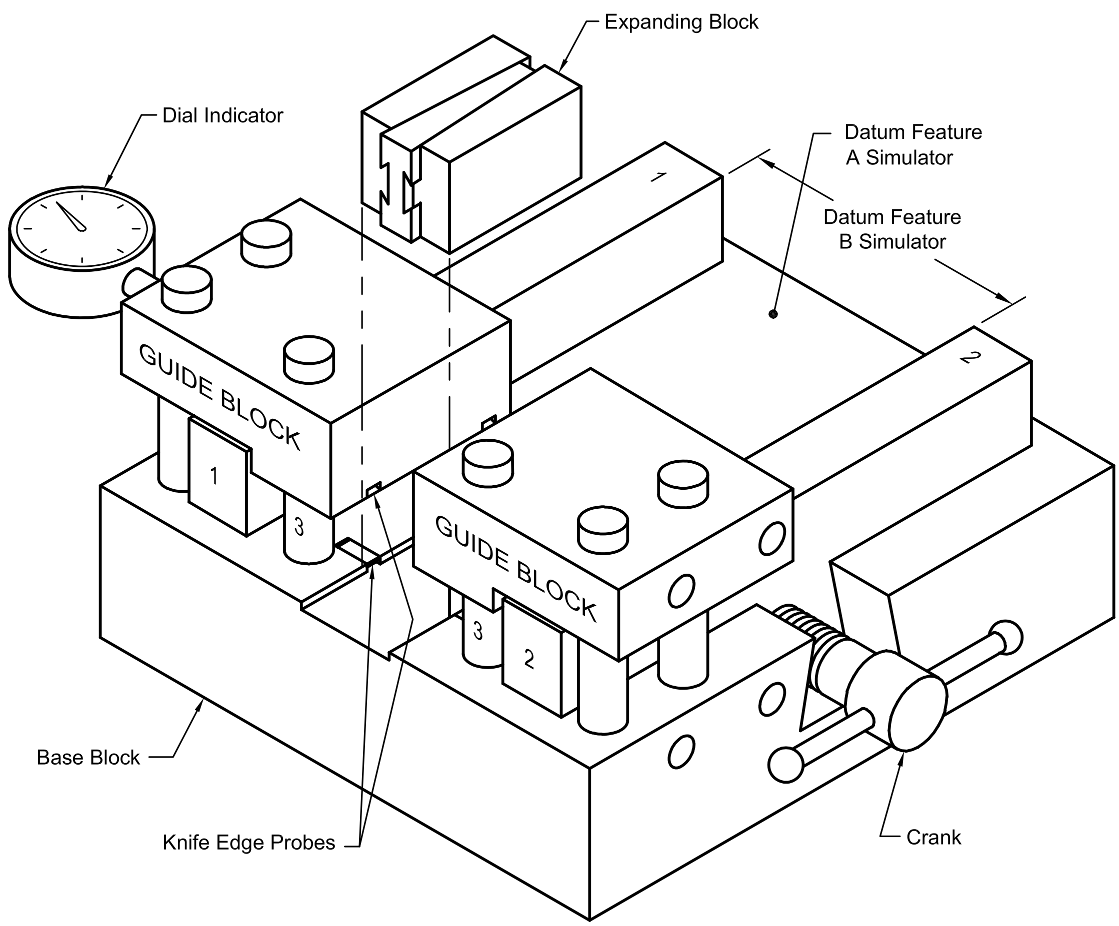


Fig. C-2 Rectangular Size Feature RFS/RMB (Cont'd)

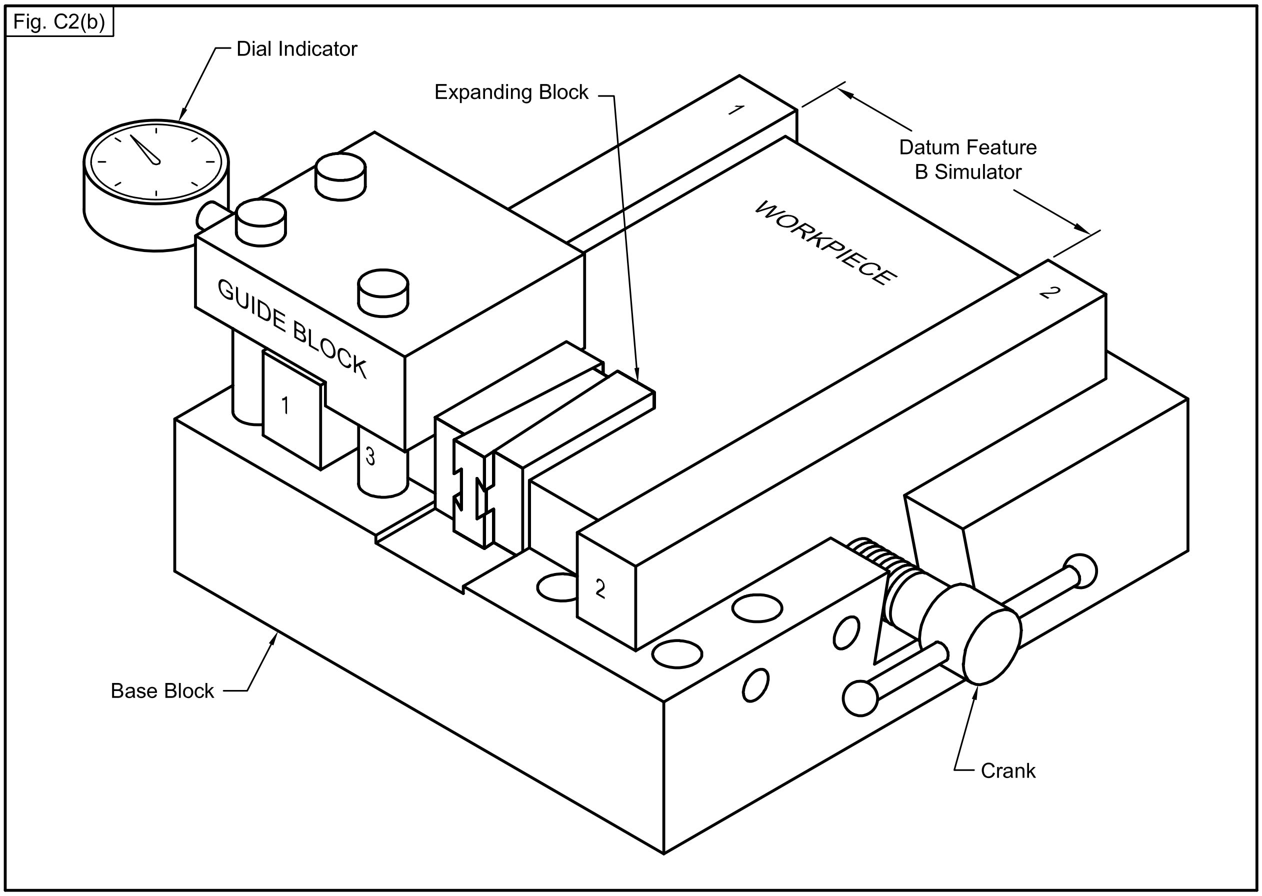


Fig. C-2 Rectangular Size Feature RFS/RMB (Cont'd)

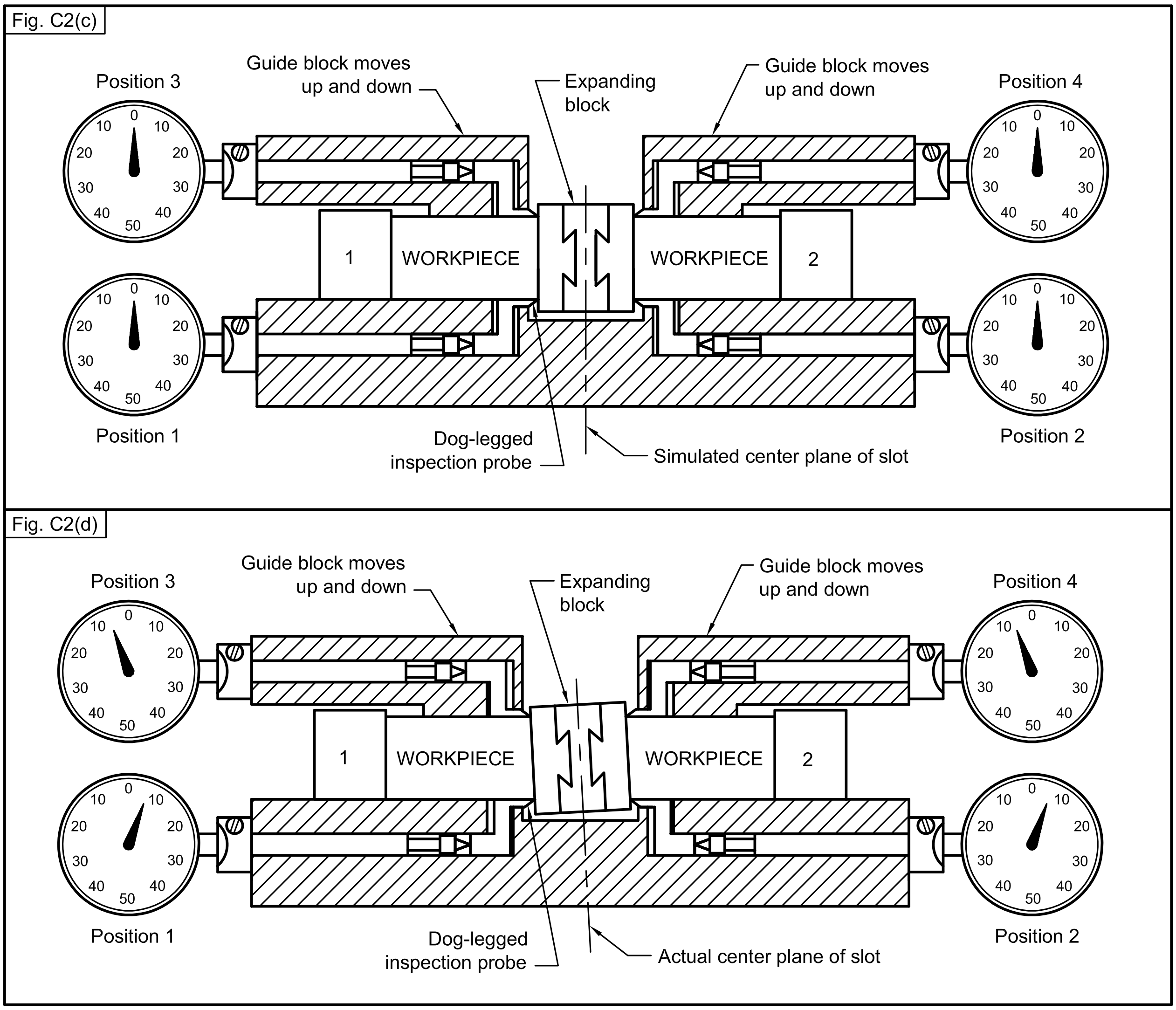


Fig. C-2 Rectangular Size Feature RFS/RMB (Cont'd)

Fig. C2(e)

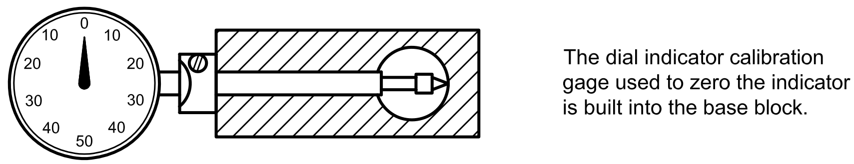


Fig. C2(f)

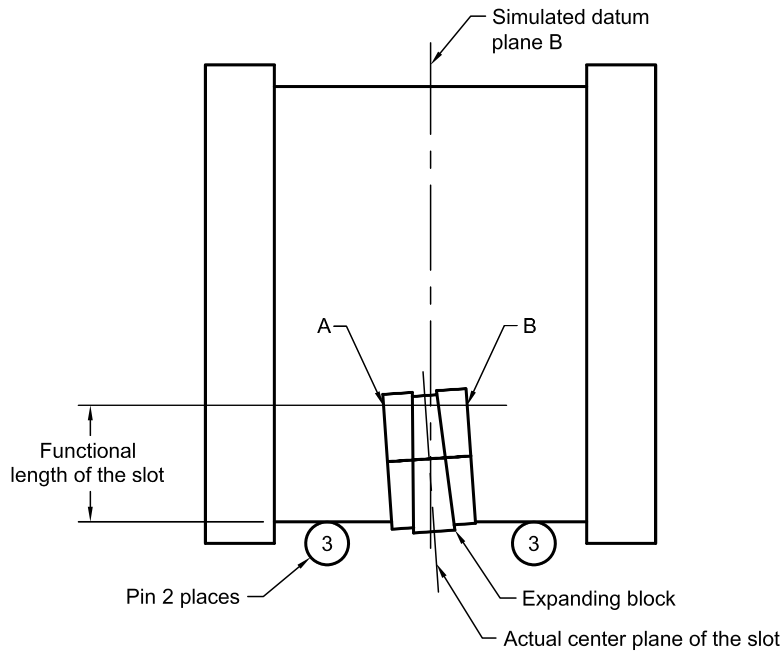


Fig. C-3 Inner Boundary of a Pattern of Pins Implied at RMB

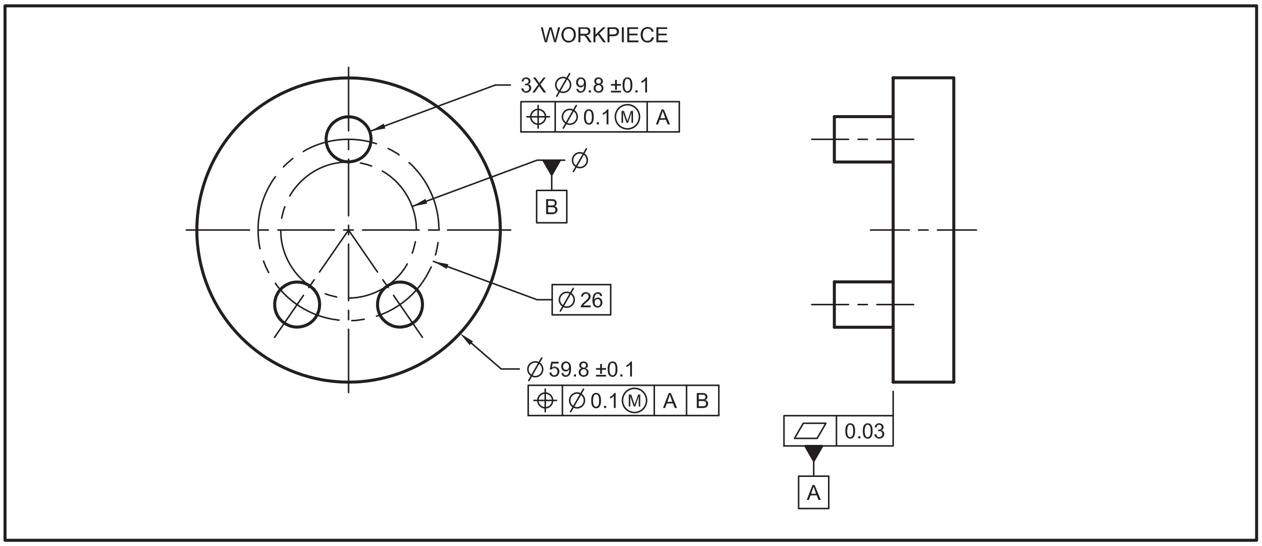


Fig. C-3 Inner Boundary of a Pattern of Pins Implied at RMB (Cont'd)

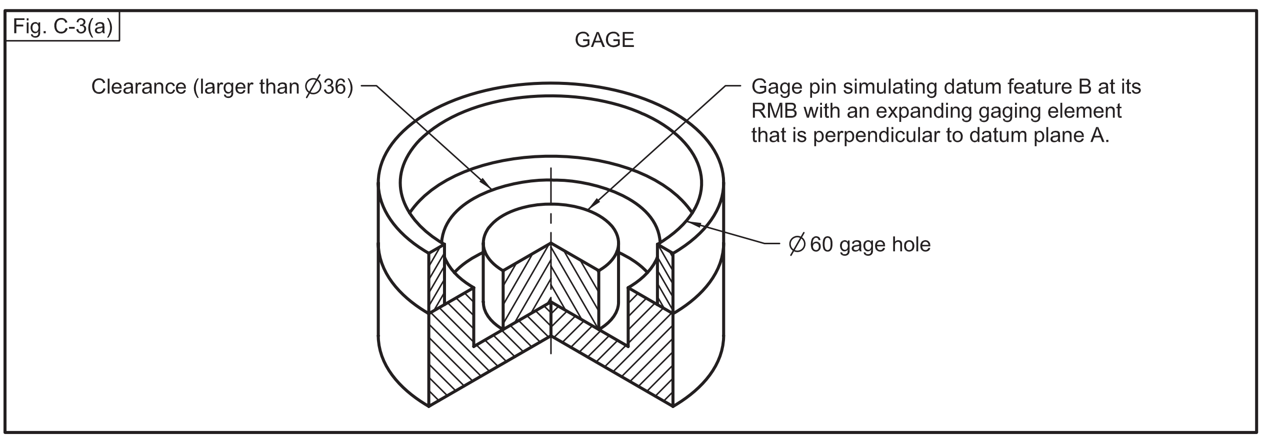


Fig. C-4 Truncated Cone as a Datum Feature RMB

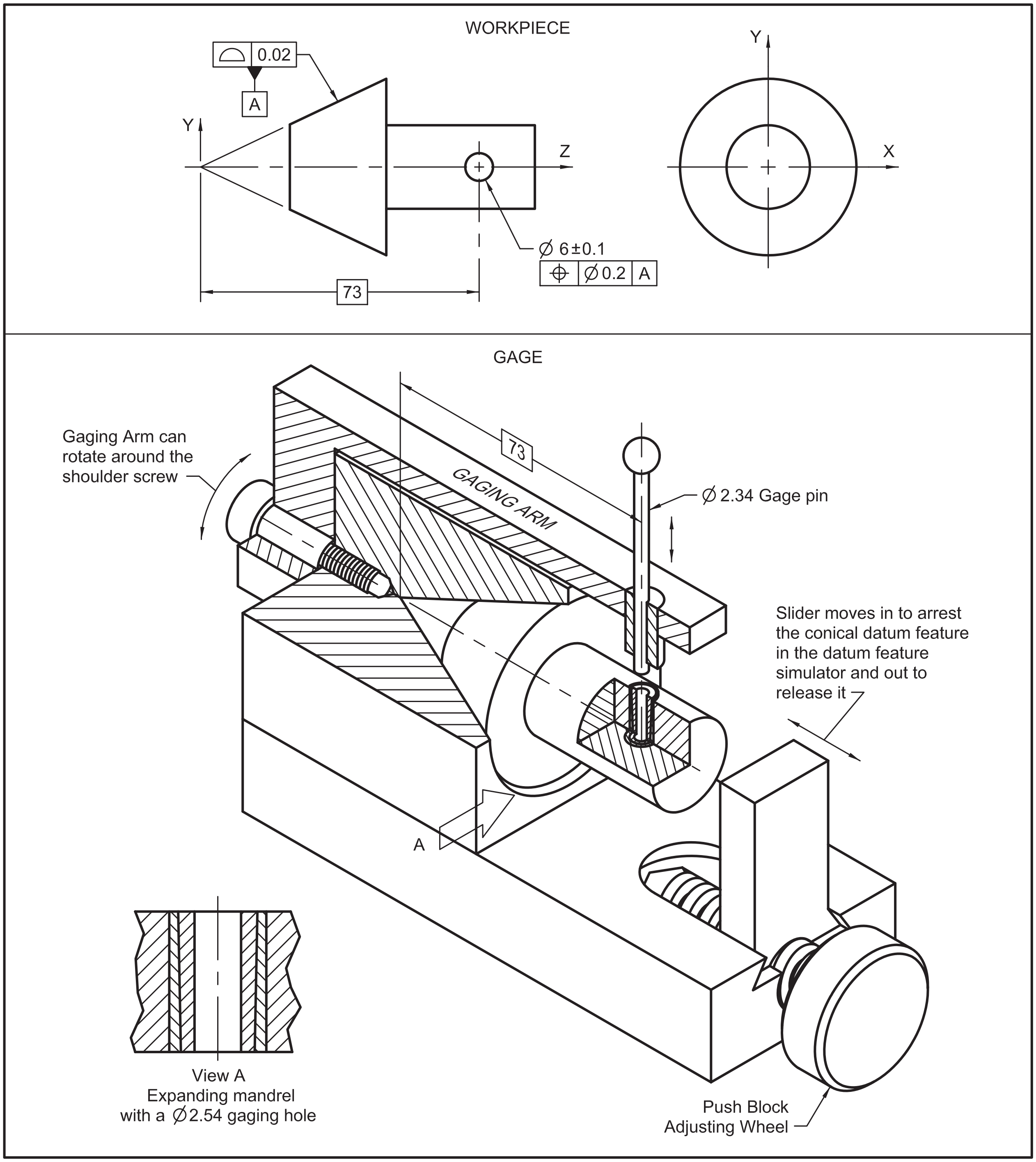


Fig. C-5 Pattern of Datum Features Referenced at RMB

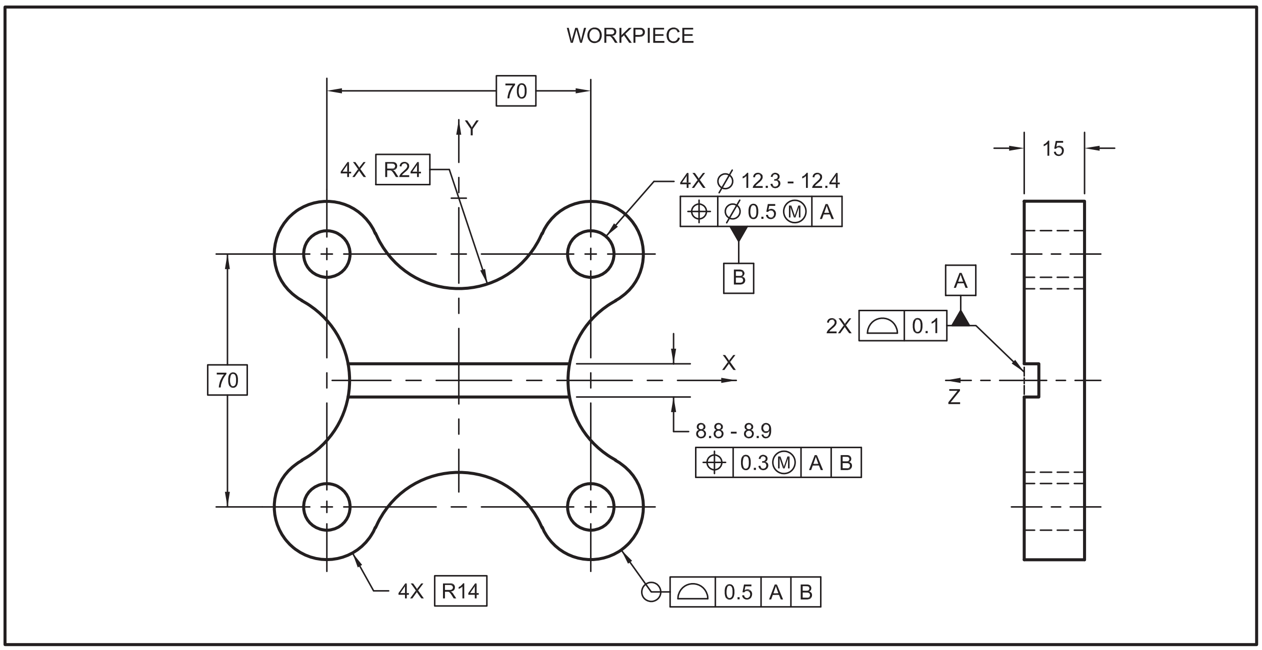


Fig. C-5 Pattern of Datum Features Referenced at RMB (Cont'd)

Fig. C-5(a)

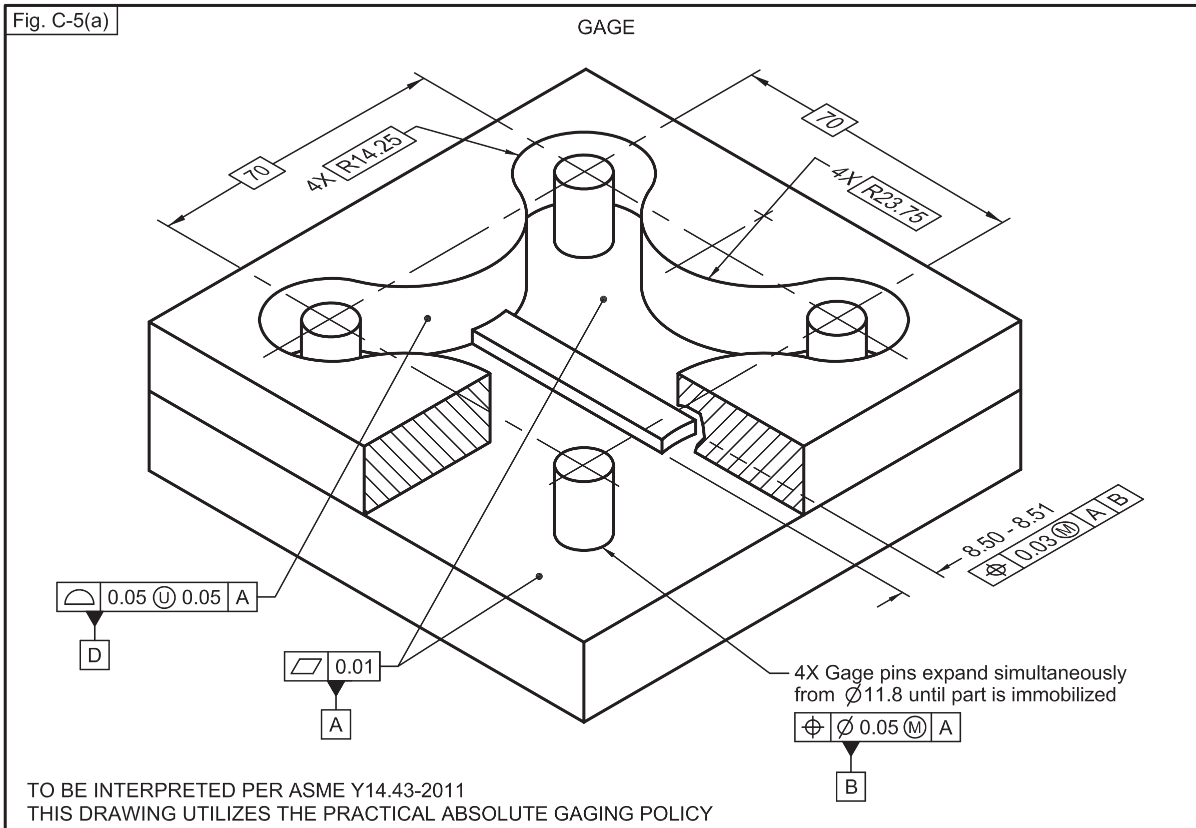


Fig. C-5(b)

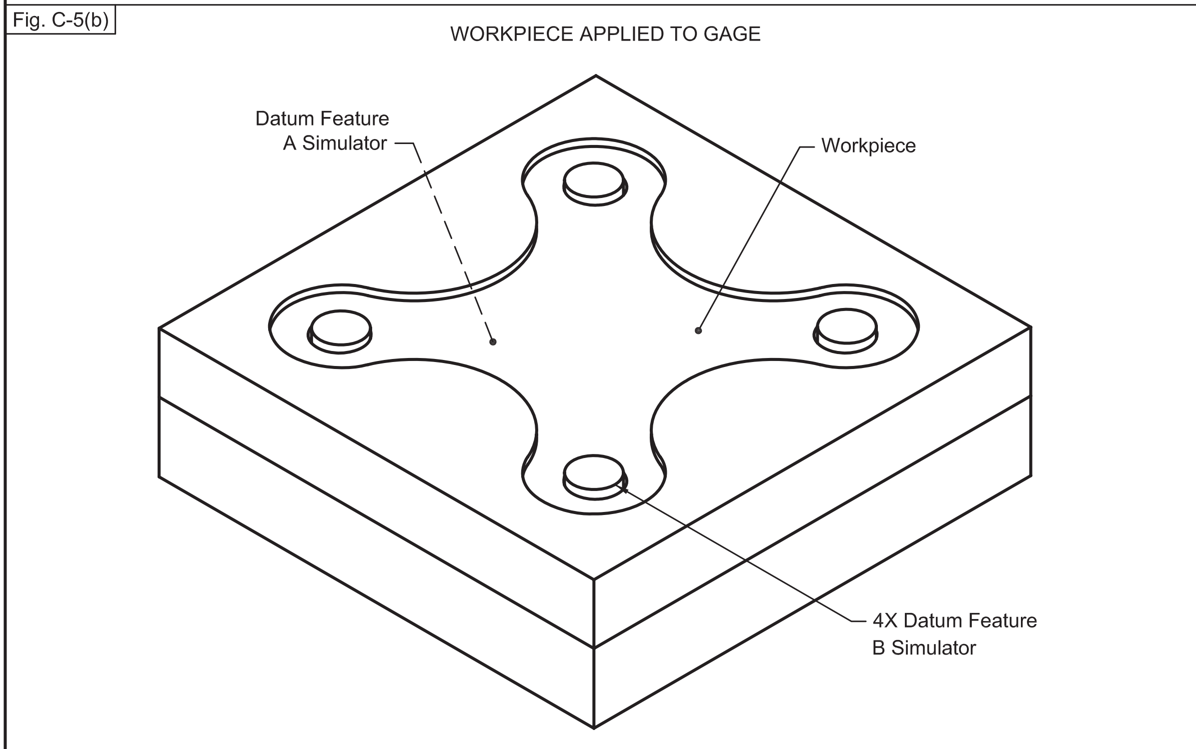


Fig. C-6 Secondary and Tertiary Datum Features: RMB Simulation

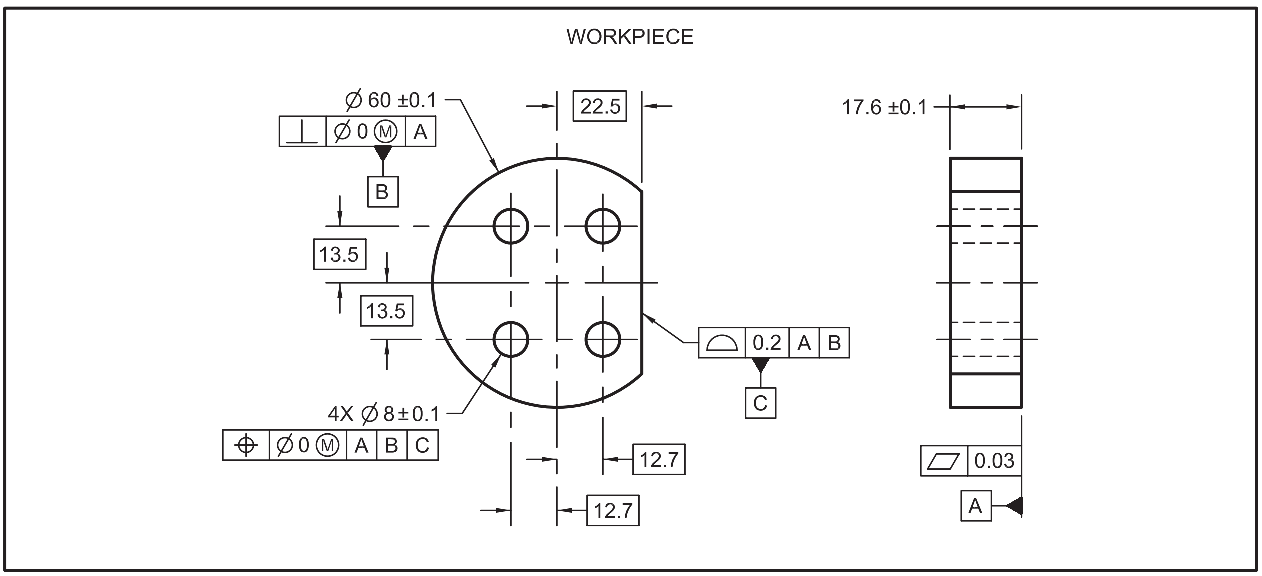


Fig. C-6 Secondary and Tertiary Datum Features: RMB Simulation (Cont'd)

Fig. C-6(a)

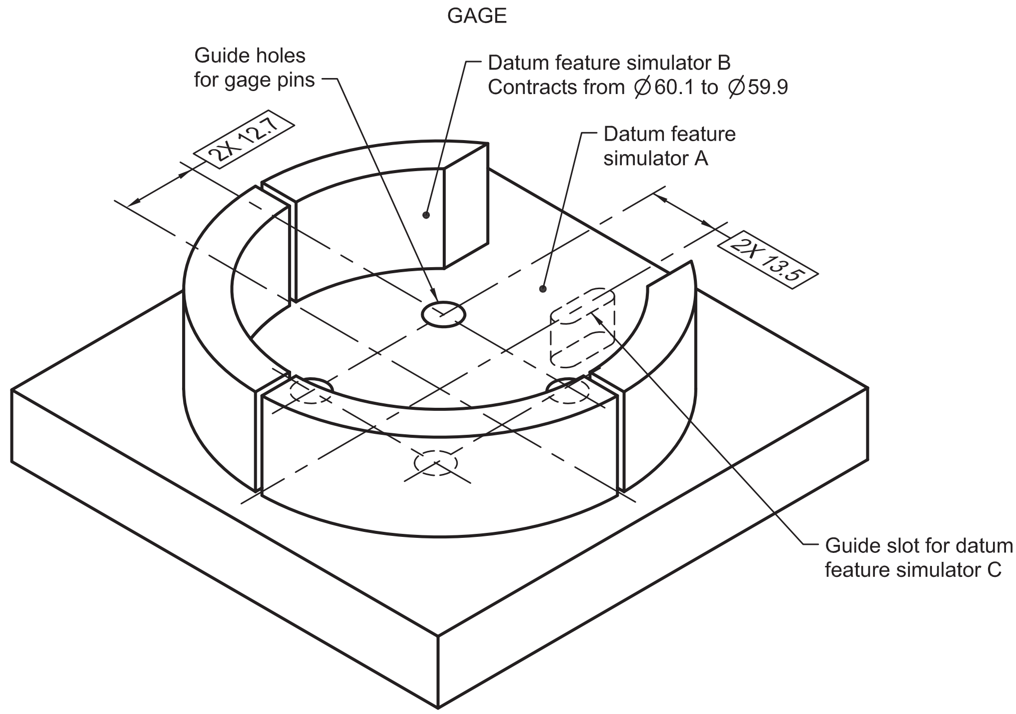


Fig. C-6(b)

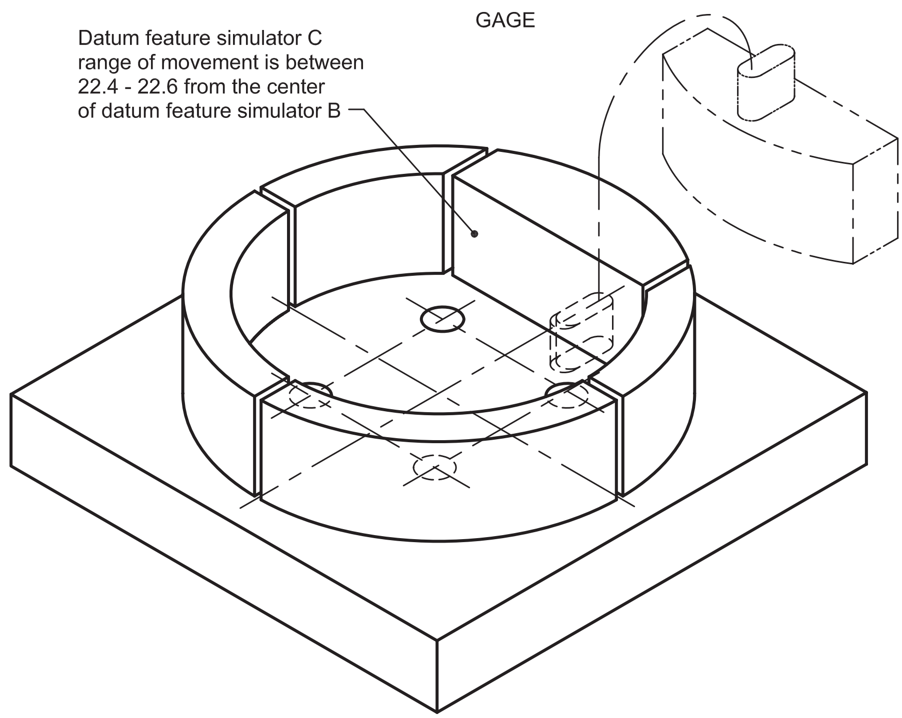


Fig. C-6 Secondary and Tertiary Datum Features: RMB Simulation (Cont'd)

Fig. C-6(c)

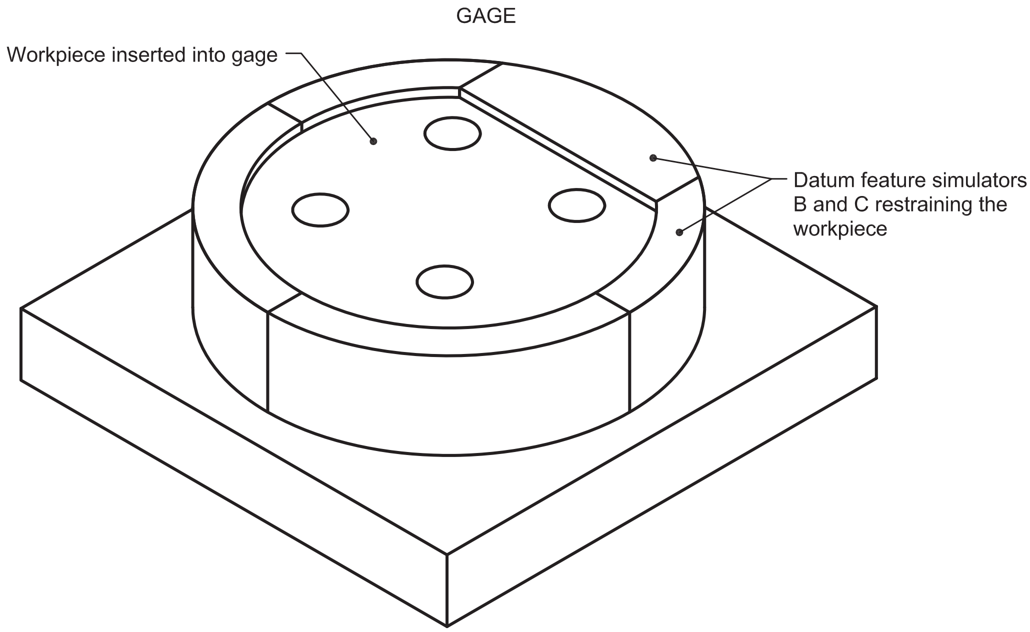
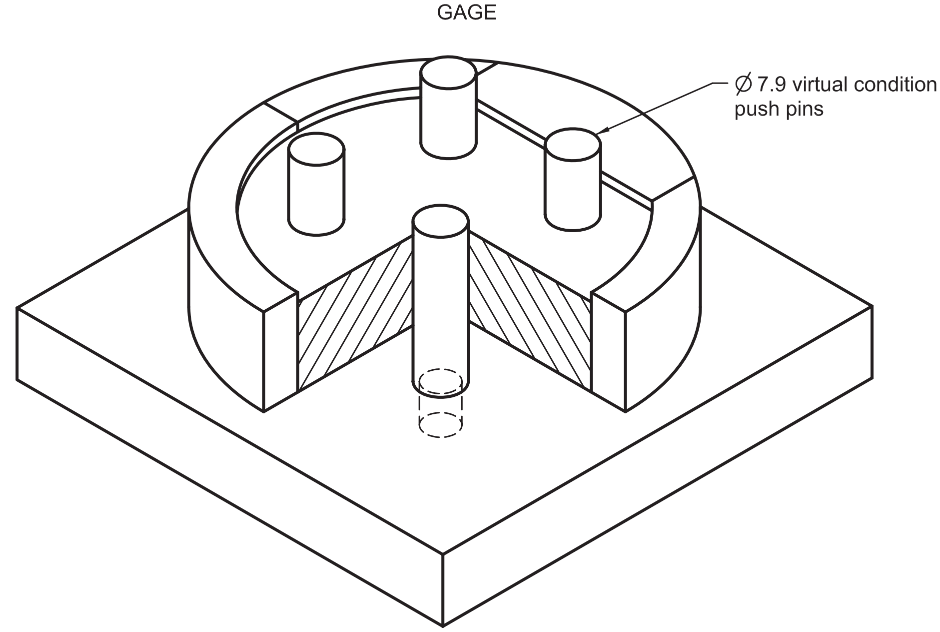


Fig. C-6(d)



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