Errata
to
ASME Y14.43-2003
Dimensioning and Tolerancing Principles for Gages and Fixtures

The following figures have been revised: Fig. I1; Fig. II1; Fig. A1 (Workpiece); Fig. A2, illustrations (c) and (d); Fig. B13(b); Fig. B18; Fig. B19; Fig. B19(a); Fig. B20(f). Revisions appear on the following pages.

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
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July 2005

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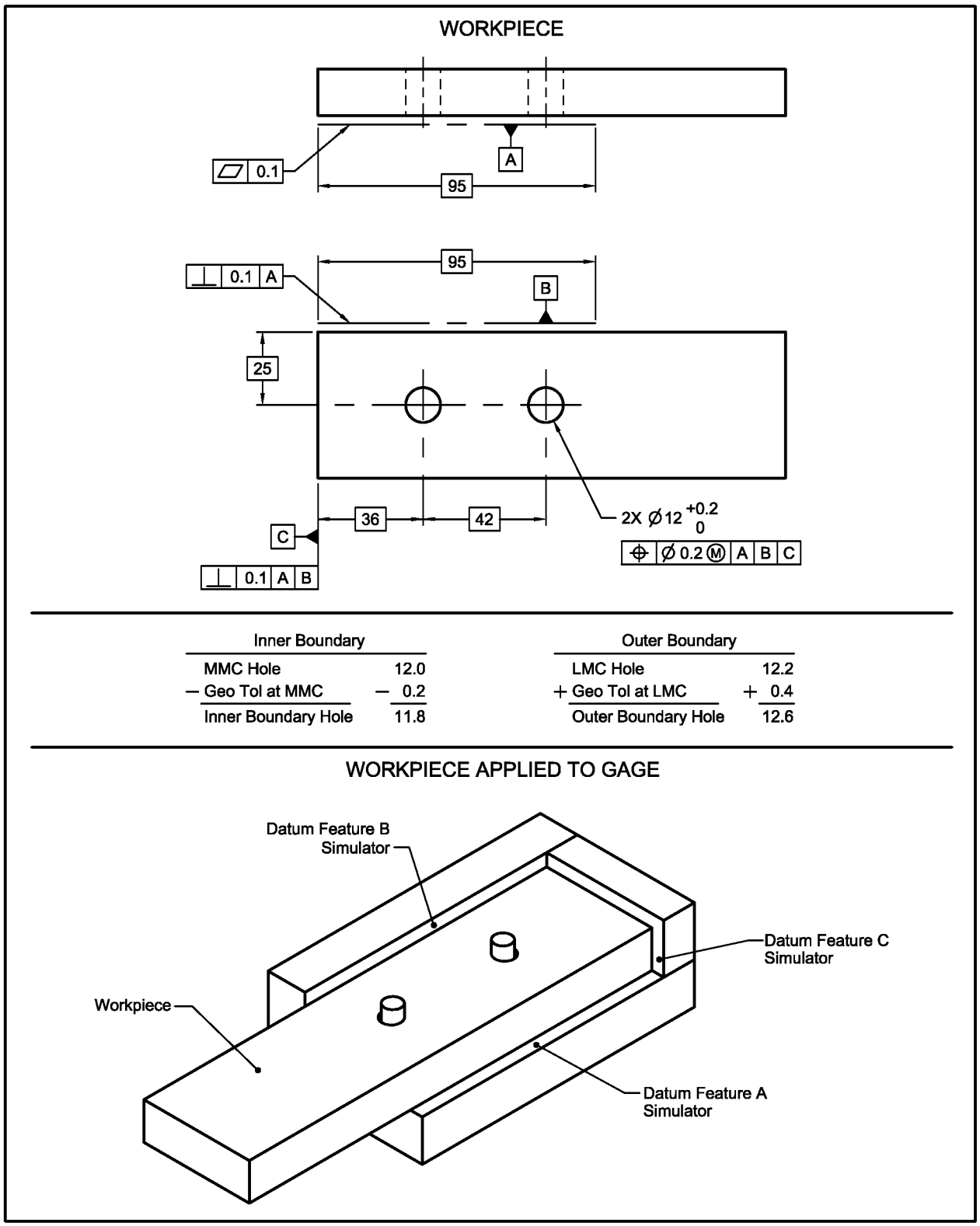


Fig. I1

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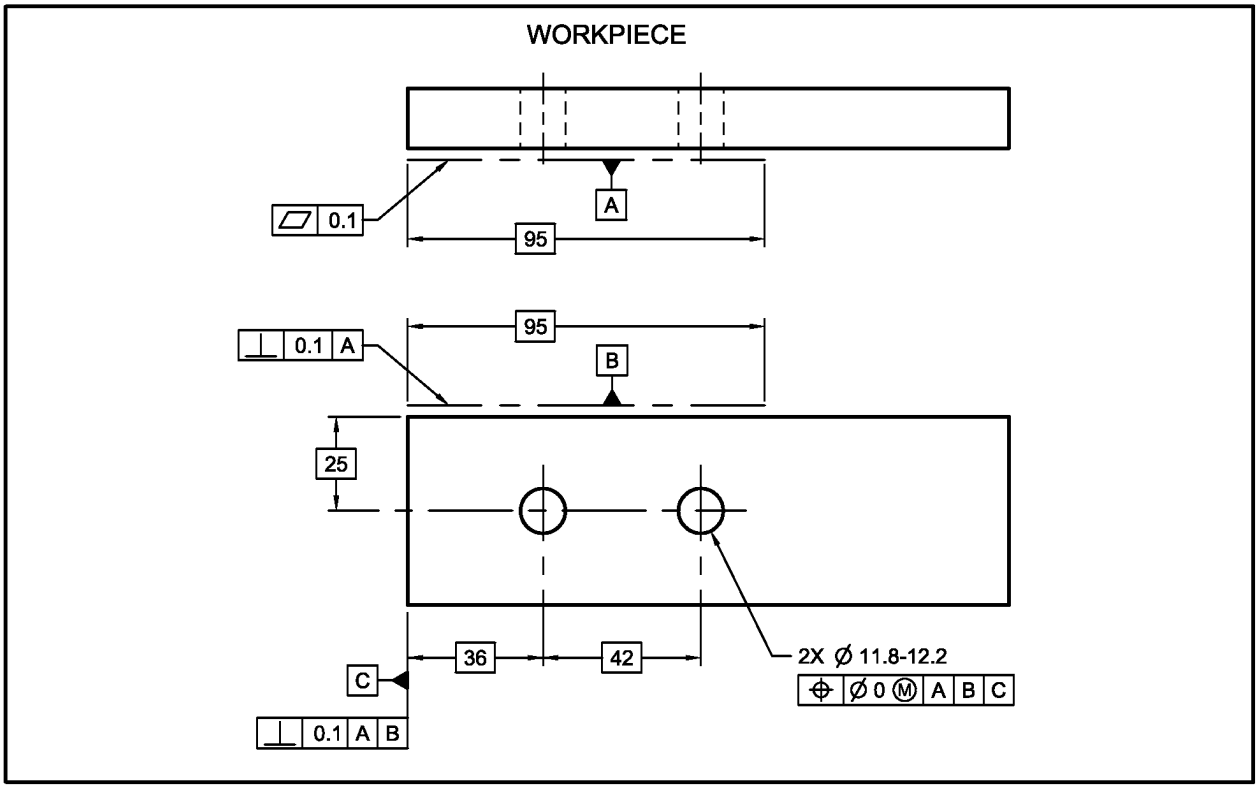


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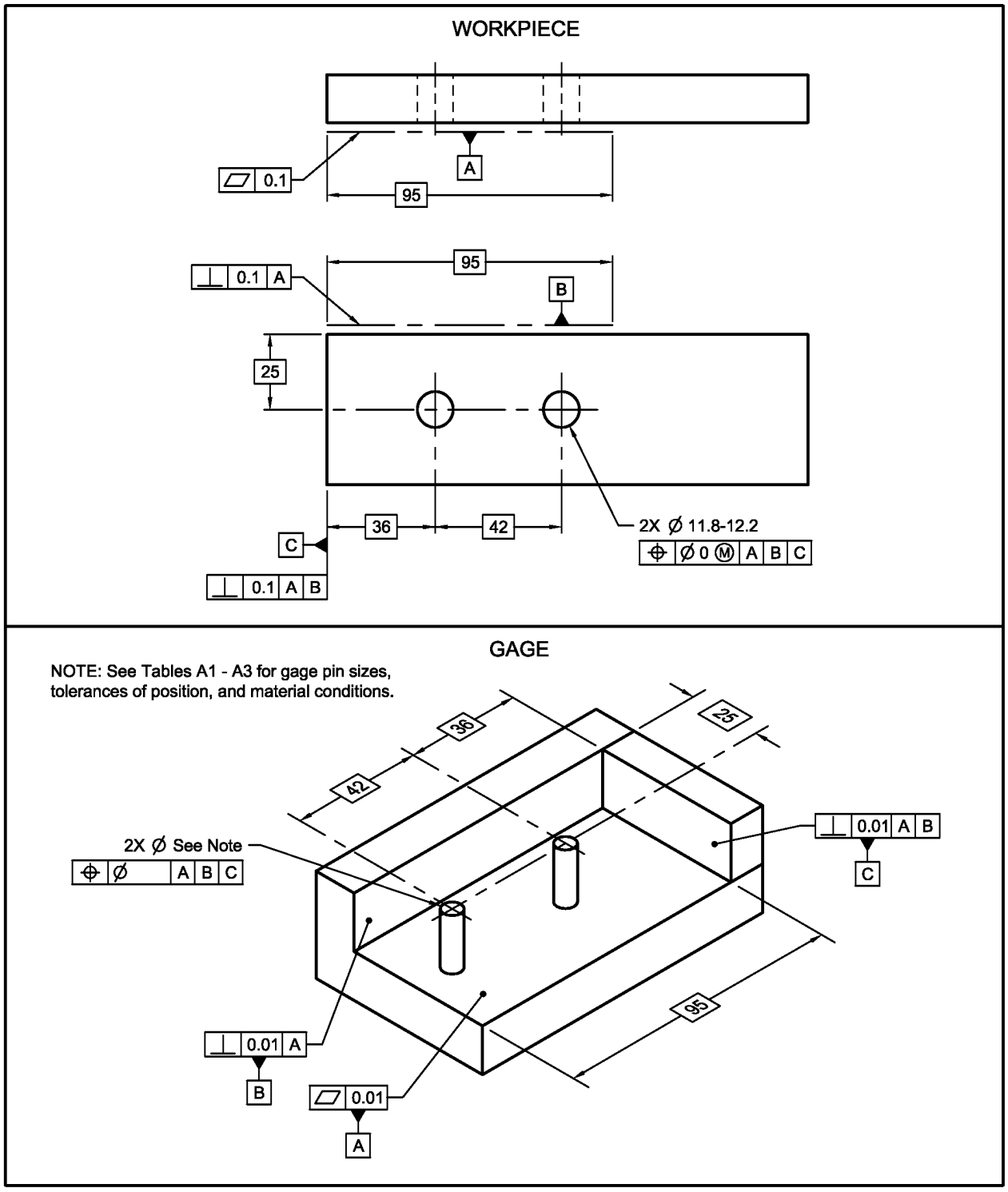
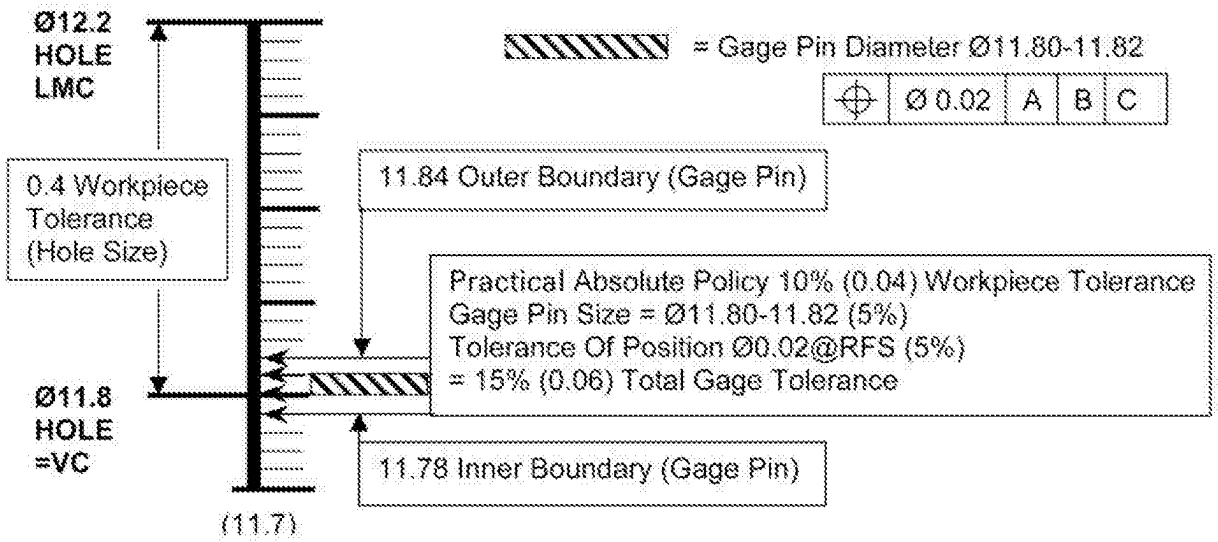
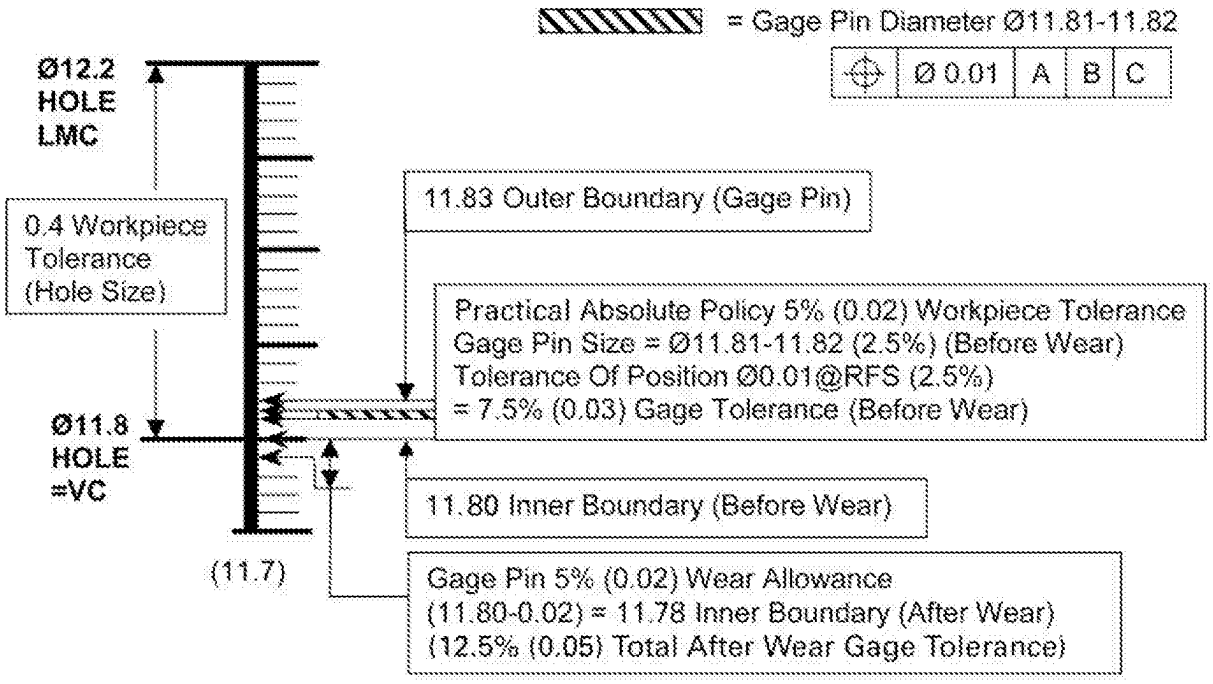


Fig. A1

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(c)

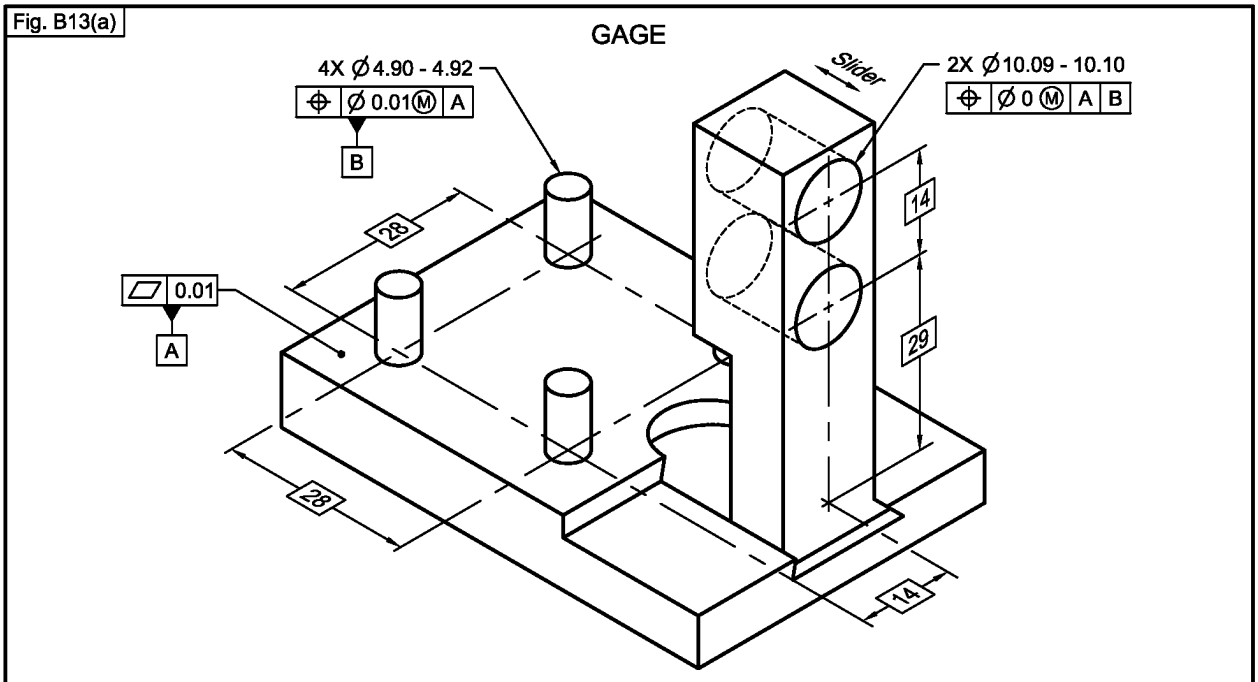


(d)

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Fig. B13(a)



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Fig. B13(b)

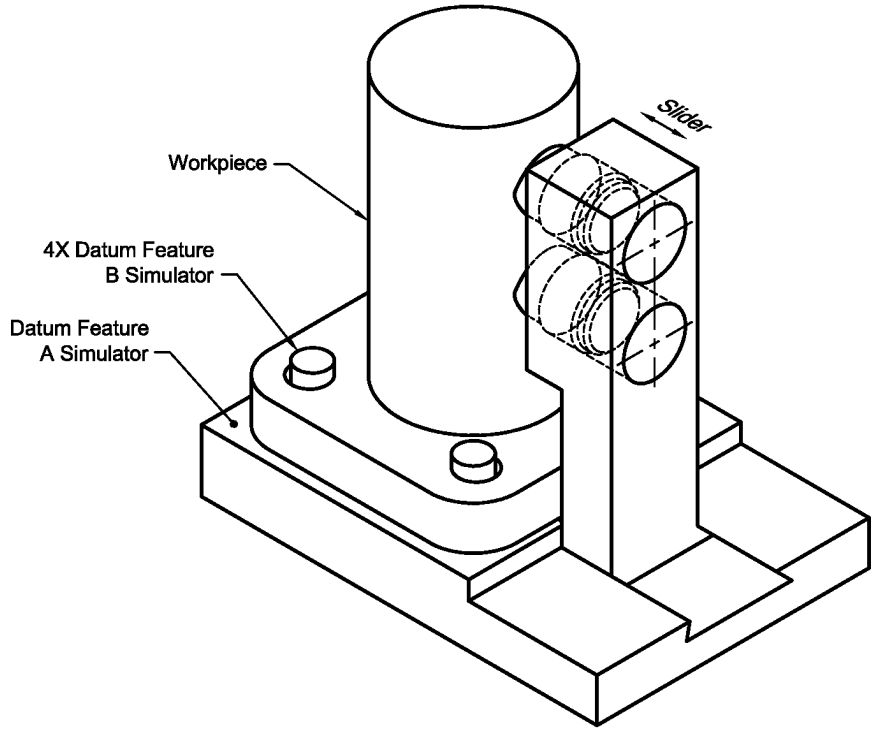


Fig. B13

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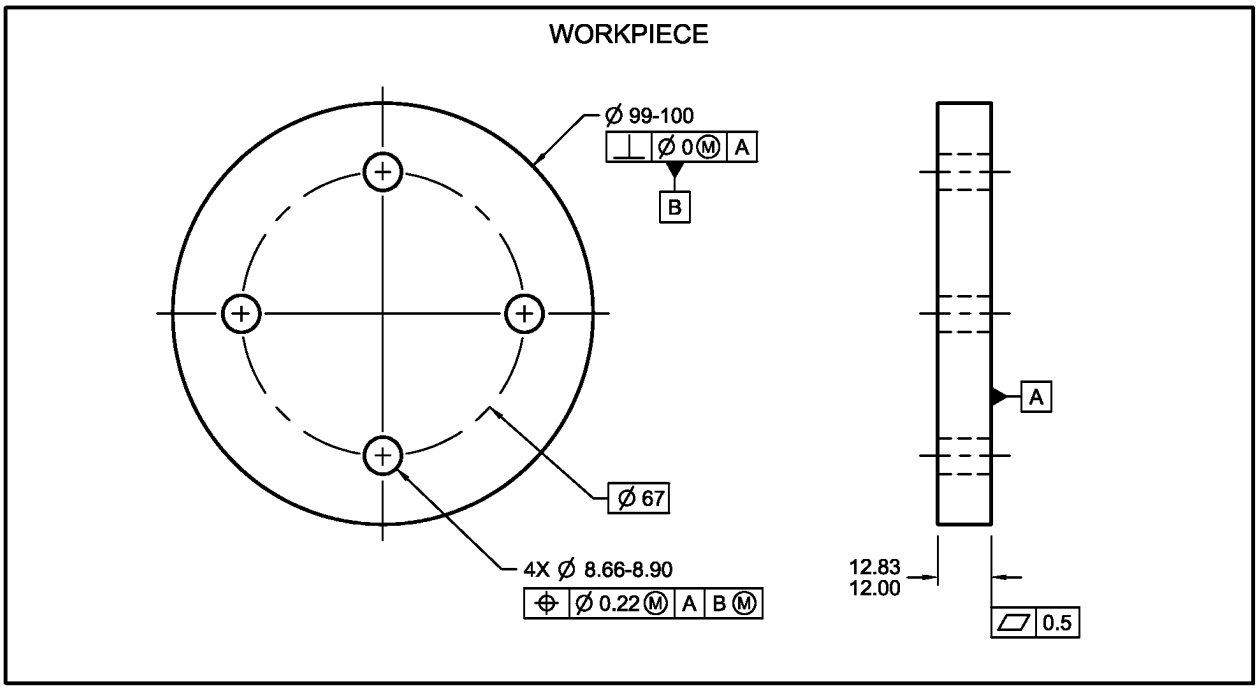


Fig. B18

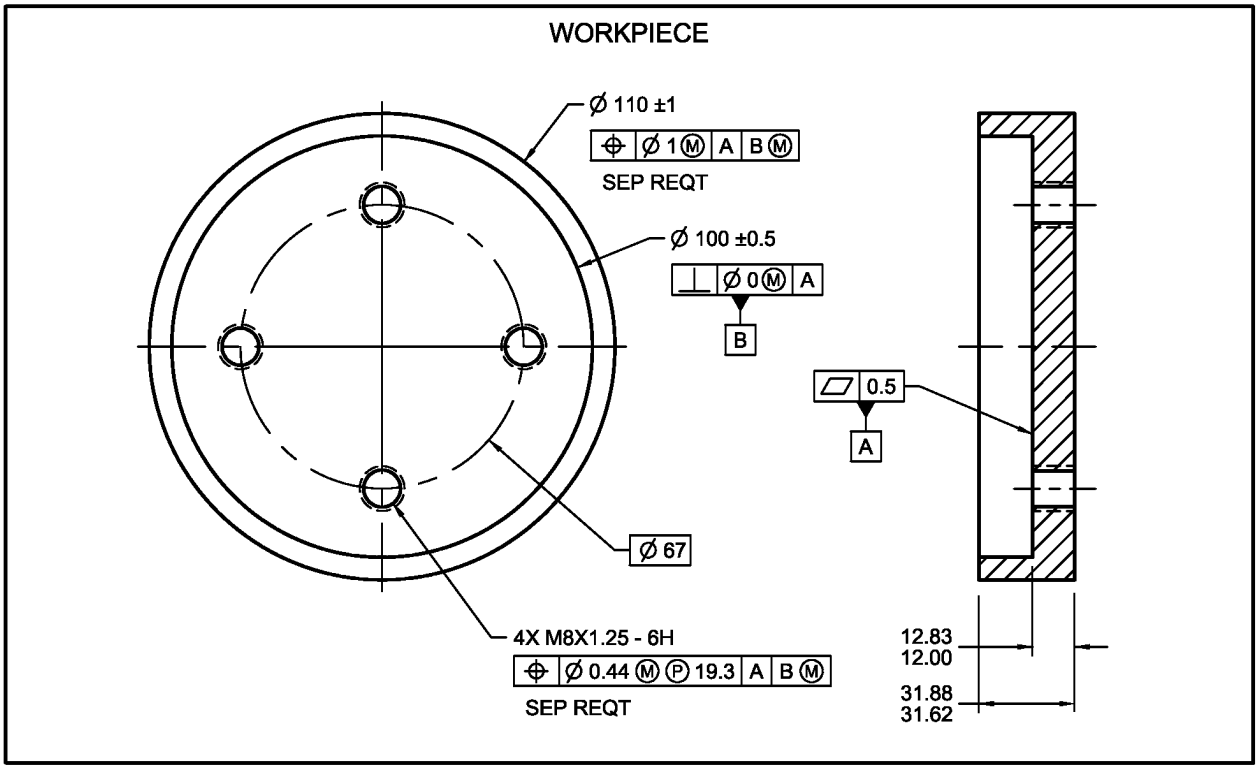


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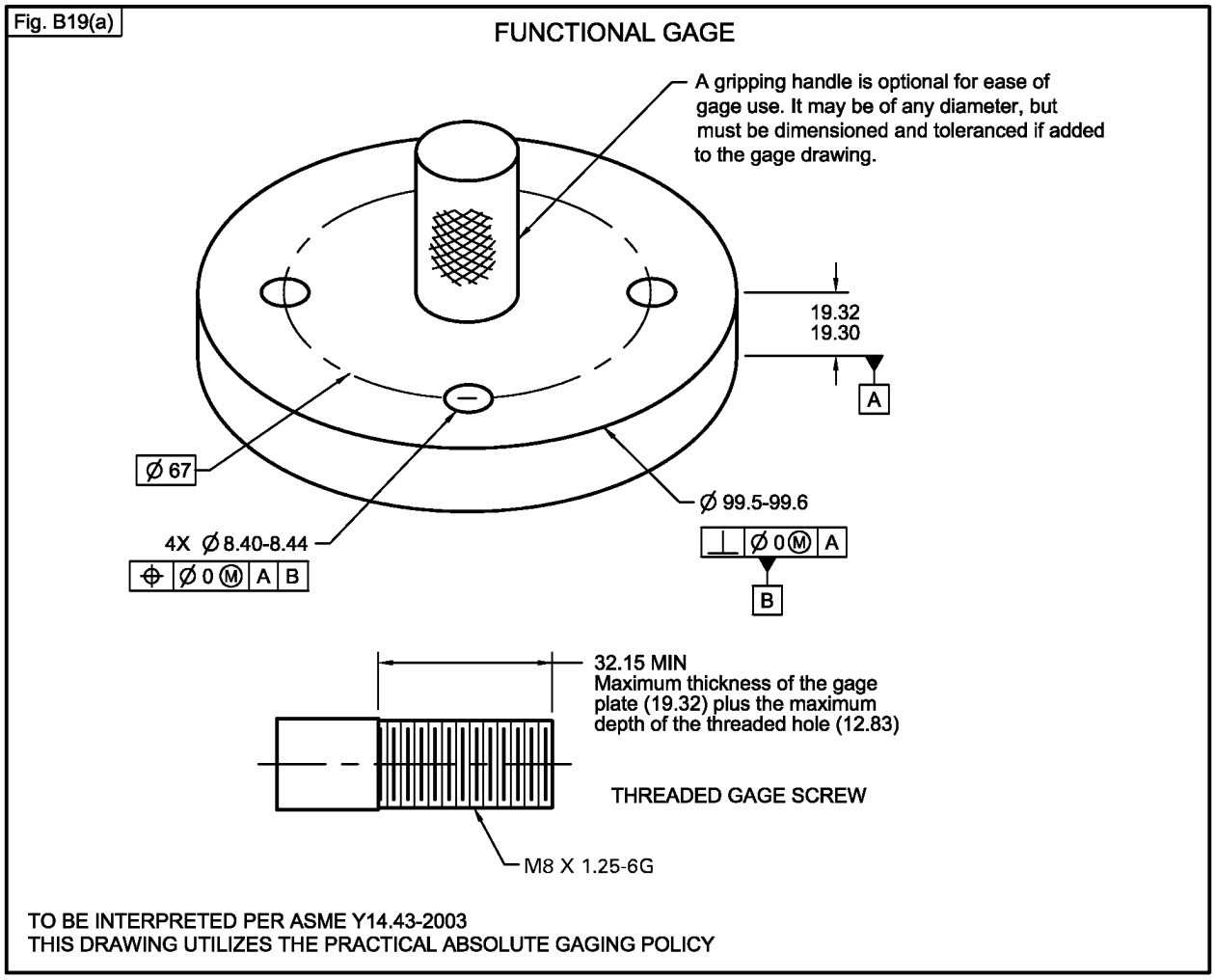
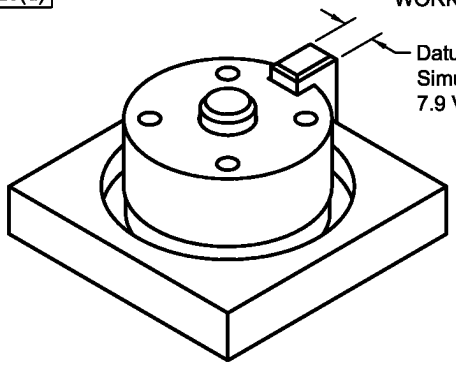


Fig. B19 (Cont'd)

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Fig. B20(d)

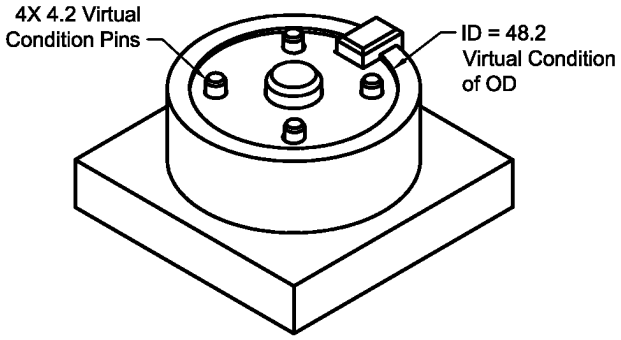
WORKPIECE APPLIED TO GAGE



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. B20(e)

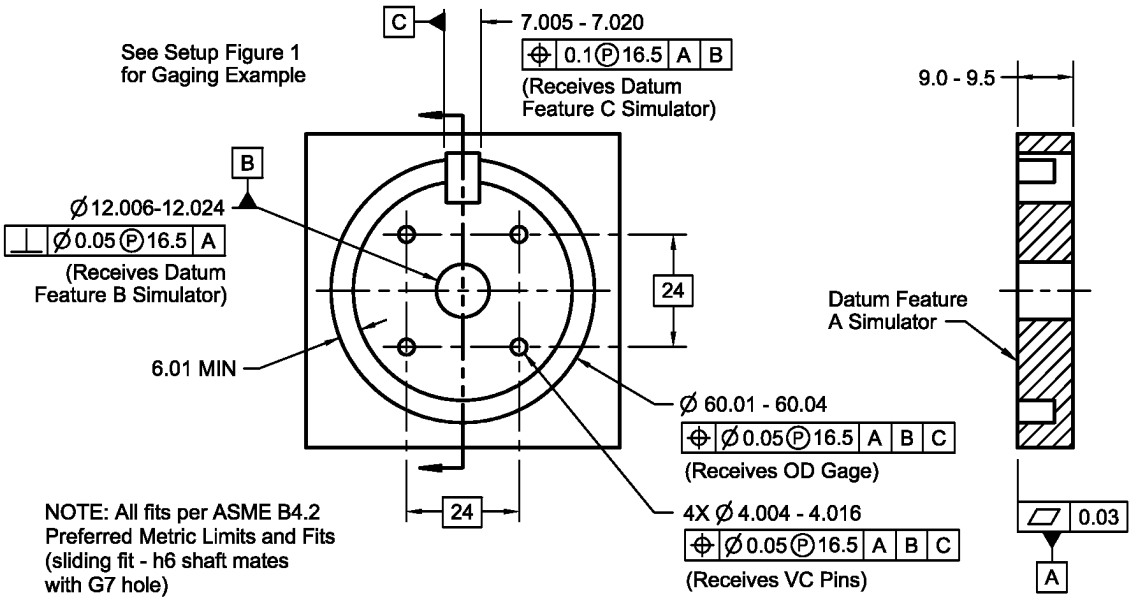
WORKPIECE APPLIED TO GAGE



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 MMC, and C at MMC. The size of Datum Feature B, Datum Feature C, the holes, and the OD must be verified separately.

Fig. B20(f)

GAGE BASE



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. B20

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Engineering Drawing and Related Documentation Practices

ASME Y14.43-2003

DIMENSIONING AND TOLERANCING PRINCIPLES FOR GAGES AND FIXTURES

An American National Standard

The American Society of Mechanical Engineers

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AN AMERICAN NATIONAL STANDARD

DIMENSIONING AND TOLERANCING PRINCIPLES FOR GAGES AND FIXTURES

ASME Y14.43-2003

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FOREWORD

This Standard contains information showing methods for creating gages and fixtures for features that use principles found in ASME Y14.5M-1994, Dimensioning and Tolerancing. It addresses GO gages for measuring maximum material condition and NOGO gages for measuring least material condition. This material was developed from ANSI B4.4M-1981, Inspection of Workpieces, which has since been retired. This Standard also addresses, for the first time, functional gages used for the measurement of geometric tolerances specifically for the verification of virtual condition boundaries (MMC concept). GO, NOGO, and functional gages are primarily utilized for the collection of attribute data.

Fixtures are also addressed. 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 Y14.5M-1994. The gages and fixtures displayed in this Standard represent the physical embodiment of the theory shown in ASME Y14.5M-1994 for the simulation of (MMC concept) virtual condition boundaries, and proper datum feature simulation.

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

The rules and principles in this Standard are consistent with the previously published information in ANSI B4.4M and ASME Y14.5M. Since this is the main focus of this Standard, more information and many more examples of gages and fixtures are presented.

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

Thanks to the committee members responsible for developing and maintaining ANSI B4.4M and ASME Y14.5M, and to Lowell Foster, for the help they have provided. Without it, we would not have been able to complete this Standard.

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

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ASME Y14.43-2003
SUMMARY OF CHANGES

Following approval by the ASME Y14 Committee and ASME, and after public review, ASME Y14.43-2003 was approved by the American National Standards Institute on January 28, 2003.

Page	*Location*	*Change*
22	Mandatory Appendix I	Figure I1 revised
28	Mandatory Appendix II	Figure II1 revised
35	Nonmandatory Appendix A	Figure A1 revised
37	Nonmandatory Appendix A	Figure A2(c) and (d) revised
76	Nonmandatory Appendix B	Figure B13(b) revised
87	Nonmandatory Appendix B	Figure B18 revised
89	Nonmandatory Appendix B	Figure B19 revised
90	Nonmandatory Appendix B	Figure B19(a) revised
93	Nonmandatory Appendix B	Figure B20(f) revised

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ENGINEERING DRAWING AND RELATED DOCUMENTATION PRACTICES

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 maximum material condition. Examples of gages used to inspect workpieces using regardless of feature size (RFS) are shown in Appendix C.

These practices focus on the design of receiver-type gages, which collect attribute data when used for the verification of workpieces dimensioned and toleranced in accordance with ASME Y14.5M-1994.

For gaging and fixturing principles and practices, see paras. 2 through 6.

1.2 Units

The International System of Units (SI) is featured in this Standard because SI units commonly supersede United States (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 Y14.5M-1994. 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, this fact shall be noted on the drawing or in a document referenced on the drawing. Reference to this Standard shall state ASME Y14.43-2003.

1.5 Appendices

1.5.1 Mandatory Appendices. The following mandatory appendices are included in this Standard:

(a) I, Illustrations of Gaging Policy
(b) II, Material Condition Explanation

1.5.2 Nonmandatory Appendices. The following nonmandatory appendices are included with this Standard:

(a) A, Examples of Gage Characteristics
(b) B, Examples and Illustrations
(c) C, Regardless of Feature Size

1.6 References

The following documents form a part of this Standard to the extent specified herein. Unless otherwise indicated, the latest edition shall apply.

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 Y14.5M-1994, Dimensioning and Tolerancing
ASME Y14.5.1M-1994, Mathematical Definition of Dimensioning and Tolerancing Principles

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1.7 Definitions

The following terms are defined as their use applies in this Standard.

1.7.1 Gaging

actual local size: the value of any individual distance at any cross section of a feature (see ASME Y14.5M-1994).

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

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

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

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

datum feature simulator: a gage or fixture element (such as a surface plate, gage surface, or mandrel) associated with the datum feature(s) and used to establish the simulated datum(s).

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.*

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

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 mating part and are identified on gage drawings using techniques found in ASME Y14.5M-1994.

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

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 or virtual condition boundaries.

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

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). (See ASME Y14.5M-1994.)

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). (See ASME Y14.5M-1994.)

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

separate gaging requirement: the condition where 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 definition for *simultaneous gaging requirement.*

simultaneous gaging requirement: the condition where 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.

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.

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

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.

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

1.7.2 Tolerancing

absolute tolerancing (pessimistic tolerancing): the policy of tolerancing gages that ensures complete random ability of parts assembly by applying gagemakers' tolerances, wear allowances, measurement uncertainties, and form controls, all within the workpiece limits of size and geometric control. See para. 2.3.1.

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

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.

optimistic tolerancing: the policy of tolerancing gages that ensures all part features within tolerance that are gaged are accepted by the gage. See para. 2.3.2.

practical absolute tolerancing: the policy of tolerancing gages that predicts most part features within tolerance

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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. 2.3.4 and Appendix II.

tolerant tolerancing: 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. 2.3.3.

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

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

2 PRINCIPLES

2.1 General

2.1.1 Gage Design Principles. Gages that check envelopes or boundaries are all designed on similar principles, whether they inspect maximum material condition (MMC) or virtual condition (MMC concept). GO gages determine compliance with the MMC envelope that is defined by ASME Y14.5M-1994, para. 2.7.1. Functional gages are used to inspect for compliance with the virtual condition boundary created by use of the MMC concept defined by ASME Y14.5M-1994, paras. 2.11 through 2.13.

2.1.2 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 as small as economically feasible.

2.1.3 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. However, 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. 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 (i.e., parts meeting drawing specification) parts compared to the acceptance of bad parts.

2.2 Function and Use of Gages

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

2.2.1 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, considerable care is required to use zero force as this may distort the hole and give a false result. For nonrigid features, perfect form at MMC is not required.

2.2.2 NOGO Gages. The least material condition 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 least material condition 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 sets of opposing points within the hole.

2.2.3 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 can-

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not 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, the axis of which is horizontal, under its own weight or the force marked on the gage

(b) pass over a dimensionally conforming shaft, the axis of which is vertical, when applied by hand without using excessive force

2.2.4 NOGO Snap Gages. A NOGO snap gage shall

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

(b) not pass over a dimensionally conforming shaft, the axis of which is vertical, when applied by hand without using excessive force

2.2.5 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-1994.) 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

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

(c) When using functional gaging principles, it is observed that specifying one datum reference frame per part requires one gage to be used for acceptance. Any increase in the number of datum reference frames will increase the number of gages and inspection setups.

2.3 Gaging Tolerance Policies

The following subparagraphs explain alternative forms of gage tolerancing policy (see para. 1.7.2 for definitions). A gage or fixture designer may select one of the following policies for specific implementation.

2.3.1 Absolute Tolerancing (Pessimistic Tolerancing). 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 in accordance with 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 Appendix I, Fig. I2.

2.3.2 Optimistic Tolerancing. 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 Appendix I, Fig. I3.

2.3.3 Tolerant Tolerancing. This is accomplished by applying gagemakers' tolerances, wear allowances, measurement uncertainties, and form controls in such a manner 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 within-tolerance features. See Appendix I, Fig. I4.

2.3.4 Practical Absolute Tolerancing. This is accomplished by applying gagemakers' tolerances, wear allowances, measurement uncertainties, and form con-

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trols 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 Appendix II.

2.4 Statistics

Statistical tolerancing may be used to calculate tolerances on parts that are to be gaged. This can have the effect of increasing part yield. However, it shall be considered that gages that use the absolute tolerancing method will reject some borderline parts that are technically within drawing tolerances. This is to ensure random interchangeability of mating parts. Statistically toleranced parts commonly use tolerances that allow virtual condition boundaries (MMC concept) to be generated on mating parts that reduce interchangeability. GO and functional gages would then accept some parts with statistically based tolerances that would not assemble in worst-case situations.

Actual value distribution is the term associated with the amount a feature has deviated from its perfect geometry. As with the parts being toleranced, it is recommended that gage deviation be studied with respect to a gage feature's manufacturing process capability and that this be used for analysis and setting of gage tolerances.

2.5 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.

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 error with the gage components.

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.

2.6 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.

2.6.1 Gage Design Criteria. It is the goal of each gage to ensure the compliance of each feature being gaged. Gages shall be designed in a manner that reflects the workpiece specification. Therefore, the workpiece needs to be specified such that the functional requirements are defined.

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

2.7 Principles of Gage Size and Full Engagement of Features

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

(a) The maximum material condition 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 maximum material condition of the workpiece feature. This GO gage should fully pass into or over an in-tolerance workpiece feature with zero force.

(b) The least material condition 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 least material condition 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.

2.7.2 Departure From Principles

(a) Some examples of considerations of departure from the principles given in paras. 2.7.1(a) and (c) [gaging maximum material condition 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, shaft, or other feature of size is so small that it does not affect the character

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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 errors of roundness and straightness of the hole are so small that they do 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. 2.7.1(b) (gaging least material condition) are as follows. Gaging the least material condition 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 almost to zero, then it will be necessary to use a NOGO ring or plug gage of full cylindrical form.

NOTE: It should be remembered that a dedicated NOGO gage to check least material condition 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.

2.8 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.

2.8.1 All Checks Free State. Workpiece measurements shall not be distorted to obtain compliant results. Unless otherwise specified, all workpieces are to be inspected in the free state. (See ASME Y14.5M-1994, para. 6.8.)

2.8.2 Restraint. If a workpiece is to be inspected in a restrained state (see ASME Y14.5M-1994, para. 6.8.2), it shall be so noted on the design drawing and on the inspection methods plan (ASME B89.7.2) for the workpiece or the feature being inspected. These notes shall be as complete as is necessary to ensure that the workpiece will be inspected as it will actually function.

2.8.3 Flexible Parts. Unless otherwise specified, all flexible parts are to be inspected in the free state. If restrained state inspection is desired, it shall be so noted on the workpiece drawing and accompanying inspection methods plan.

2.9 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 maximum material condition limit of size. The maximum diameter at any position in the hole shall not exceed the least material condition 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 maximum material condition limit of size. The minimum diameter at any position on the shaft shall not be less than the least material condition 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 (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 maximum material condition, 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 least material condition.

(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 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) a drawing note, such as "Perfect form at MMC is not required" (see ASME Y14.5M-1994)

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

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

(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 a least material condition symbol after the specified geometric tolerance. Such features controlled at LMC shall, when measured for size violations, conform to perfect form at LMC and for MMC violations at every two diametrically opposed points (e.g., on a diameter).

(f) *Cross Section Versus Two Point Versus Envelope.* Unless otherwise specified, all rigid 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 small hole gages.

2.10 Functional Gages Verify Ability to Assemble

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

2.11 Gaging Temperatures

Gages shall be calibrated at 20°C (68°F). See para. 5.2.1.

2.12 Economics

When it is determined that 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 GO or functional gage. These computer-generated GO and functional gages simulate the function of hard gages. Still, it shall be remembered that 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.

2.12.1 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

2.12.2 Speed and Capability: Hard Versus Soft Gages. 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 much greater speed than many other inspection tools. However, it shall be remembered that 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.

3 GAGE DESIGN

3.1 GO/NOGO Gages

3.1.1 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 0.010 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 gag-

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ing 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 it has two equal segments cut off by planes normal to the axis of the handle. In the transverse plane, the diameter shall conform everywhere 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 conform everywhere to the limiting dimensions of the gage.

3.1.2 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 of each 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).

3.1.3 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.

3.1.4 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.

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

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

3.1.7 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 with a long GO gage. Alternatively, 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).

3.2 Functional Gage Configuration

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

3.2.1 Relationship of Detail to Assembly or Other Function. Each feature to be gaged is to be inspected in ways that ensure relationships that shall be met in the assembly are being gaged. This is to ensure that once the features and workpieces are put into the assembly, they will assemble in a functional manner. If the functional criteria are something other than assembly, the gage shall ensure that the specific functional requirements have been met if the component has been passed by the gage.

3.2.2 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.

(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) which is 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 it serves the purpose of angular orientation only, it shall be simulated by a cylindrical surface or a diamond pin.

(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 MMC 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. The pin size for the simulation of a secondary and/or tertiary datum

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feature shall be the virtual condition size. For a single hole referenced on an RFS basis, the gage pin shall be, as a minimum, capable of simulating the range of sizes from the inner boundary to the least material condition. 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) which is 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 it serves the purpose of angular orientation only, it shall be simulated by a cylindrical surface or an elongated hole.

(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 MMC 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. The hole size for the simulation of a secondary and/or tertiary datum feature shall be the virtual condition size. For a shaft referenced on an RFS basis, the gage hole shall be, as a minimum, capable of simulating the range of sizes from the inner boundary to the least material condition. That is, rather than a fixed-size hole, a contractible 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 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 MMC 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 straightness tolerance. If the datum feature's center plane is controlled by a straightness tolerance, the simulator shall be the virtual condition size. The fixed separation for the simulation of secondary and/or tertiary datum features shall be the virtual condition size of the feature. For a slot width referenced on an RFS basis, the gage surfaces shall be, as a minimum, capable 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 feature's size while maintaining its basic orientation and location to the datum(s) 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 MMC 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 straightness tolerance. If the datum feature's center plane is controlled by a straightness tolerance, the simulator shall be the virtual

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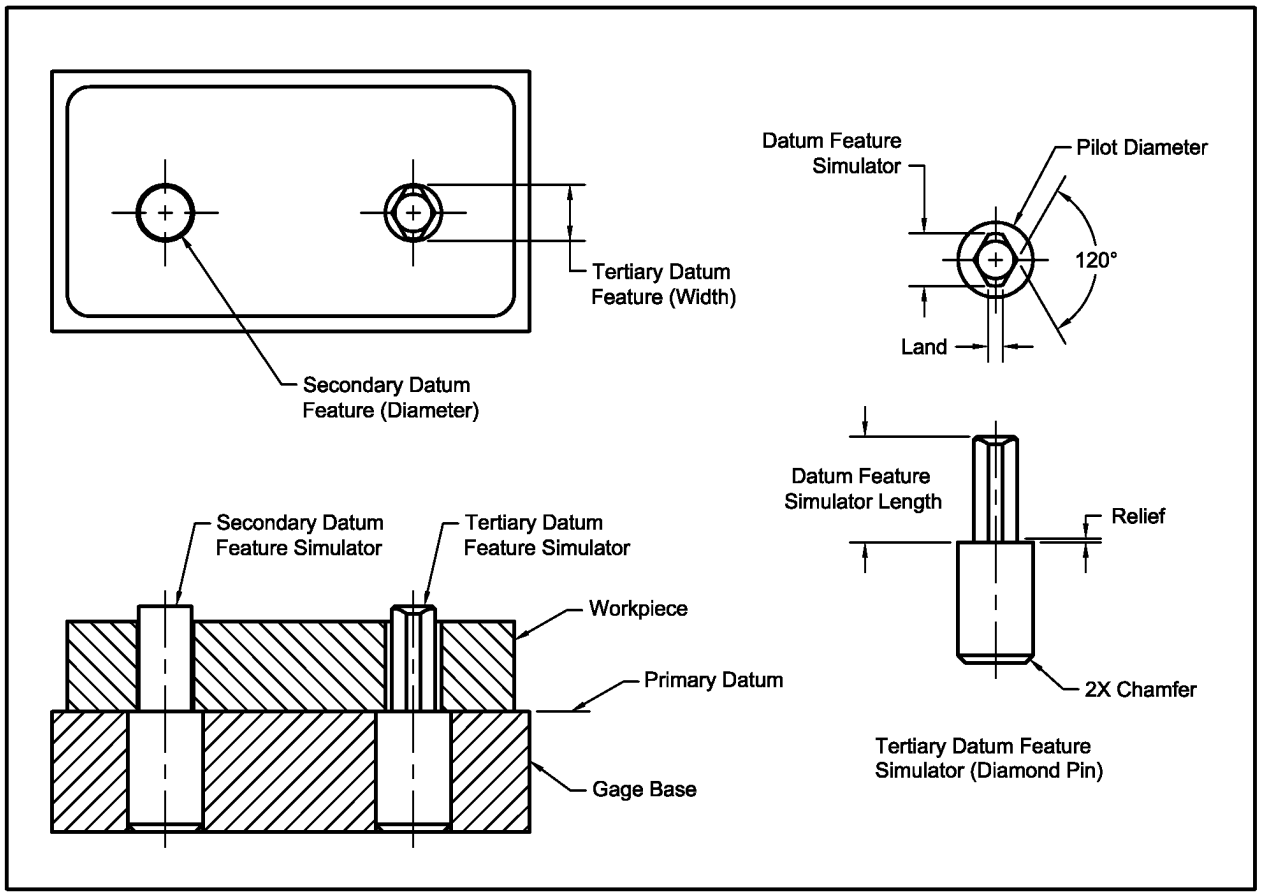


Fig. 1 Diamond Pin Construction

condition size. The fixed separation for the simulation of secondary and/or tertiary datum features shall be the virtual condition size of the feature. For a tab referenced on an RFS basis, the gage surfaces shall be, as a minimum, capable of simulating the range of sizes from the inner boundary to the LMC. That is, rather than a fixed-size gap, a contractible 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 datum(s) 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:

(1) contact the surface at its nominal geometry if it is a nonclosed feature;

(2) simulate the appropriate boundary condition if it is a closed feature.

(g) Special Condition Datum Simulators

(1) Although not the preferred practice, diamond pins are commonly used as tertiary datum feature simulators to represent cylindrical angular orientation datum features. See Fig. 1. The pilot diameter, if different from the datum feature simulator (DFS) diameter, should be of a standard size. The corner of the pilot diameter should be chamfered to aid in assembly. The DFS diameter shall be the virtual condition of the workpiece's datum feature. The length of the DFS diameter shall be, at a minimum, the maximum length of the workpiece's datum feature. The land is the portion of the DFS diameter that contacts the workpiece. The land should be one-third of the DFS diameter. The relieved area of the DFS diameter should be two opposed angles of 120° inclusive. The chamfer on the corner of the DFS diameter aids in guiding the workpiece onto the DFS.

(2) As the preferred practice, cylindrical datum features of size are simulated for purposes of angular orientation by a cylindrical gaging element capable of a sliding motion. This movement shall be allowed in a direction that shall contain the part's remaining functional degrees of freedom.

3.2.3 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

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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.

3.2.4 Datum Target Configuration

(a) Datum Target Point Simulator. Spherical or hemispherical pins are used to represent datum target points. The center of the spherical simulator shall be located offset normal to the nominal part surface by an amount equal to the spherical radius. When a datum target is purposely not located in a particular direction, it is to allow a movable datum target simulator to be 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 that has been left undimensioned.

(b) Datum Target Line Simulator. The use of the side of a cylindrical pin to represent datum target lines is preferred in most instances. When a datum target is purposely not located in a particular direction, it is to allow a movable datum target simulator to be used. The simulator is to be set at the specified basic dimensions and may move in the direction that has been left undimensioned.

(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, when used, 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(s). 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.

3.2.5 Material Condition Modifiers. Material condition 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. 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 MMC or LMC will allow the controlled gaging elements to shift as a pattern as the datum feature(s) departs from virtual condition, MMC, or LMC, as appropriate. This will have the effect of allowing 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 a direction that is the same as the gage elements have shifted. More likely, though, is the possibility that the gage pattern shift will not be in the same direction as the workpiece pattern shift. This may have the effect of the gage rejecting in-tolerance workpieces due to the inaccuracies of the gage allowed by the pattern shift.

This Standard, therefore, recommends the use of the regardless of feature size (RFS) 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 RFS 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.

The use of the LMC concept is most compliant in satisfying the absolute tolerance practice. The use of the MMC concept, however, provides the benefit of a significant increase in the number of in-tolerance parts passed by the gage at the cost of a small risk of accepting marginally bad parts. For a discussion of the ramifications of material condition symbol selection and examples of each, see Appendix II.

3.2.6 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. No matter what the controlled feature configuration, it is

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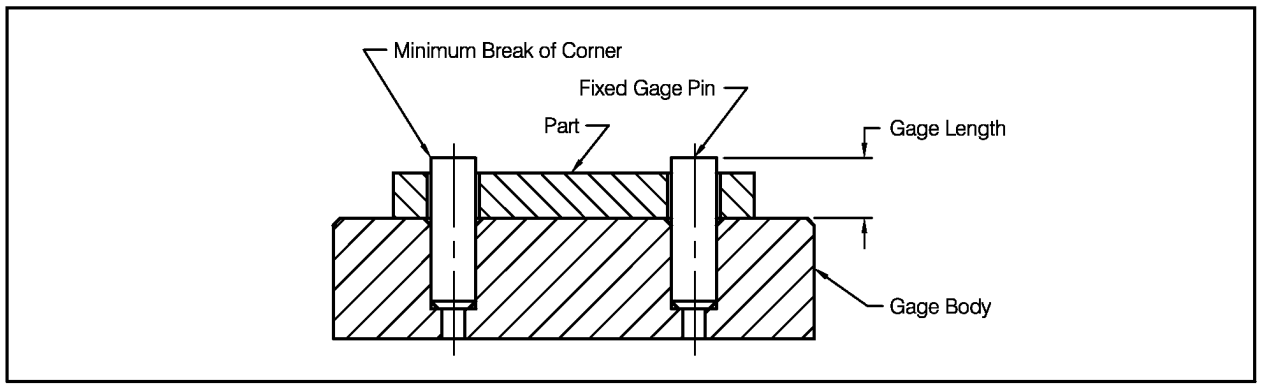


Fig. 2 Fixed Pin Construction

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, when fixed pin gages are used, 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. 2. 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. This is 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) Pushpins. To facilitate loading and unloading the workpiece, pushpin gage design may often be more desirable than the fixed pin concept. The pushpin concept allows the part to first 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 pushpin gage design is to inspect multiple patterns of features which allow separate gaging requirements. This could reduce the total number of gages required.

If the pushpin 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 pushpin gages to ensure 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 absolute tolerancing, 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 has the effect of possibly increasing the virtual size of the gage pin (MMC concept virtual condition), consequently infringing on the controlled hole's virtual condition boundary (MMC concept). This has the effect of creating a gage pin virtual condition larger than the virtual condition of the hole it checks. The more tolerance that is 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 the gage pin shall be kept to a minimum. See ASME B4.2 for sliding fits.

Pushpins are designed to be movable or removable, depending upon the application. Two types of pushpins will be referred to as Type 1 and Type 2.

(1) Type 1 pushpins are designed to be removed from the gage base or body while loading and unloading the workpiece being inspected. See Fig. 3. The pilot is the portion of the pushpin 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 should be 2.5 to 3 times the diameter of the pilot. This is 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.

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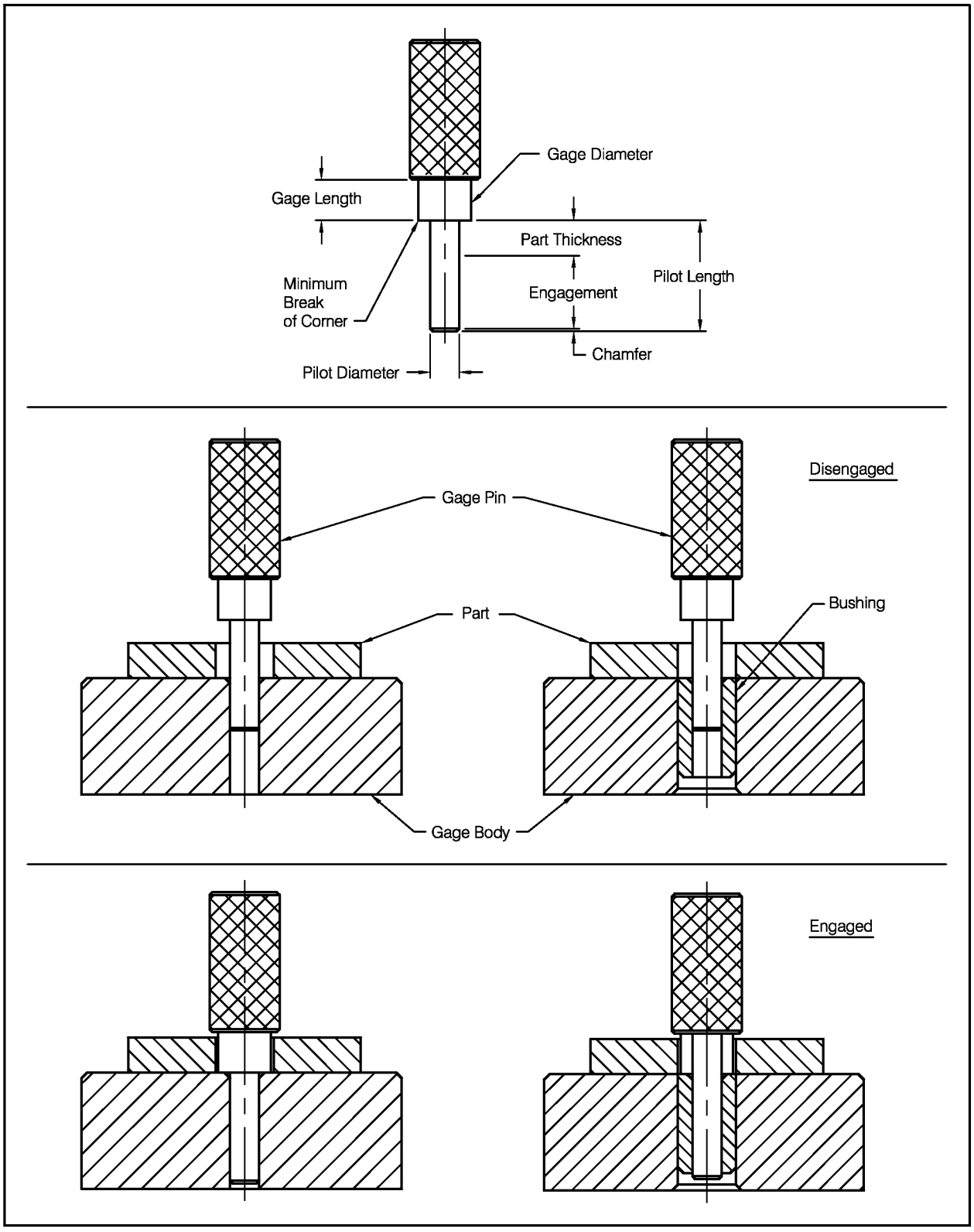


Fig. 3 Pushpin Construction — Type 1

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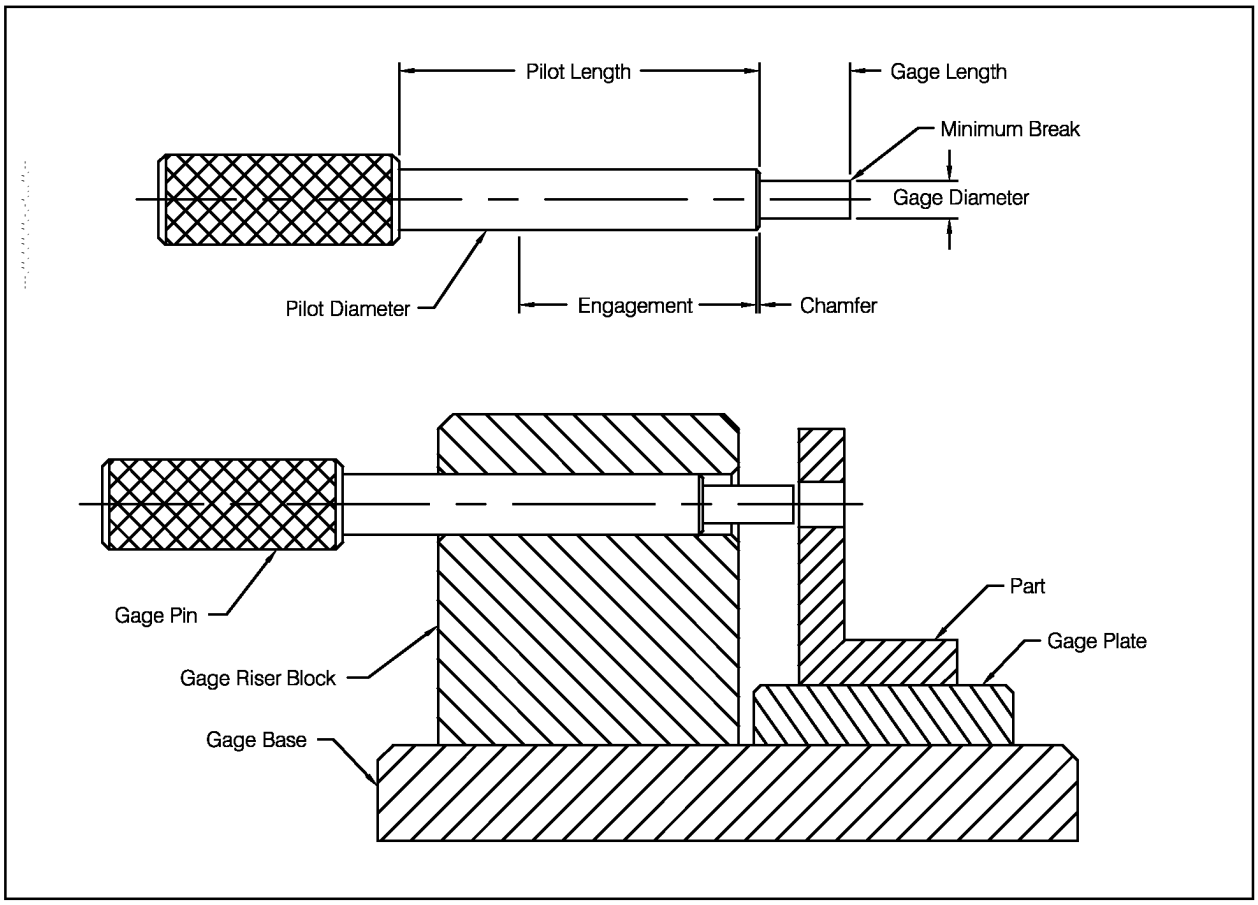


Fig. 4 Pushpin Construction — Type 2

(2) Type 2 pushpins are designed to remain assembled with the gage block or body, but are retracted to facilitate loading and unloading the workpiece. See Fig. 4. 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 should be at least 4 times the diameter of the pilot, to assure stable positioning of the pushpin. The pilot is the portion of the pushpin that engages the gage body, giving the pushpin 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 pushpin. 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) The boundary concept is used when tolerance zones are to be verified by gaging the virtual condition (MMC concept) boundaries generated. Originally explained in previous editions of ASME Y14.5M for elongated holes and shafts, the concept was expanded in ASME Y14.5M-1994 to include the more unusual shaped features not considered features of size in past editions of ASME Y14.5M. 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. In such instances where the boundary is to be gaged specifically in lieu of a tolerance zone, the word "BOUNDARY" is noted beneath the controlled feature's feature control frame.

(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 condition modifiers after any datum features of size 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 would 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.

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Although separate gaging requirements would, in concept, accept a greater number of workpieces gaged, it shall be remembered that such gaging methods would not ensure that the multiple patterns of features gaged with separate gages would assemble with one part that contained 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, e.g., all simultaneously mating with multiple patterns of features that are also simultaneously gaged on the mating parts in the assembly. When it is desired to clarify that patterns are to be simultaneously gaged, a note (as allowed by ASME Y14.5M-1994) such as SIM REQT may be placed on the product drawing next to all features that are part of the simultaneous gaging requirement. When it is desired to clarify that patterns may be separately gaged, a note such as SEP REQT may be placed on the product drawing next to all features that may be confused as a simultaneous gaging requirement.

It is important to remember that 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.

3.3 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.

3.3.1 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 the maintenance.

3.3.2 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 costs of the gages.

3.3.3 Size and Weight. Whenever possible, gages should be made at a physical size and weight that allow 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.

3.3.4 Physical Properties. The material used for gages shall be selected with due 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 (e.g., 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 the use of special materials (e.g., glass) is 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 700 HV (60 HRC).

(c) Stabilization. The gage manufacturer shall ensure that the gages are adequately stabilized by a method appropriate to the material, their 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. See ASME B4.2 and ASME B46.1. Consideration should be given to specifying additional surface texture parameters that will provide greater control of surface topography than does the R_a specification and will allow greater likelihood of conforming to the design criteria listed in para. 3.

3.3.5 Marking. Each gage and fixture, and its associated hardware, shall be legibly and permanently marked with the particulars listed below. The marking shall be on other than gaging surfaces and shall not affect the accuracy of the gages. Mark

(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) manufacturer's name or trademark

(d) serial or part number (optional)

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

3.3.6 Ergonomic Requirements. A gage shall be designed that considers ease of use. Not only are size and weight to be considered, but also 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

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configuration optimized for ability to be handled 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 could include pushpins, setting blocks, and calibration artifacts.

3.3.7 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, due 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.

3.4 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. 3.3.4(b).

(b) Gages With Components of Different Material. 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 on the gaging process shall be analyzed. However, inspecting the parts at 20°C (68°F) will control the effects of thermal expansion.

3.5 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.

3.6 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.

4 DIMENSIONING AND TOLERANCING

4.1 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 ten to twenty times tighter than the features being gaged.

4.2 Tolerance Calculation

4.2.1 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.

4.2.2 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 Appendix A.

4.2.3 Gage Tolerance. It is recommended that 5% of the workpiece tolerance be used as gagemakers' tolerance, with an optional 5% considered for wear allowance. Combined, they make up the total gage tolerance (5–10%), which is applied to the MMC size limit for a GO gage or to the virtual condition (MMC concept) limit for a functional gage. See paras. 4.3.1 and 4.3.2.

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

4.2.5 Virtual Condition (MMC Concept). Virtual condition (MMC concept) for all internal features of size is

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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.

4.3 Tolerance Distribution

4.3.1 Size and Geometric Tolerances. The distribution of gage tolerances between size and geometric controls should be done in a way that optimizes the manufacture of the gage and the acceptance of all gages within the extremes of the range of total gage tolerance. This may, at times, 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 some in the size limits, the RFS concept may be employed.

4.3.2 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.

5 USAGE

5.1 General

Functional gages inspect for violations of the virtual condition boundary 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 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.

5.2 Environmental Conditions

5.2.1 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, which is other than 20°C (68°F), both will expand by an amount that can be calculated as $KL(T-20)$, where K is the coefficient of expansion, L is the length, and T is the temperature in degrees Celsius.

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, which can cause them to twist and bend. The uncertainty of this shall be taken into consideration and, if possible, avoided.

(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 which 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.

5.2.2 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 could 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.

5.2.3 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.

5.3 Certification and Calibration

5.3.1 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

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all of the dimensions and tolerances are met. A gage can be certified as a master gage, which is rarely used, for use in checking other gages. A gage can be certified for use in a sample-checking area for checking parts and be held to a more open tolerance. The third gage is a shop gage, and 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.

5.3.2 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 all 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, the gage can be downgraded from a master gage to a sample-checking gage or some other 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.

5.3.3 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.

5.3.4 Methodology

(a) Control of Geometric Characteristics. The composite tolerance on geometric characteristics of fixed gages shall not exceed 50% of the applicable tolerance on the workpiece feature being gaged. The geometric tolerances shall be held within the workpiece size limit dimensions. Geometric tolerances that may be used on gages include straightness, flatness, circularity, cylindricity, profile, perpendicularity, parallelism, angularity, position, concentricity, symmetry, and runout. See ASME Y14.5M-1994.

(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 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 described below.

(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 utilizes 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 utilizes a setting master disc, with a diameter smaller than the working size of the snap gage, in conjunction with a set of gage blocks and is appropriate to both GO and NOGO snap gages. The gage block combination is adjusted such 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 method (1), which is mainly used for fixed snap gages.

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5.4 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. Most of the discussion in this Standard deals with gaging finished product requirements. There are also requirements for in-process gaging procedures. It is often considered good gaging practice to have available two sets of gages. 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.*

5.4.1 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, which are 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.

5.4.2 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.

5.5 Alignment Principle

The principle of alignment should be followed as closely as possible in all instruments for measuring dimensions. For example, the axis or center plane of the feature or dimension being measured should be aligned with the appropriate reference element of the gage. It may be the appropriate alignment is perpendicular to the axis or center plane, 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.

5.6 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 it is determined the measurement force exerted is not sufficient to interfere with the accuracy of measurements as they pertain to part function.

5.7 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.

6 FIXTURES

6.1 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.

6.2 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.

6.2.1 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

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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 Y14.5M-1994 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 (setup 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-1994) 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.

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

6.2.3 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 fewer times a part is removed from the fixture between measurements, the more repeatable the measurements.

6.3 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

Figures I1 through I4 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.

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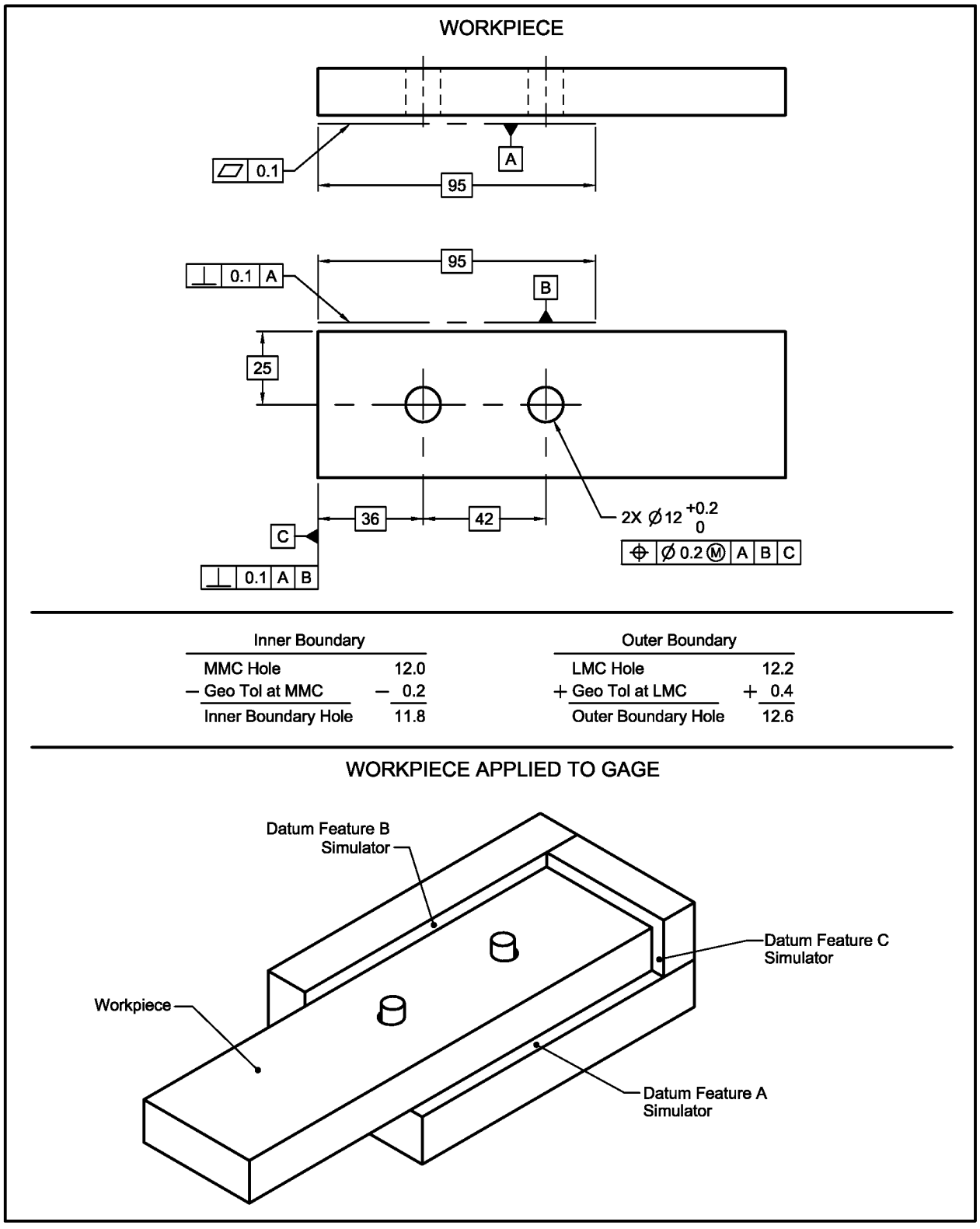


Fig. I1 Workpiece for Gaging Policy Examples

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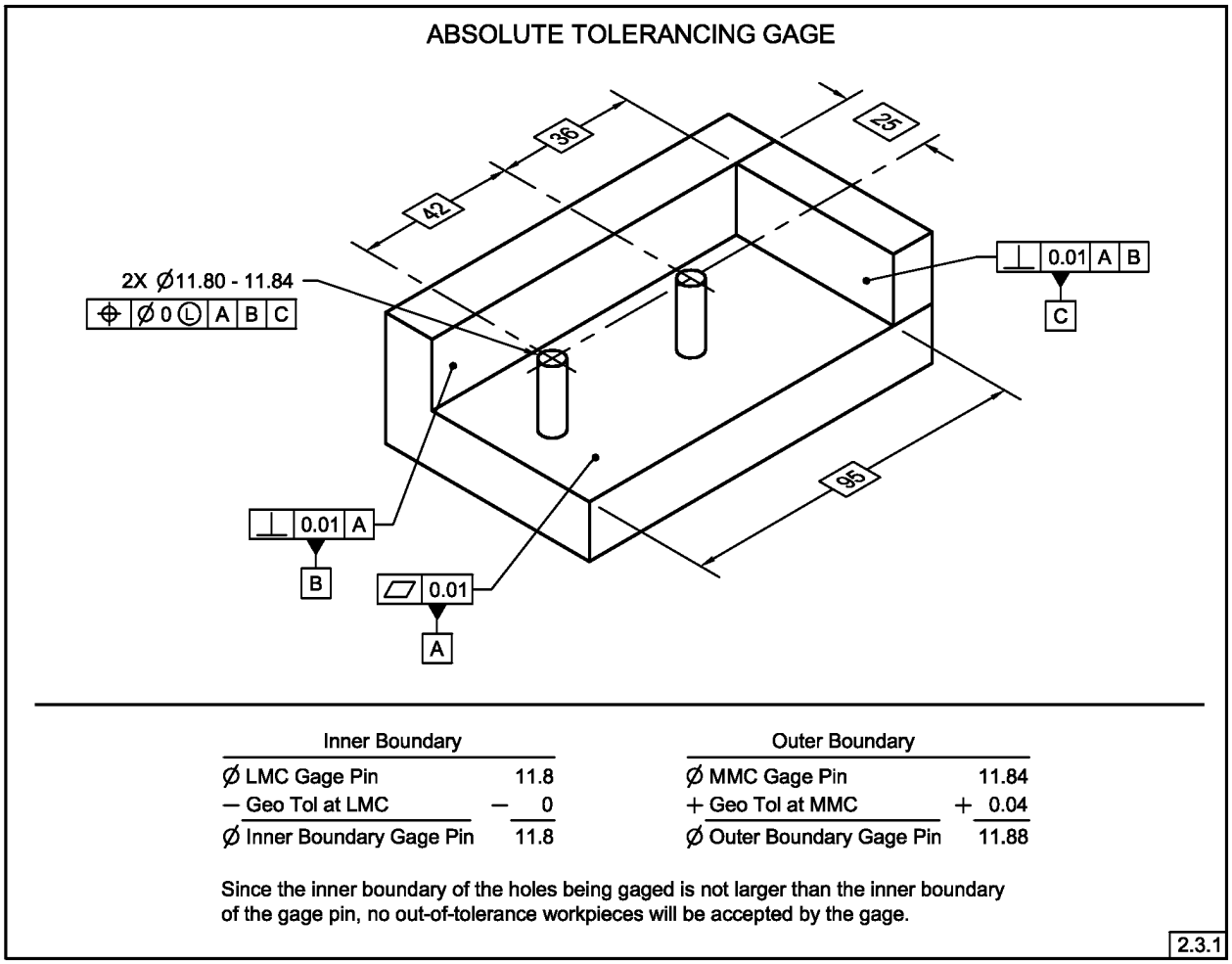
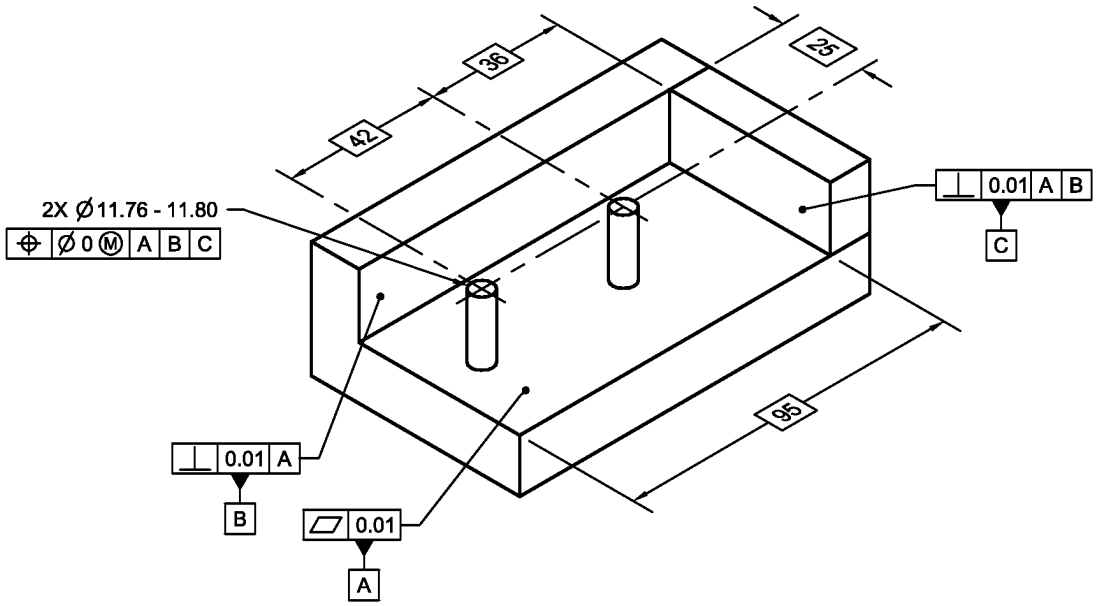


Fig. I2 Absolute Gaging Policy

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Fig. I3(a)

OPTIMISTIC TOLERANCING GAGE



EXAMPLE 1: Not Quite Optimistic.

Inner Boundary		Outer Boundary	
Ø LMC Gage Pin	11.76	Ø MMC Gage Pin	11.8
− Geo Tol at LMC	− 0.04	+ Geo Tol at MMC	+ 0
Ø Inner Boundary Gage Pin	11.72	Ø 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.

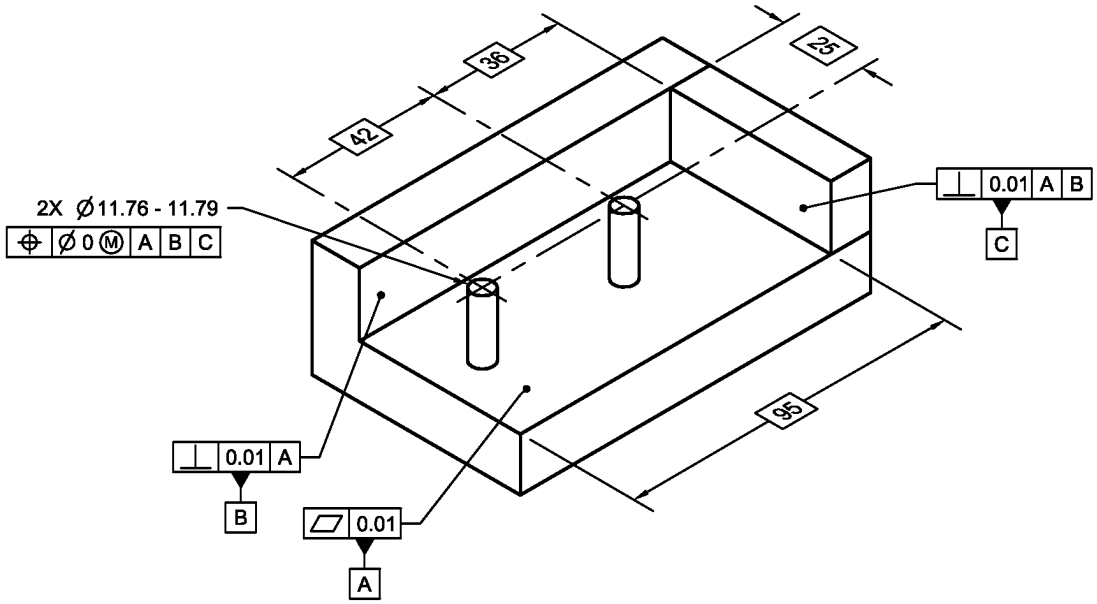
2.3.2

Fig. I3 Optimistic Gaging Policy

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Fig. I3(b)

OPTIMISTIC TOLERANCING GAGE



EXAMPLE 2: Optimistic.

Inner Boundary		Outer Boundary	
Ø LMC Gage Pin	11.76	Ø MMC Gage Pin	11.79
− Geo Tol at LMC	− 0.03	+ Geo Tol at MMC	+ 0
Ø Inner Boundary Gage Pin	11.73	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.

Fig. I3 Optimistic Gaging Policy (Cont'd)

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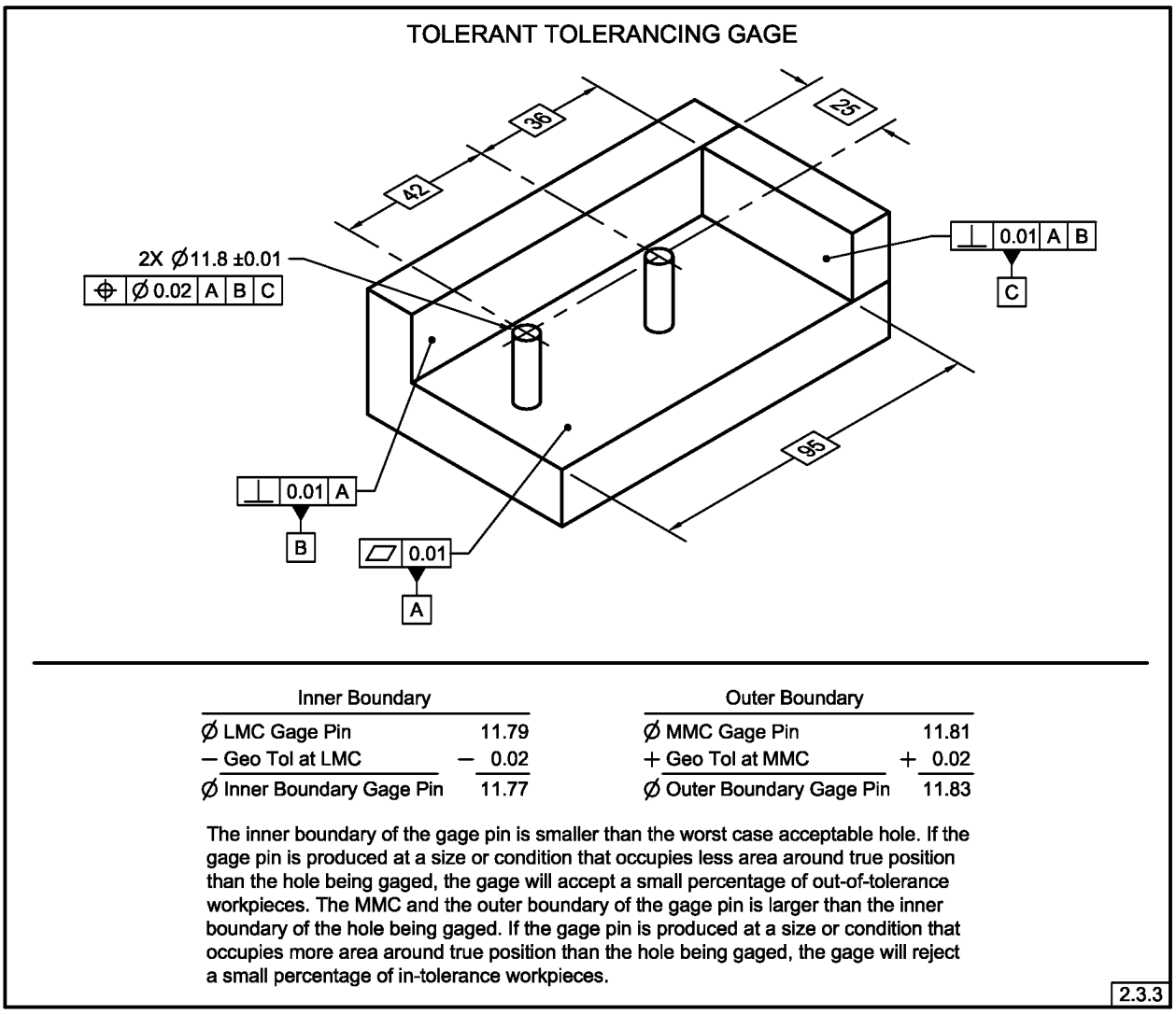


Fig. I4 Tolerant Gaging Policy

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MANDATORY APPENDIX II
MATERIAL CONDITION EXPLANATION

Figure II1 will be used here to show 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, because this allows the total workpiece hole tolerance to be shown in the size requirements. Each hole diameter is 11.8 to 12.2. This would 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. II2, could be sized and geometrically controlled by 2× 11.80–11.84 DIA. with a zero positional tolerance at MMC. If the MMC modifier was used in the gage pins feature control frame, it would generate an inner boundary for the gage pin of a diameter of 11.76 (11.80 – 0.04) and an outer boundary for the gage pin of a diameter of 11.84 (11.84 + 0). The actual smallest gage pin diameter is 11.8.

For comparison, let us consider the situation if the gage pins, as shown in Fig. II3, 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 would 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 would be 11.8.

If a hole is produced that is in violation of its positional tolerance, it would 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 a technically bad part may be accepted. If, for example, an 11.8 hole was produced out of position (which violates its zero at MMC tolerance) by the same exact amount and in the same exact 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 would 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 would not be accepted even in the most favorable position.

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

So, 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 would. 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 was the same; the MMC controlled gage pin used the tolerance difference between the 11.84 and 11.76 diameter boundaries it generated, while the LMC controlled gage pin used the tolerance difference between the 11.88 and 11.80 diameter boundaries it generated. In each case, the total tolerance used was a diameter of 0.08. This is 10% of the tolerance between the 12.6 outer and 11.8 inner boundaries 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. II1 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. II4, if the gage pin size tolerance was 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 was experienced by the gage pin, then

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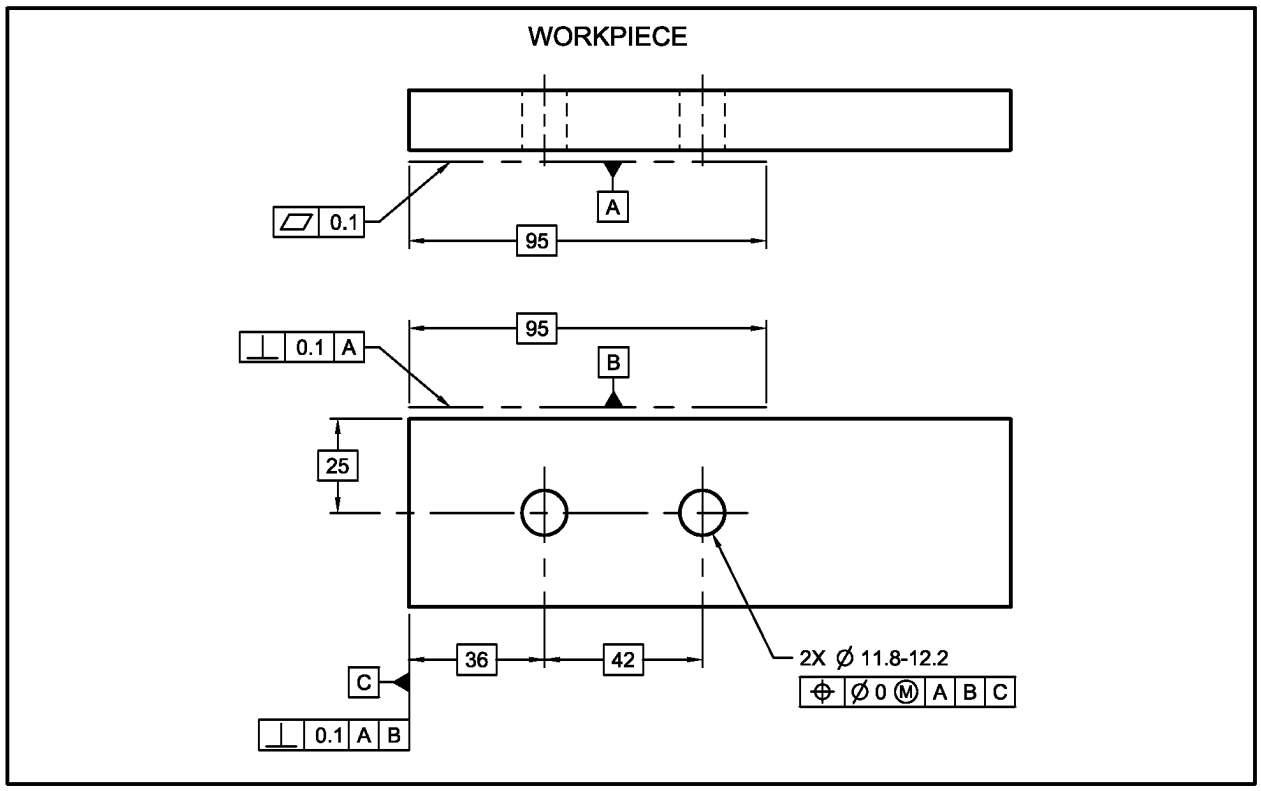


Fig. II1 Workpiece for Material Condition Modifier Examples

the gage pin would generate an inner boundary of a diameter of 11.78 (11.8 – 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 was available to either the MMC or the LMC controlled gages (which both had a range of 0.08). This RFS controlled gage would therefore be 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.

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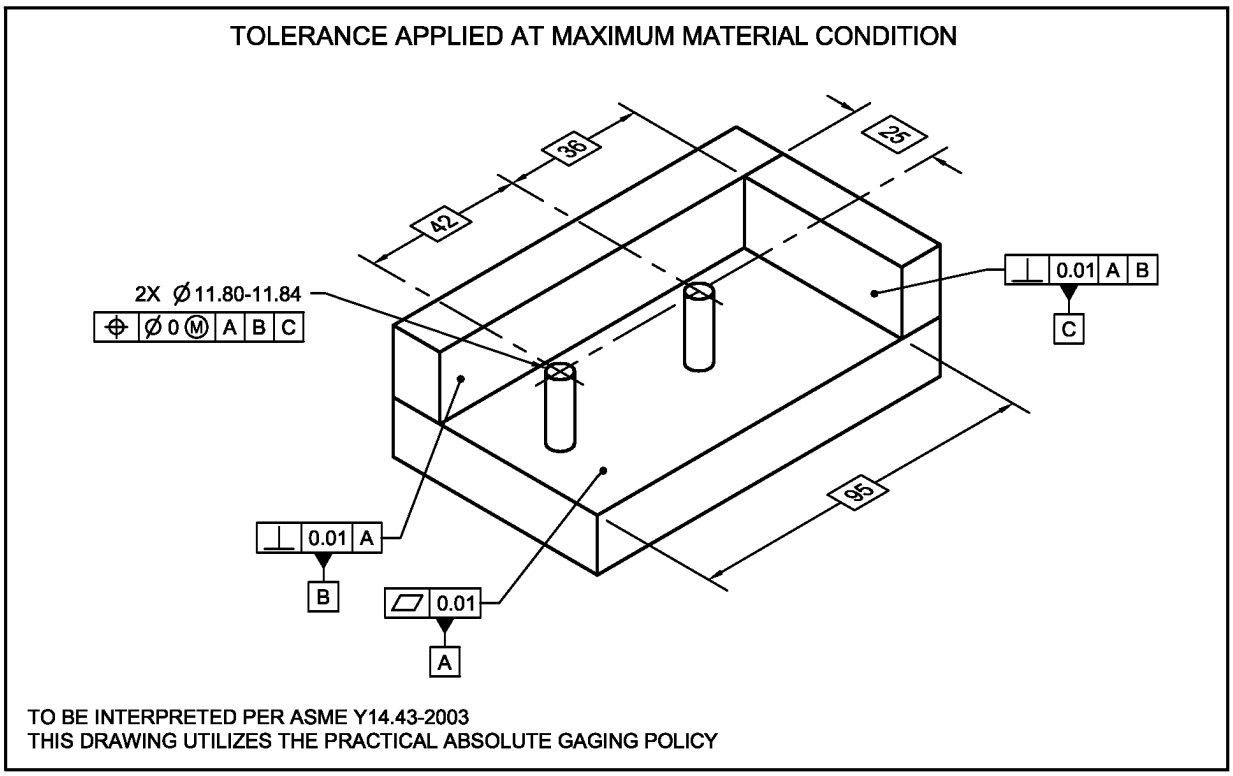


Fig. II2 MMC Modifier for Gages

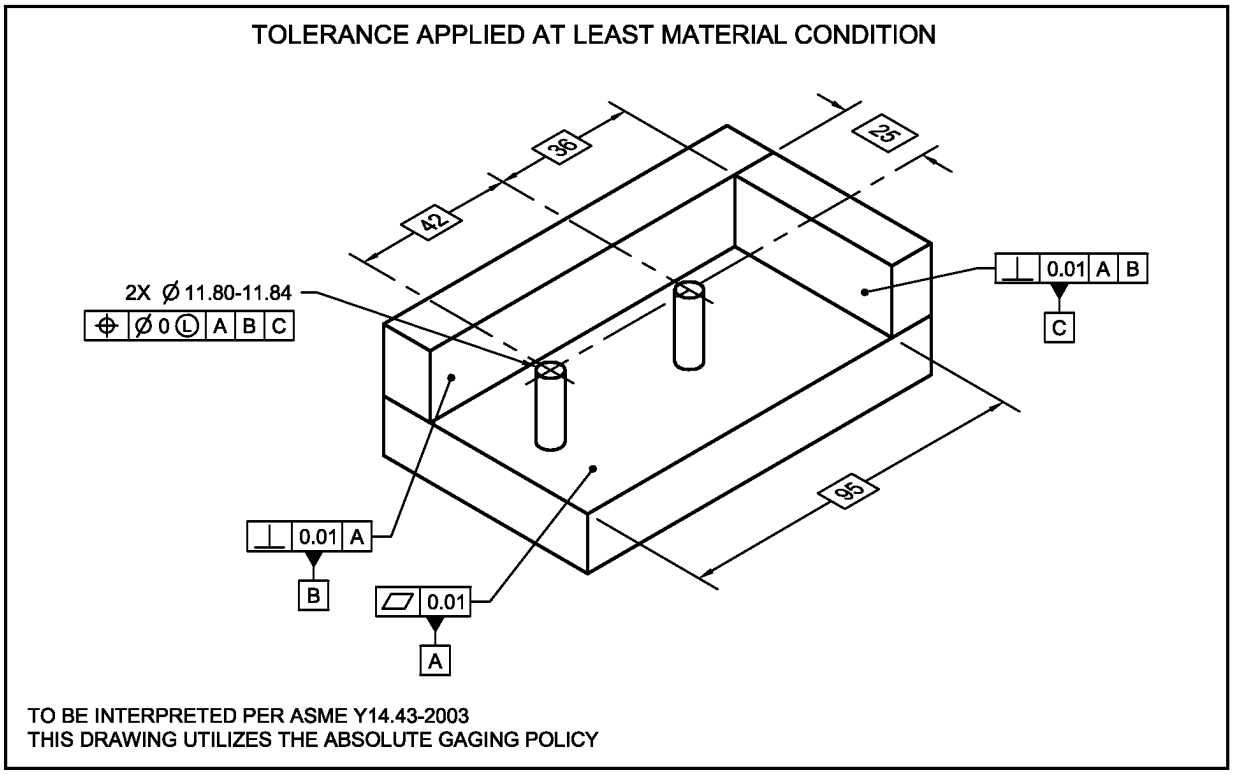


Fig. II3 LMC Modifier for Gages

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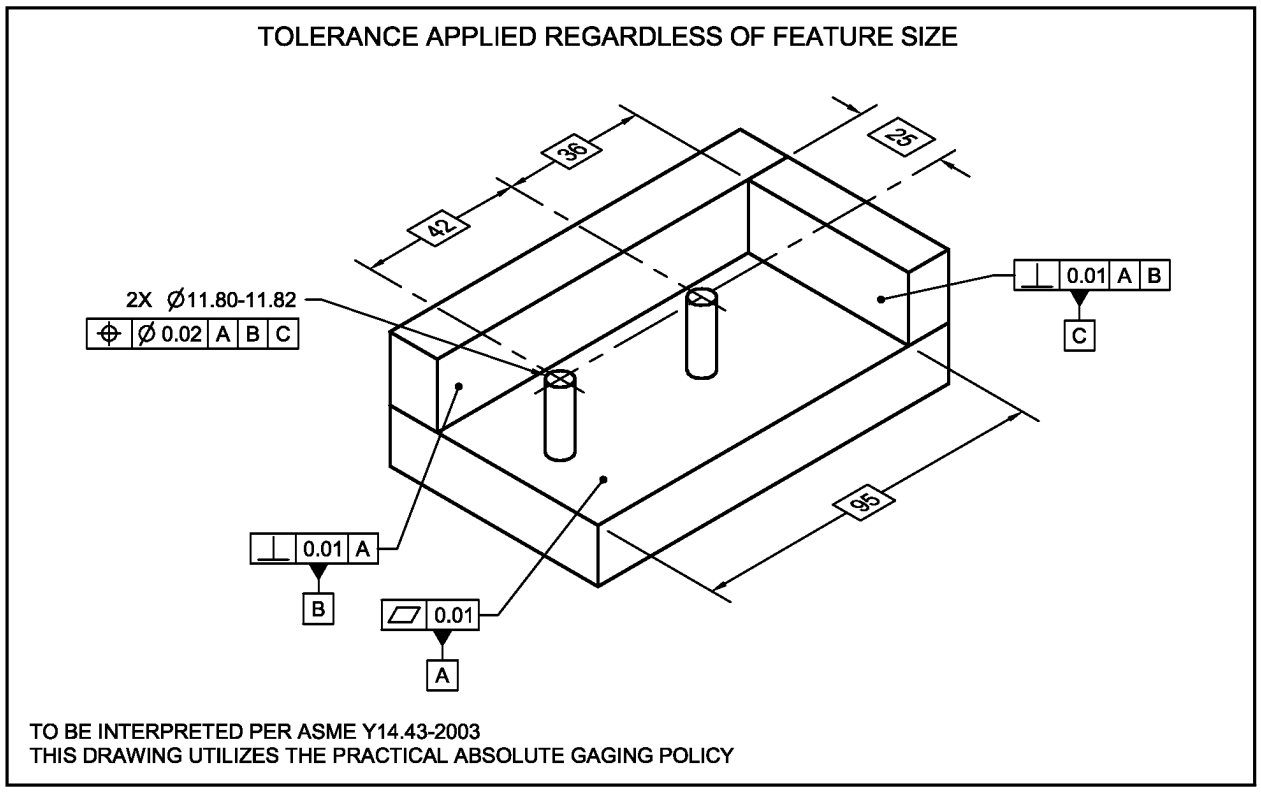


Fig. II4 RFS Modifier for Gages

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NONMANDATORY APPENDIX A
EXAMPLES OF GAGE CHARACTERISTICS

A1 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 A1 through A3 and Figs. A1 through A4 show gage design examples based on different functional characteristics from the use of various policies, material conditions, and wear allowances.

A2 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 assure 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 A2 and A3, and Figs. A3 and A4.)

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 A1 and Fig. A2.)

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 nonconformant 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 will reject only a small number of compliant workpieces. (See Tables A2 and A3.)

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 A2 and A3.)

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

A3 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 illustrations 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 Appendix.

(a) The first method, *direct percentage,* is when the gage tolerance (10%) is applied to the gage pin size, with the location tolerance of position (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.

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Table A1 Practical Absolute Direct Percentage Gage 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% of workpiece tolerance): Pin Ø 11.80–11.84 TOP Ø 0 (20%) [Note (1)] MMC 11.84 = Ø 0 tol. LMC 11.80 = Ø 0.04 tol. (OB = 11.84) (IB = 11.76) See Fig. A2, sketch (a)	Statistically based gage tolerance 0.04 (10% of workpiece tolerance): Not recommended	Statistically based gage tolerance 0.04 (10% of workpiece tolerance): Pin Ø 11.80–11.82 TOP Ø 0.02 (15%) [Note (1)] MMC 11.82 = Ø 0.02 tol. LMC 11.80 = Ø 0.02 tol. (OB = 11.84) (IB = 11.78) See Fig. A2, sketch (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 Ø 11.82–11.84 TOP Ø 0 (10%) [Note (1)] MMC 11.84 = Ø 0 tol. LMC 11.82 = Ø 0.02 tol. (OB = 11.84) (IB = 11.80) See Fig. A2, sketch (b)	Statistically based gage tolerance 0.02 (5% of workpiece tolerance): Not recommended	Statistically based gage tolerance 0.02 (5% of workpiece tolerance): Pin Ø 11.81–11.82 TOP Ø 0.01 (7.5%) [Note (1)] MMC 11.82 = Ø 0.01 tol. LMC 11.81 = Ø 0.01 tol. (OB = 11.83) (IB = 11.80) See Fig. A2, sketch (d)

NOTE:

(1) The practical absolute policy (see Fig. A2) 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 which 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 Ø 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 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 Fig. A3, sketches (a) and (b), and Fig. A4, sketches (a) and (b)] 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 an LMC modifier on the gage with the proper size tolerance. The same conditions described apply when wear allowance is applied.

(b) The second method, *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.

A4 MATERIAL CONDITION MODIFIER USED ON GAGE ELEMENTS

The 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; examples are shown in Figs. A1 through A4. 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.

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Table A2 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 Ø 11.84–11.88 TOP Ø 0 (20%) [Note (1)] MMC 11.88 = Ø 0 tol. LMC 11.84 = Ø 0.04 tol. (OB = 11.88) (IB = 11.80) See Fig. A3, sketch (a)	Direct percentage gage tolerance 0.04 (10% of workpiece tolerance): Pin Ø 11.80–11.84 TOP Ø 0 (20%) [Note (1)] LMC 11.80 = Ø 0 tol. MMC 11.84 = Ø 0.04 tol. (OB = 11.88) (IB = 11.80) See Fig. A3, sketch (c)	Direct percentage gage tolerance 0.04 (10% of workpiece tolerance): Pin Ø 11.82–11.84 TOP Ø 0.02 (15%) [Note (1)] MMC 11.84 = Ø 0.02 tol. LMC 11.82 = Ø 0.02 tol. (OB = 11.86) (IB = 11.80) See Fig. A3, sketch (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 Ø 11.84–11.86 TOP Ø 0 (10%) [Note (1)] MMC 11.86 = Ø 0 tol. LMC 11.84 = Ø 0.02 tol. (OB = 11.86) (IB = 11.82) See Fig. A3, sketch (b)	Direct percentage gage tolerance 0.02 (5% of workpiece tolerance): Pin Ø 11.82–11.84 TOP Ø 0 (10%) [Note (1)] LMC 11.82 = Ø 0 tol. MMC 11.84 = Ø 0.02 tol. (OB = 11.86) (IB = 11.82) See Fig. A3, sketch (d)	Direct percentage gage tolerance 0.02 (5% of workpiece tolerance): Pin Ø 11.83–11.84 TOP Ø 0.01 (7.5%) [Note (1)] MMC 11.84 = Ø 0.01 tol. LMC 11.83 = Ø 0.01 tol. (OB = 11.85) (IB = 11.82) See Fig. A3, sketch (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 Ø 11.78–11.82 TOP Ø 0 (20%) MMC 11.82 = Ø 0 tol. LMC 11.78 = Ø 0.04 tol. (OB = 11.82) (IB = 11.74)	Direct percentage gage tolerance 0.04 (10% of workpiece tolerance): Pin Ø 11.78–11.82 TOP Ø 0 (20%) LMC 11.78 = Ø 0 tol. MMC 11.82 = Ø 0.04 tol. (OB = 11.86) (IB = 11.78)	Direct percentage gage tolerance 0.04 (10% of workpiece tolerance): Pin Ø 11.78–11.80 TOP Ø 0.02 (15%) MMC 11.80 = Ø 0.02 tol. LMC 11.78 = Ø 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 Ø 11.80–11.82 TOP Ø 0 (10%) MMC 11.82 = Ø 0 tol. LMC 11.80 = Ø 0.02 tol. (OB = 11.82) (IB = 11.78)	Direct percentage gage tolerance 0.02 (5% of workpiece tolerance): Pin Ø 11.80–11.82 TOP Ø 0 (10%) LMC 11.80 = Ø 0 tol. MMC 11.82 = Ø 0.02 tol. (OB = 11.84) (IB = 11.80)	Direct percentage gage tolerance 0.02 (5% of workpiece tolerance): Pin Ø 11.80–11.81 TOP Ø 0.01 (7.5%) MMC 11.81 = Ø 0.01 tol. LMC 11.80 = Ø 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 Ø 11.76–11.80 TOP Ø 0 (20%) MMC 11.80 = Ø 0 tol. LMC 11.76 = Ø 0.04 tol. (OB = 11.80) (IB = 11.72)	Direct percentage gage tolerance 0.04 (10% of workpiece tolerance): Pin Ø 11.76–11.80 TOP Ø 0 (20%) LMC 11.76 = Ø 0 tol. MMC 11.80 = Ø 0.04 tol. (OB = 11.84) (IB = 11.76)	Direct percentage gage tolerance 0.04 (10% of workpiece tolerance): Pin Ø 11.76–11.78 TOP Ø 0.02 (15%) MMC 11.78 = Ø 0.02 tol. LMC 11.76 = Ø 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 Ø 11.78–11.80 TOP Ø 0 (10%) MMC 11.80 = Ø 0 tol. LMC 11.78 = Ø 0.02 tol. (OB = 11.80) (IB = 11.76)	Direct percentage gage tolerance 0.02 (5% of workpiece tolerance): Pin Ø 11.78–11.80 TOP Ø 0 (10%) LMC 11.78 = Ø 0 tol. MMC 11.80 = Ø 0.02 tol. (OB = 11.82) (IB = 11.78)	Direct percentage gage tolerance 0.02 (5% of workpiece tolerance): Pin Ø 11.78–11.79 TOP Ø 0.01 (7.5%) MMC 11.79 = Ø 0.01 tol. LMC 11.78 = Ø 0.01 tol. (OB = 11.80) (IB = 11.77)

NOTE:
(1) See Table A1, Note (1).

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Table A3 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 Ø11.82–11.84 TOP Ø0 (10%) [Note (1)] MMC 11.84 = Ø0 tol. LMC 11.82 = Ø0.02 tol. (OB = 11.84) (IB = 11.80) See Fig. A4, sketch (a)	Adjusted boundary gage tolerance 0.04 (10% of workpiece tolerance): Pin Ø11.80–11.82 TOP Ø0 (10%) [Note (1)] LMC 11.80 = Ø0 tol. MMC 11.82 = Ø0.02 tol. (OB = 11.84) (IB = 11.80) See Fig. A4, sketch (c)	Adjusted boundary gage tolerance 0.04 (10% of workpiece tolerance): Pin Ø11.81–11.83 TOP Ø0.01 (10%) [Note (1)] MMC 11.83 = Ø0.01 tol. LMC 11.81 = Ø0.01 tol. (OB = 11.84) (IB = 11.80) See Fig. A4, sketch (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 Ø11.83–11.84 TOP Ø0 (5%) [Note (1)] MMC 11.84 = Ø0 tol. LMC 11.83 = Ø0.01 tol. (OB = 11.84) (IB = 11.82) See Fig. A4, sketch (b)	Adjusted boundary gage tolerance 0.02 (5% of workpiece tolerance): Pin Ø11.82–11.83 TOP Ø0 (5%) [Note (1)] LMC 11.82 = Ø0 tol. MMC 11.83 = Ø0.01 tol. (OB = 11.84) (IB = 11.82) See Fig. A4, sketch (d)	Adjusted boundary gage tolerance 0.02 (5% of workpiece tolerance): Pin Ø11.825–11.835 TOP Ø0.005 (5%) [Note (1)] MMC 11.835 = Ø0.005 tol. LMC 11.825 = Ø0.005 tol. (OB = 11.84) (IB = 11.82) See Fig. A4, sketch (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 Ø11.80–11.82 TOP Ø0 (10%) MMC 11.82 = Ø0 tol. LMC 11.80 = Ø0.02 tol. (OB = 11.82) (IB = 11.78)	Adjusted boundary gage tolerance 0.04 (10% of workpiece tolerance): Pin Ø11.78–11.80 TOP Ø0 (10%) LMC 11.78 = Ø0 tol. MMC 11.80 = Ø0.02 tol. (OB = 11.82) (IB = 11.78)	Adjusted boundary gage tolerance 0.04 (10% of workpiece tolerance): Pin Ø11.79–11.81 TOP Ø0.01 (10%) MMC 11.81 = Ø0.01 tol. LMC 11.79 = Ø0.01 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 Ø11.81–11.82 TOP Ø0 (5%) MMC 11.82 = Ø0 tol. LMC 11.81 = Ø0.01 tol. (OB = 11.82) (IB = 11.80)	Adjusted boundary gage tolerance 0.02 (5% of workpiece tolerance): Pin Ø11.80–11.81 TOP Ø0 (5%) LMC 11.80 = Ø0 tol. MMC 11.81 = Ø0.01 tol. (OB = 11.82) (IB = 11.80)	Adjusted boundary gage tolerance 0.02 (5% of workpiece tolerance): Pin Ø11.805–11.815 TOP Ø0.005 (5%) MMC 11.815 = Ø0.005 tol. LMC 11.805 = Ø0.005 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 Ø11.78–11.80 TOP Ø0 (10%) MMC 11.80 = Ø0 tol. LMC 11.78 = Ø0.02 tol. (OB = 11.80) (IB = 11.76)	Adjusted boundary gage tolerance 0.04 (10% of workpiece tolerance): Pin Ø11.76–11.78 TOP Ø0 (10%) LMC 11.76 = Ø0 tol. MMC 11.78 = Ø0.02 tol. (OB = 11.80) (IB = 11.76)	Adjusted boundary gage tolerance 0.04 (10% of workpiece tolerance): Pin Ø11.77–11.79 TOP Ø0.01 (10%) MMC 11.79 = Ø0.01 tol. LMC 11.77 = Ø0.01 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 Ø11.79–11.80 TOP Ø0 (5%) MMC 11.80 = Ø0 tol. LMC 11.79 = Ø0.01 tol. (OB = 11.80) (IB = 11.78)	Adjusted boundary gage tolerance 0.02 (5% of workpiece tolerance): Pin Ø11.78–11.79 TOP Ø0 (5%) LMC 11.78 = Ø0 tol. MMC 11.79 = Ø0.01 tol. (OB = 11.80) (IB = 11.78)	Adjusted boundary gage tolerance 0.02 (5% of workpiece tolerance): Pin Ø11.785–11.795 TOP Ø0.005 (5%) MMC 11.795 = Ø0.005 tol. LMC 11.785 = Ø0.005 tol. (OB = 11.80) (IB = 11.78)

NOTE:
(1) See Table A1, Note (1).

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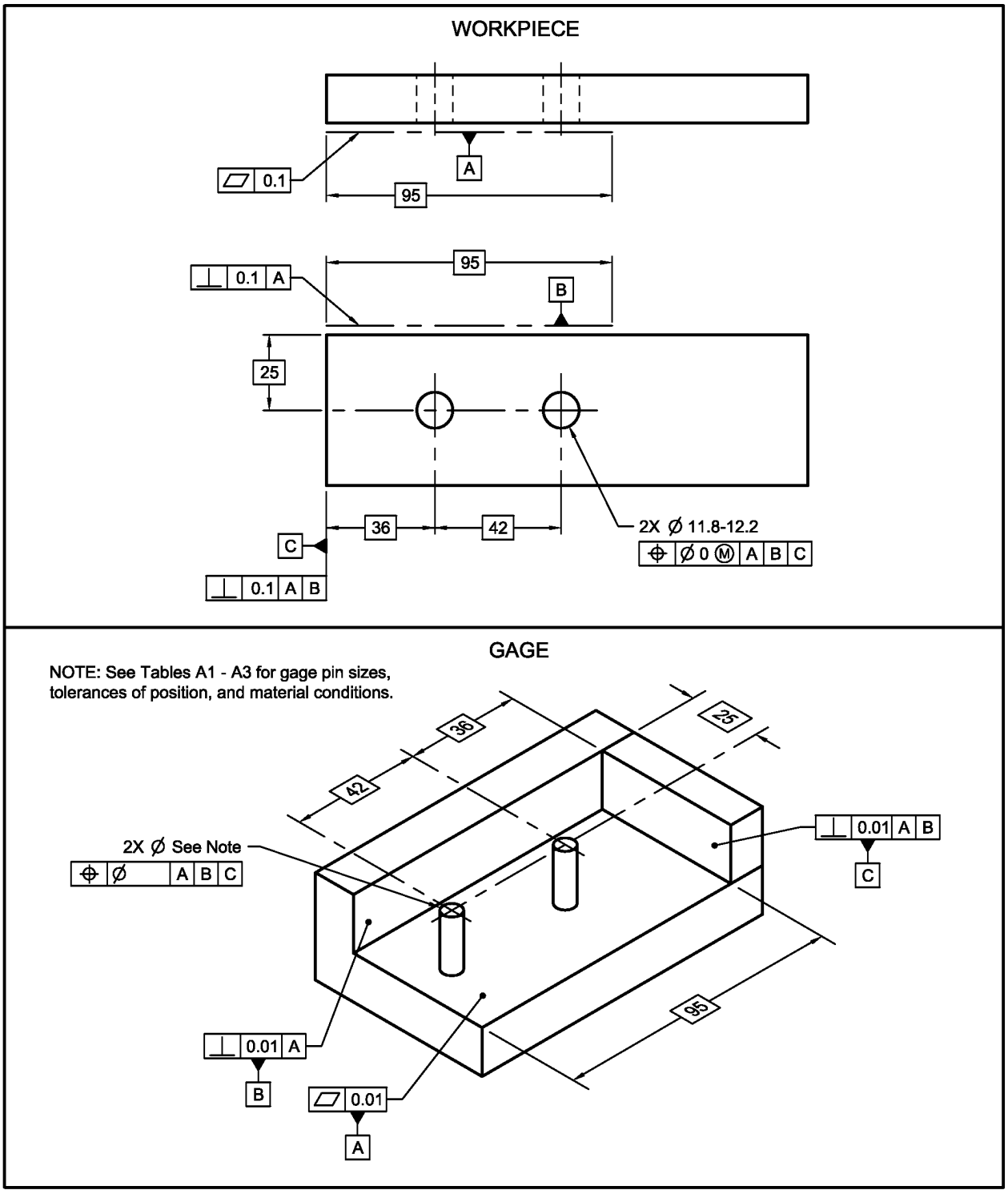
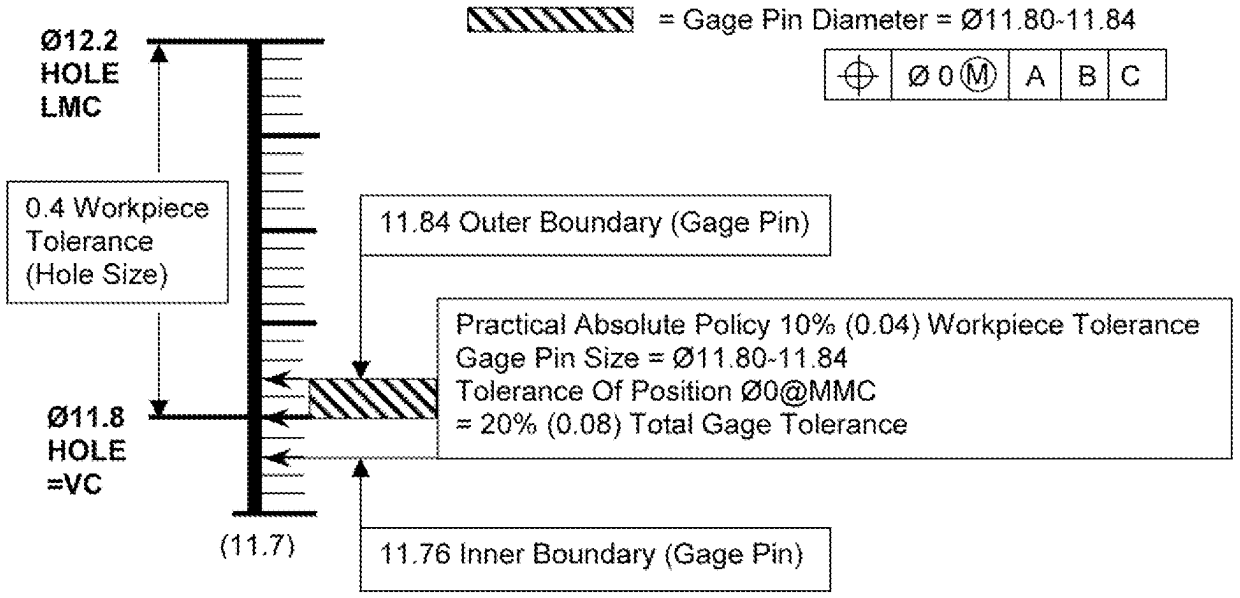
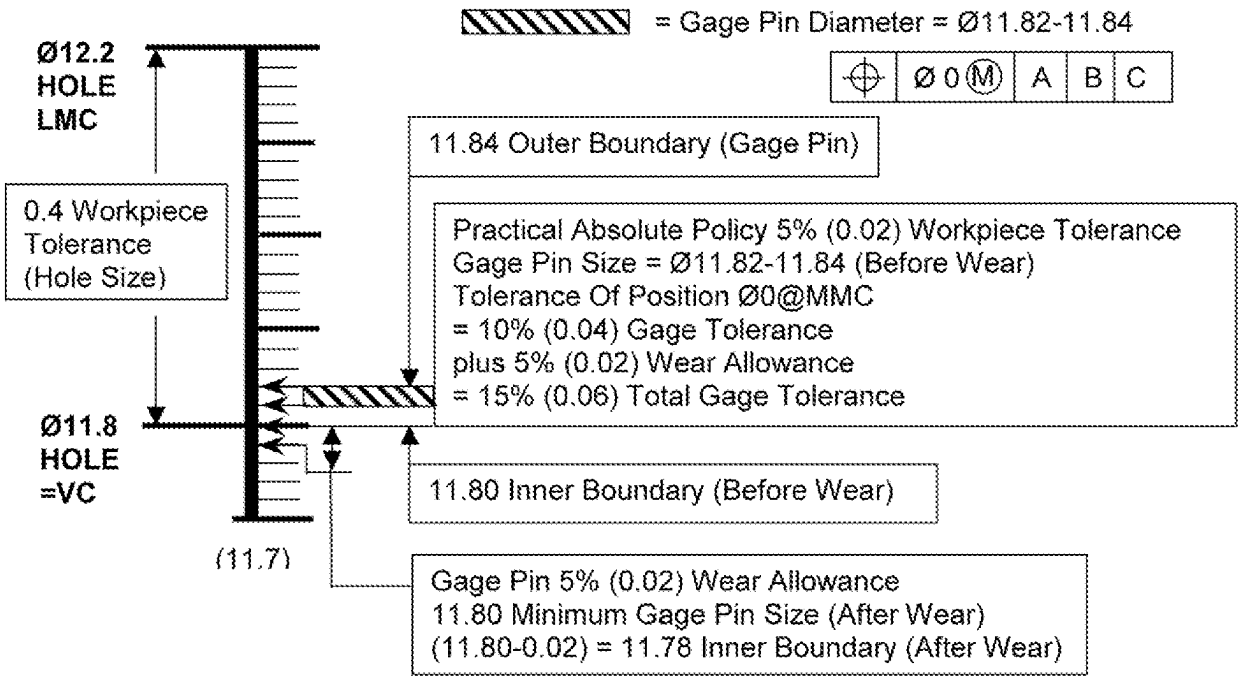


Fig. A1 Workpiece and Associated Gage

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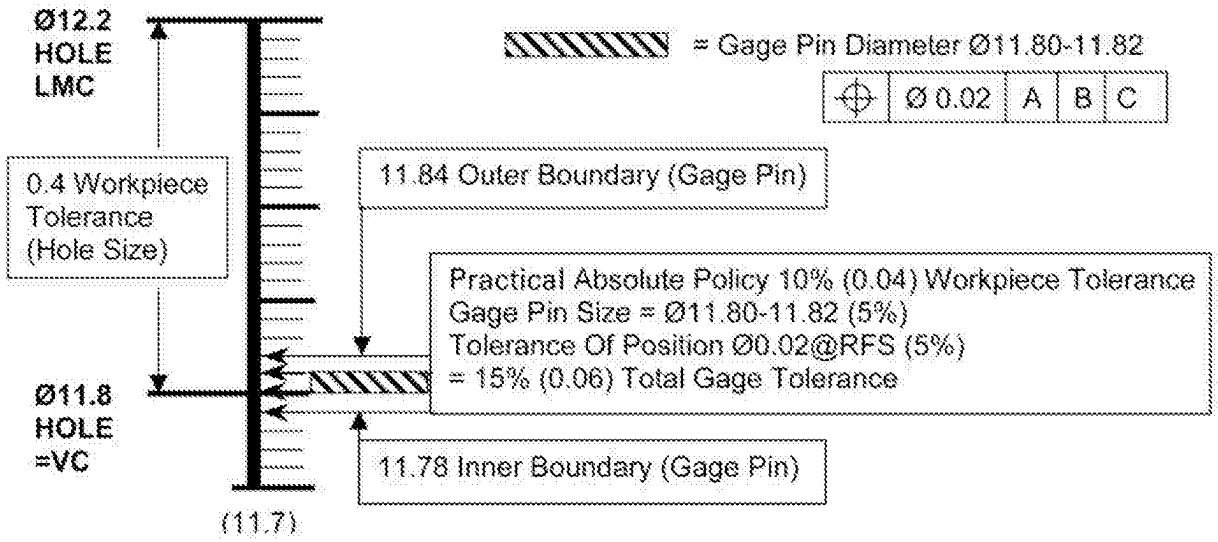
(a)



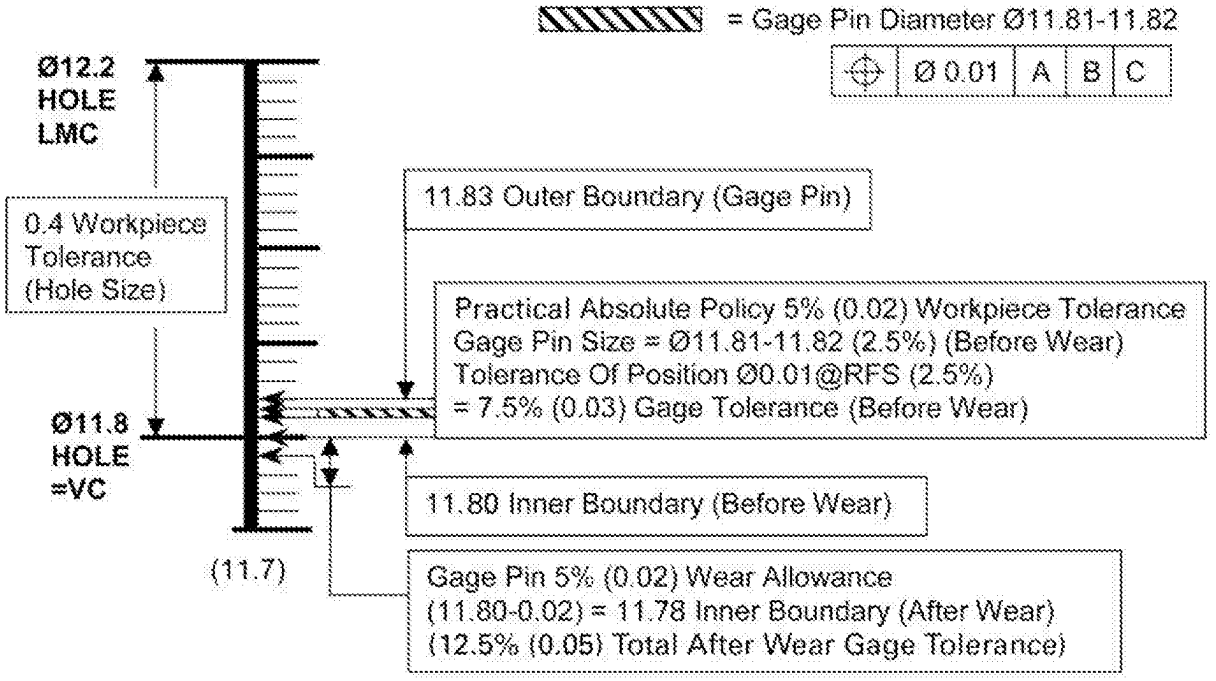
(b)

Fig. A2 Practical Absolute — Direct Percentage Tolerance Method

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(c)



(d)

Fig. A2 Practical Absolute — Direct Percentage Tolerance Method (Cont'd)

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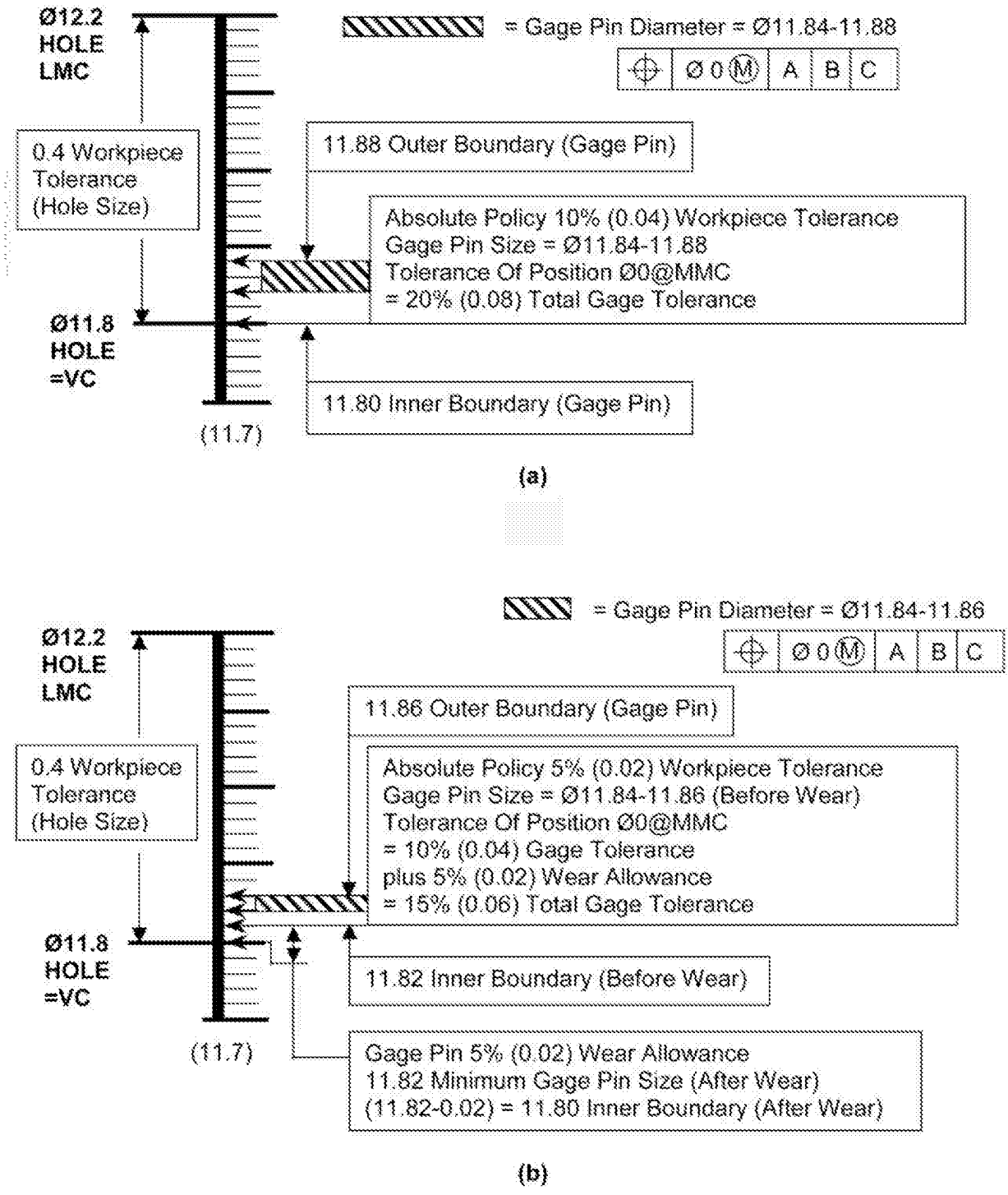
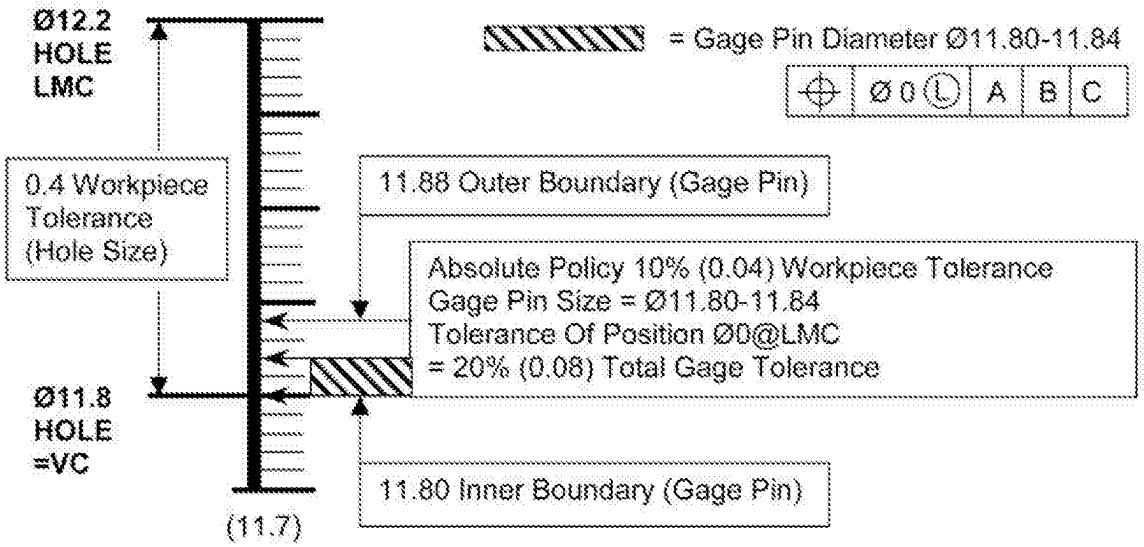
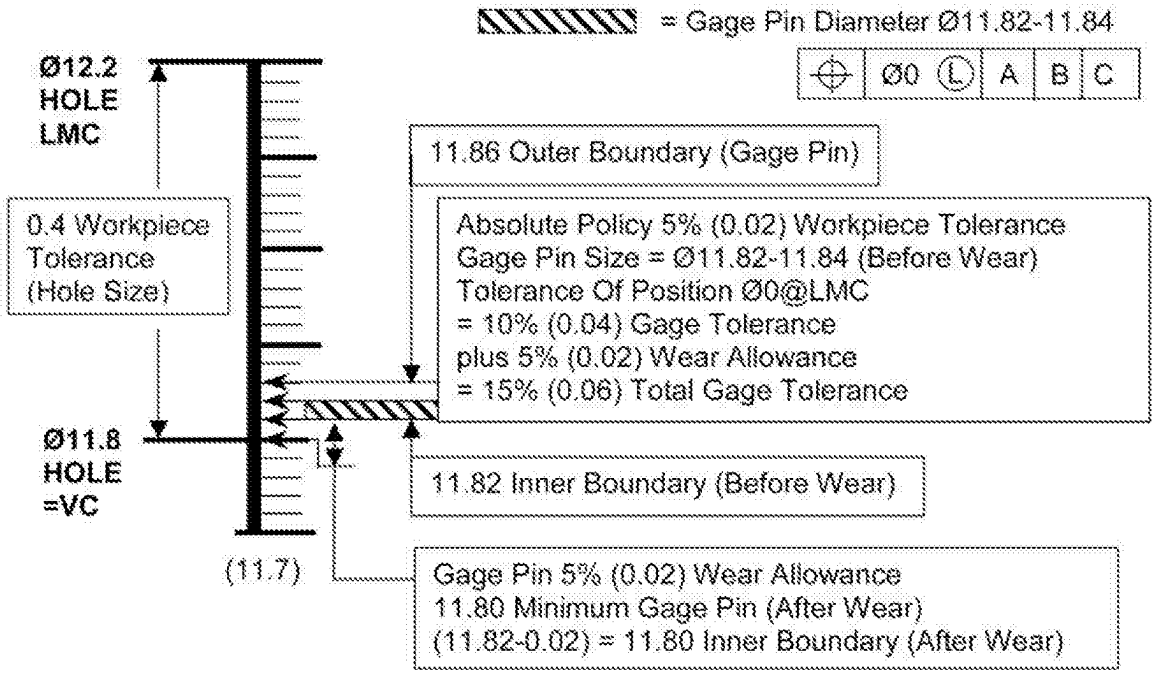


Fig. A3 Direct Percentage Based Gage Tolerance Method

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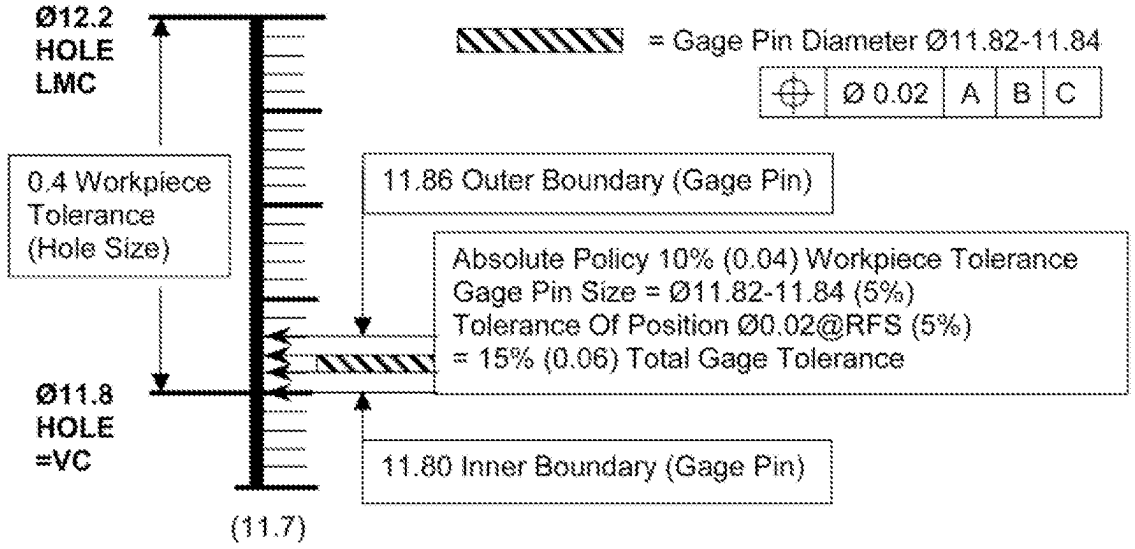
(c)



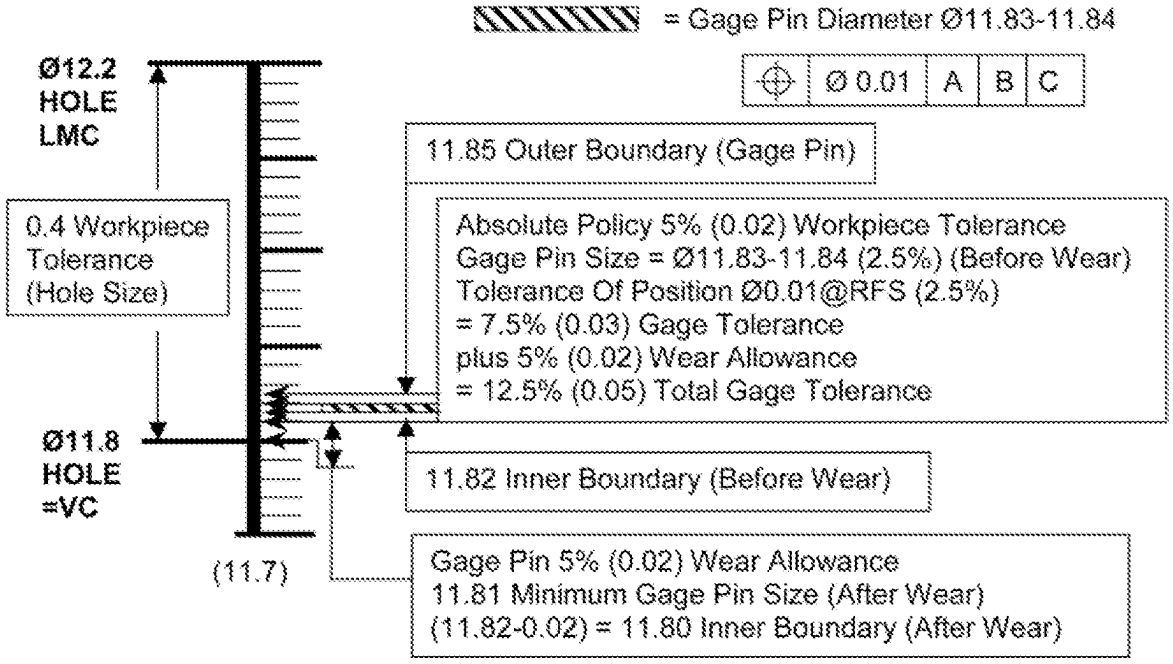
(d)

Fig. A3 Direct Percentage Based Gage Tolerance Method (Cont'd)

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(e)



(f)

Fig. A3 Direct Percentage Based Gage Tolerance Method (Cont'd)

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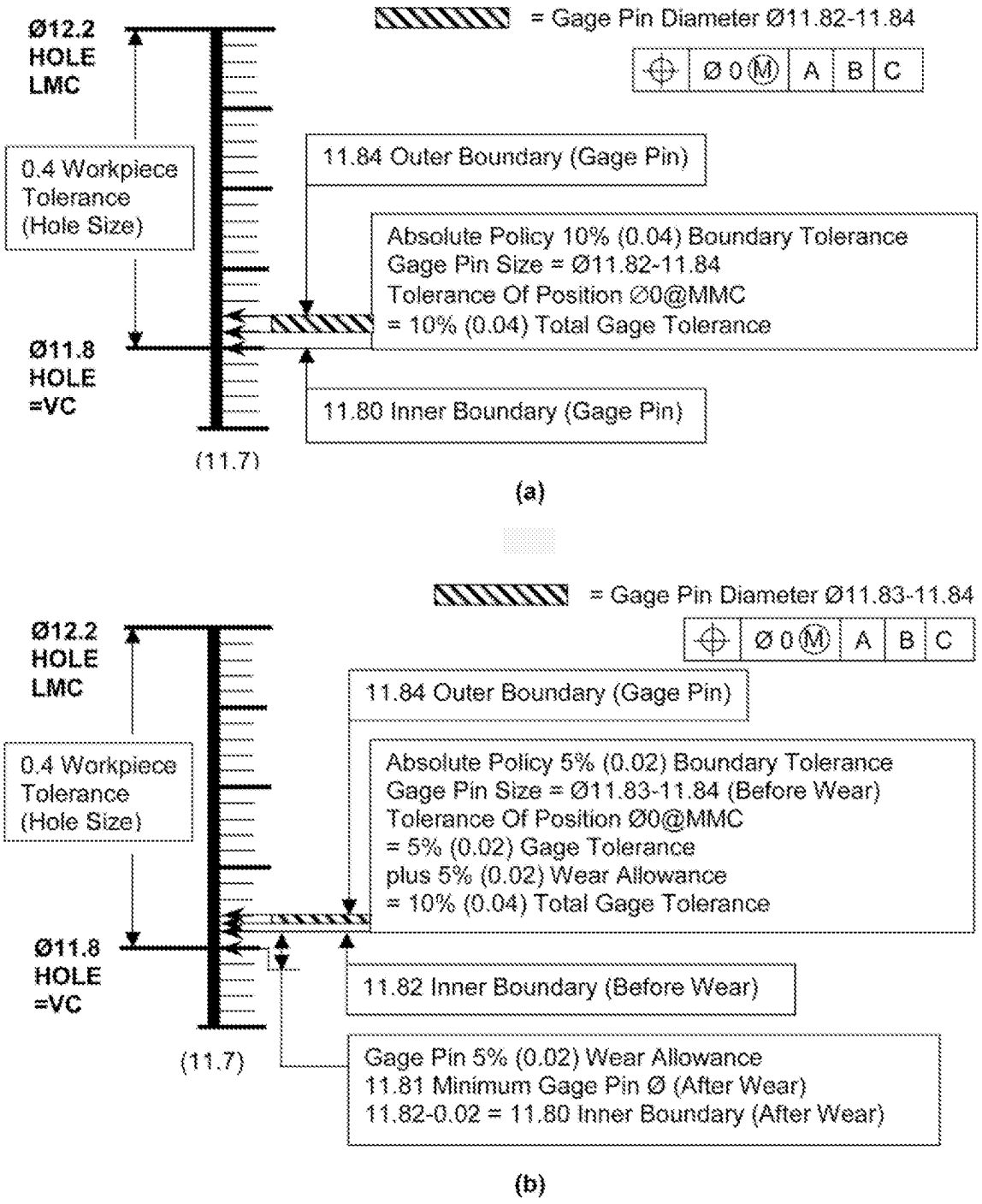
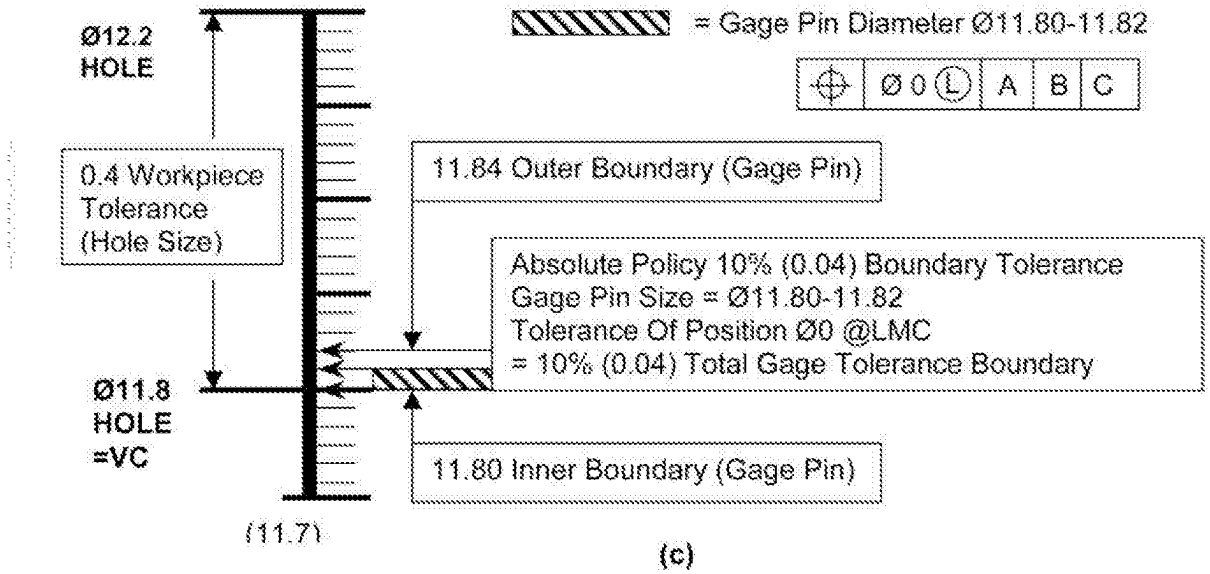
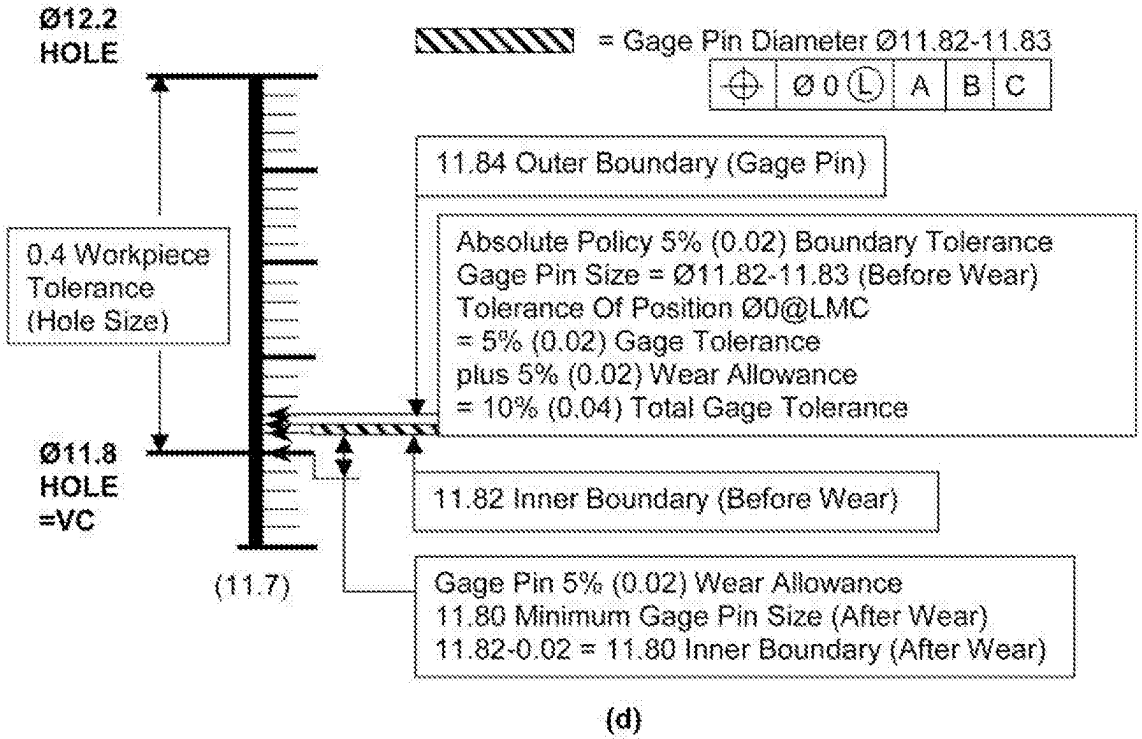


Fig. A4 Adjusted Boundary Based Gage Tolerance Method

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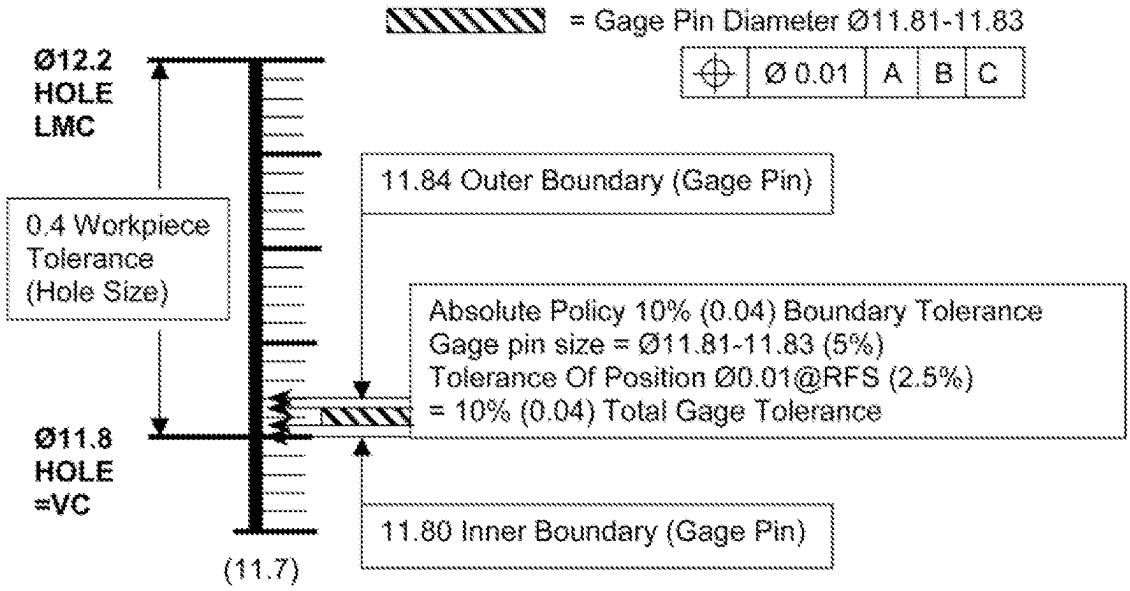
(c)



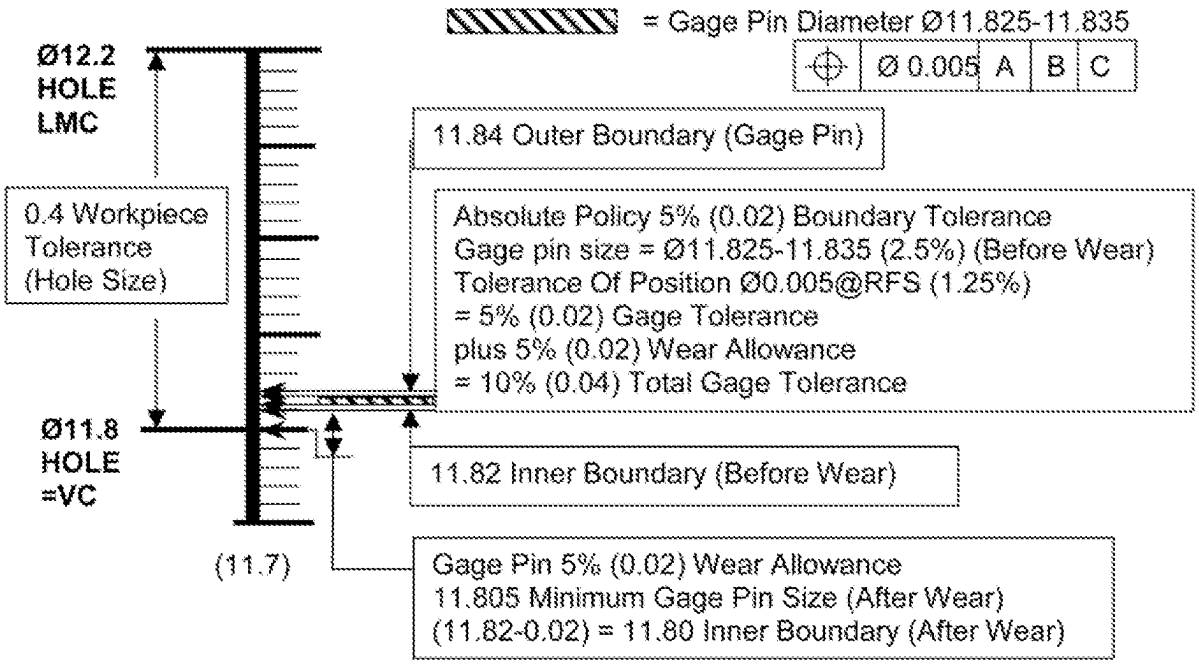
(d)

Fig. A4 Adjusted Boundary Based Gage Tolerance Method (Cont'd)

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(e)



(f)

Fig. A4 Adjusted Boundary Based Gage Tolerance Method (Cont'd)

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A5 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 toward the lower size limit, the gage 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 Appendix only with the absolute and practical absolute methods, but could be applied as desired to any of the other gaging policies.

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NONMANDATORY APPENDIX B
EXAMPLES AND ILLUSTRATIONS

B1 GENERAL

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

(a) Fig. B1, multiple surface datums (Fig. 4-20)

(b) Fig. B2, inclined datum features (Fig. 4-4)

(c) Fig. B3, cylindrical datum features (Fig. 4-5)

(d) Fig. B4, cylindrical and rectangular datum features of size (Fig. 4-6)

(e) Fig. B5, internal cylindrical and rectangular datum features of size (Fig. 4-16)

(f) Fig. B6, simultaneous position and profile tolerances (Fig. 4-26)

(g) Fig. B7, two rectangular datum features of size at MMC (Fig. 5-4)

(h) Fig. B8, rectangular features of size at MMC (Fig. 5-59)

(i) Fig. B9, size and planar datum features

(j) Fig. B10, controlling rotation with datum features of size (Fig. 4-8)

(k) Fig. B11, interrelated datum reference frames (Fig. 4-24)

(l) Fig. B12, two datum features — single datum axis (Fig. 4-19)

(m) Fig. B13, hole pattern as a datum (Fig. 4-22)

(n) Fig. B14, equalizing datums (Fig. 4-38)

(o) Fig. B15, irregular closed feature used as a datum feature

(p) Fig. B16, radial hole pattern located by composite position (Fig. 5-24)

(q) Fig. B17, datum targets on a complex part (Fig. 4-39)

(r) Fig. B18, pushpin gages for part clearance holes

(s) Fig. B19, pushpin gages for part threaded holes

(t) Fig. B20, sequential gaging

B2 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 CAD model for purposes of part acceptance/rejection. In general terms, the soft gaging process works as follows:

(a) A part's nominal geometry is modeled with CAD software.

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

(c) 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.*

(d) A part is measured on a CMM, generating a cloud of coordinate data points.

(e) The soft gaging software compares this cloud of points (or, sometimes, a reverse-engineered CAD 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.

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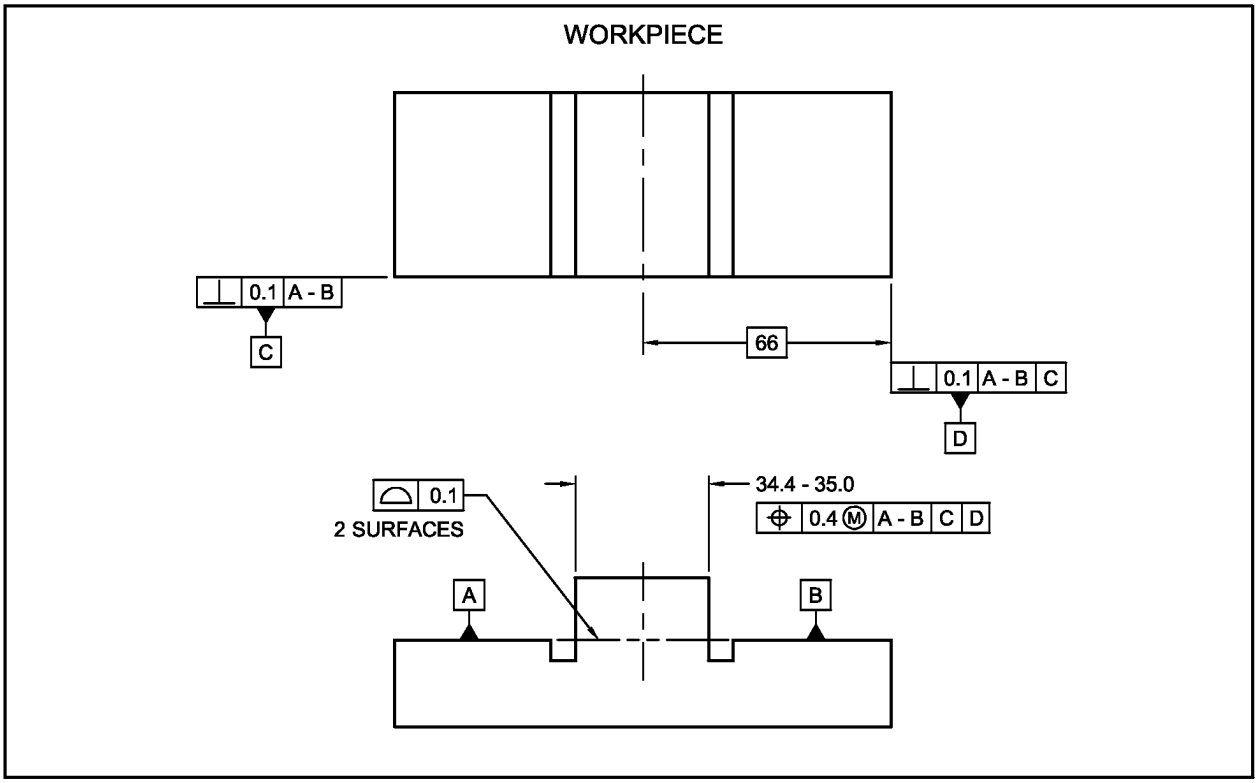
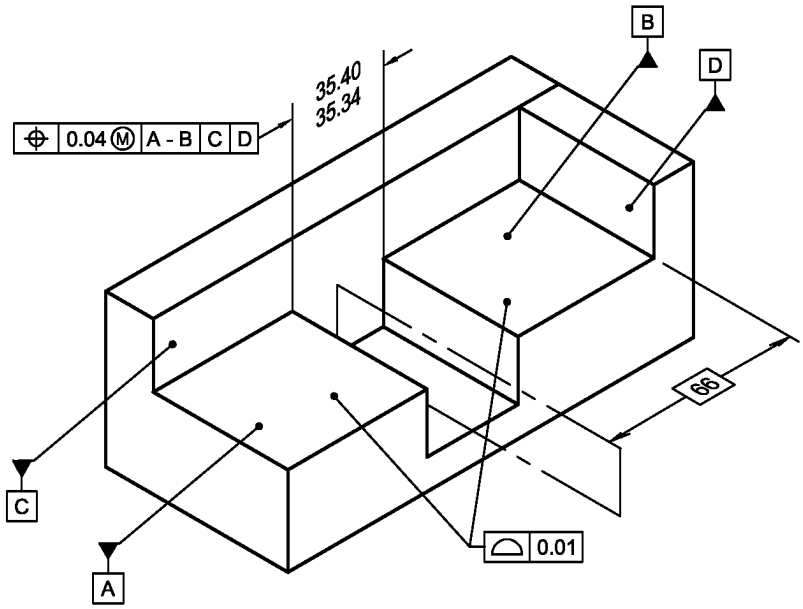


Fig. B1 Multiple Surface Datums

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Fig. B1(a)

GAGE



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Fig. B1(b)

WORKPIECE APPLIED TO GAGE

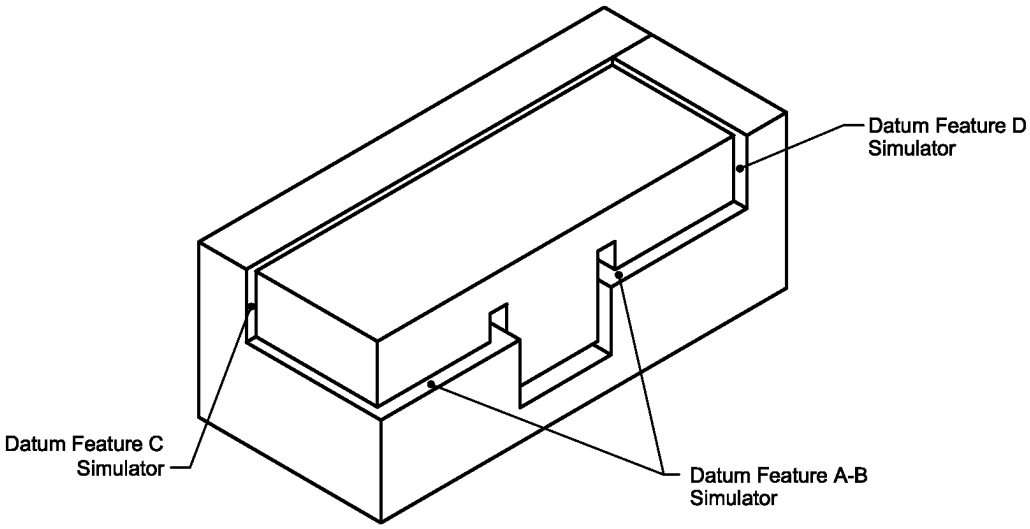


Fig. B1 Multiple Surface Datums (Cont'd)

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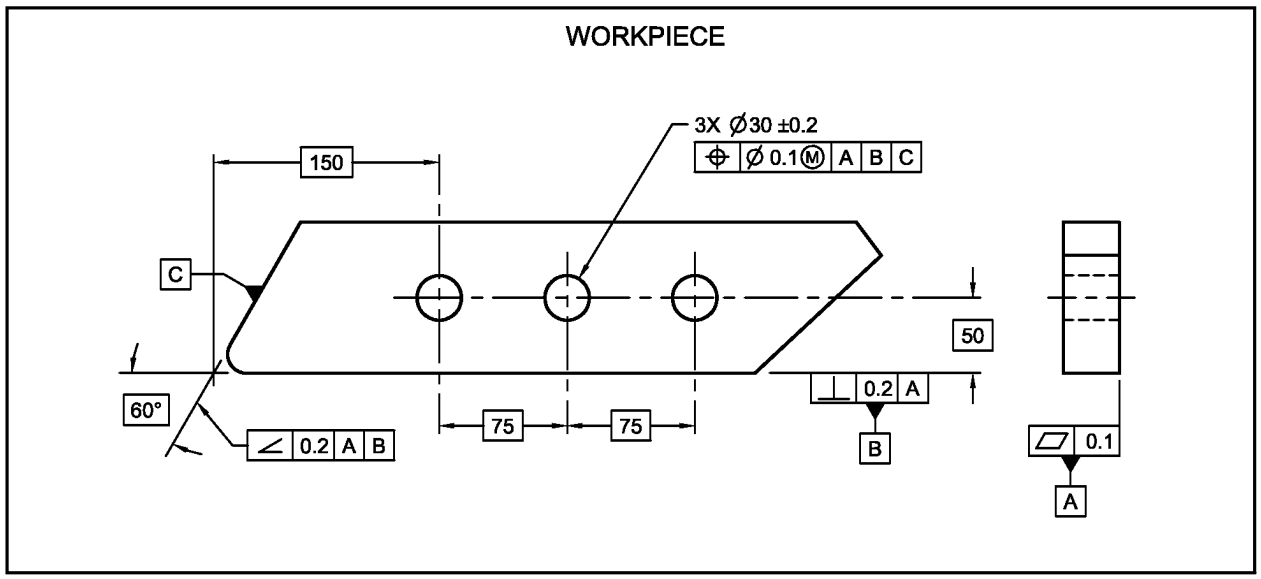
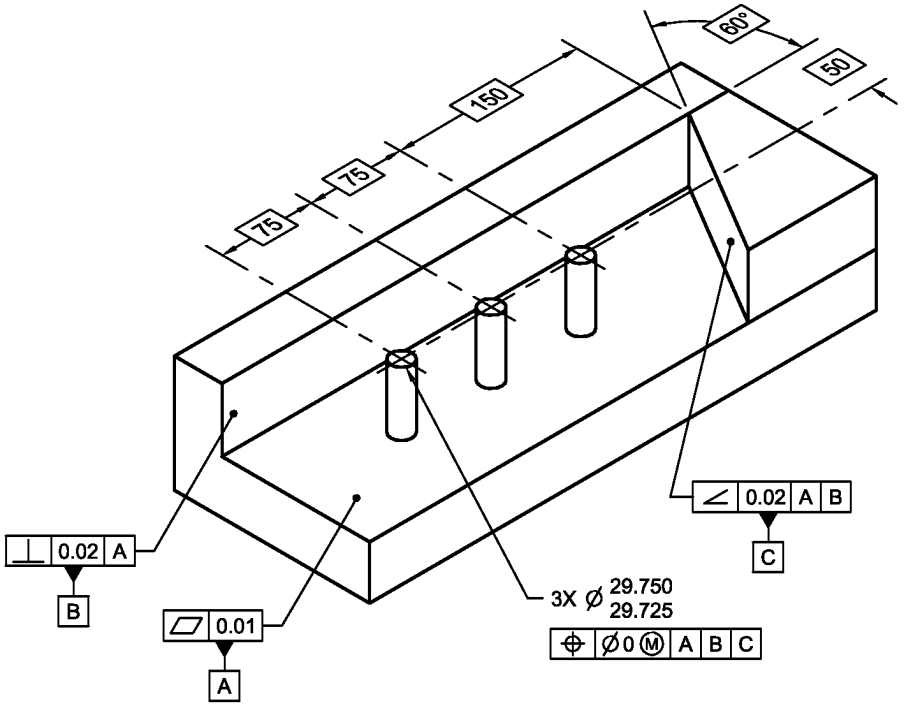


Fig. B2 Inclined Datum Features

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Fig. B2(a)

GAGE



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Fig. B2(b)

WORKPIECE APPLIED TO GAGE

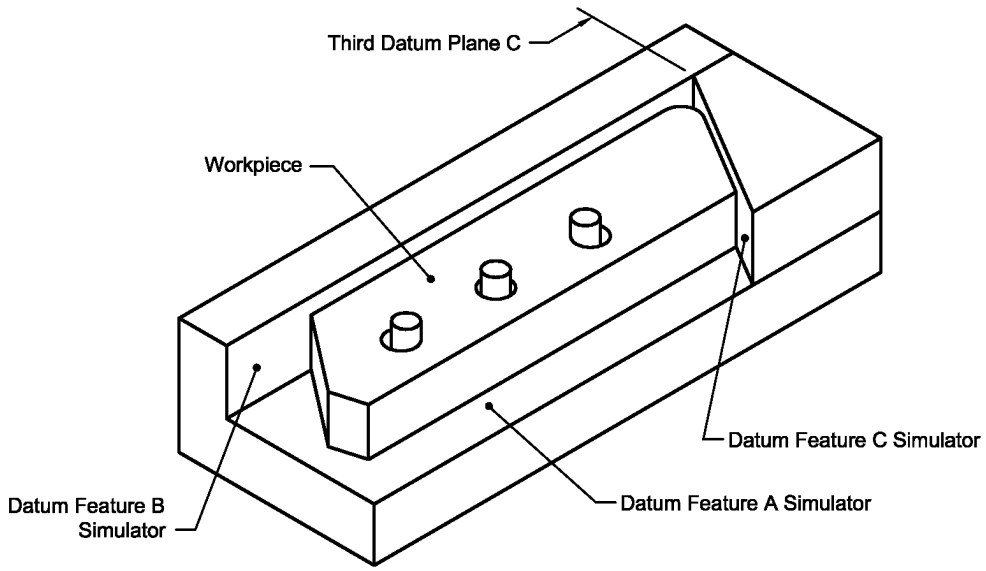


Fig. B2 Inclined Datum Features (Cont'd)

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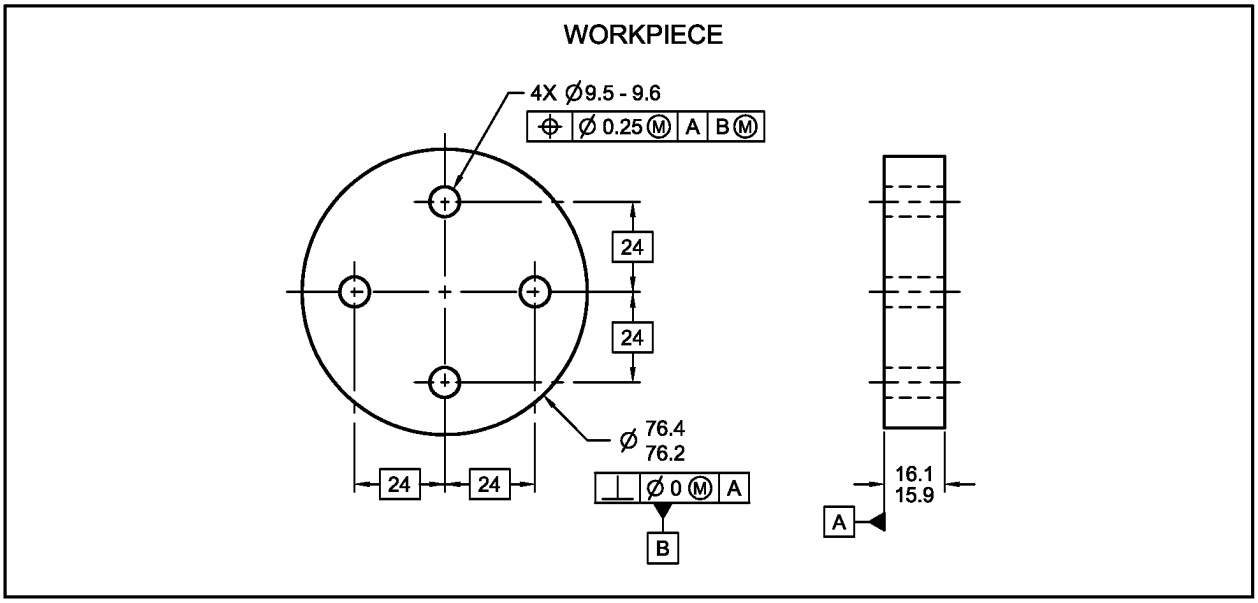
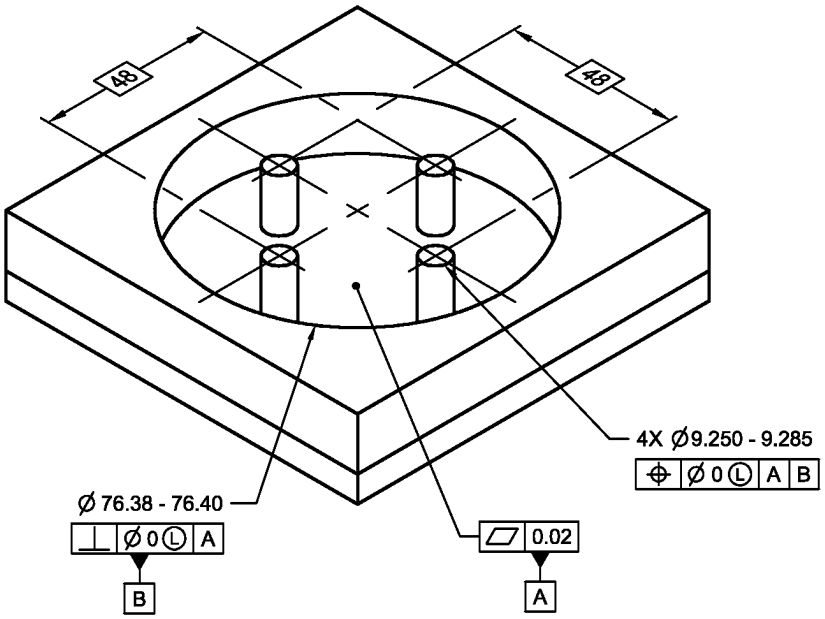


Fig. B3 Cylindrical Datum Features

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Fig. B3(a)

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Fig. B3(b)

WORKPIECE APPLIED TO GAGE

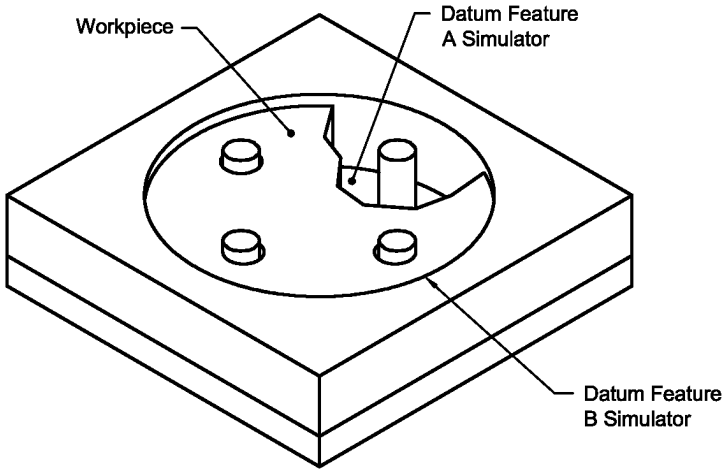


Fig. B3 Cylindrical Datum Features (Cont'd)

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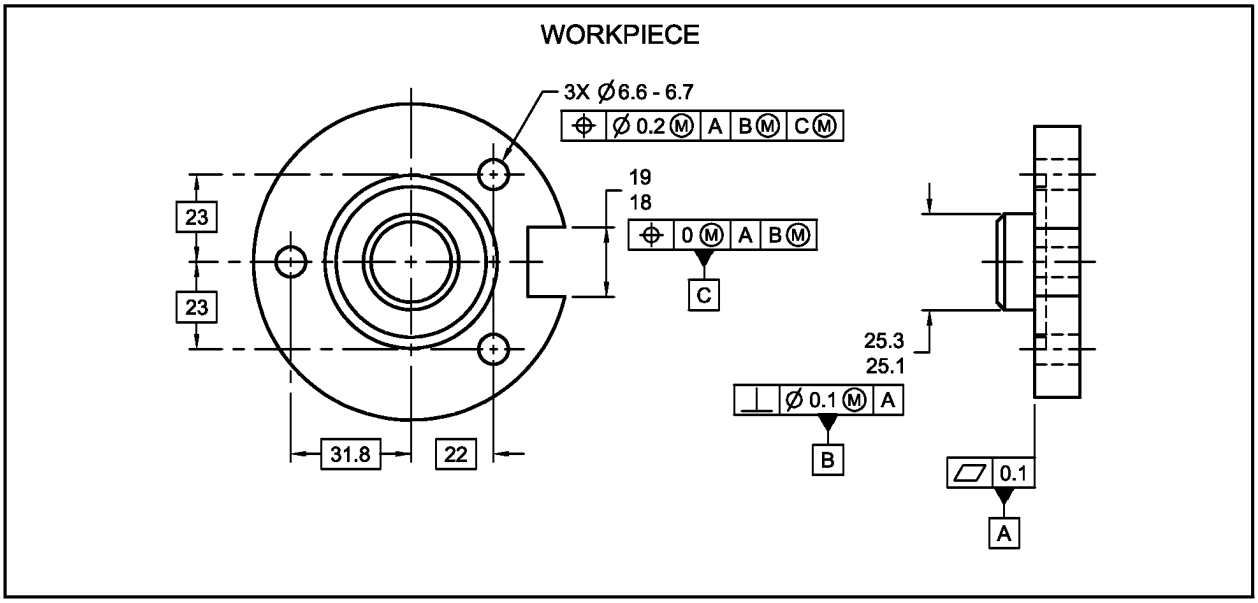


Fig. B4 Cylindrical and Rectangular Datum Features of Size

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Fig. B4(a)

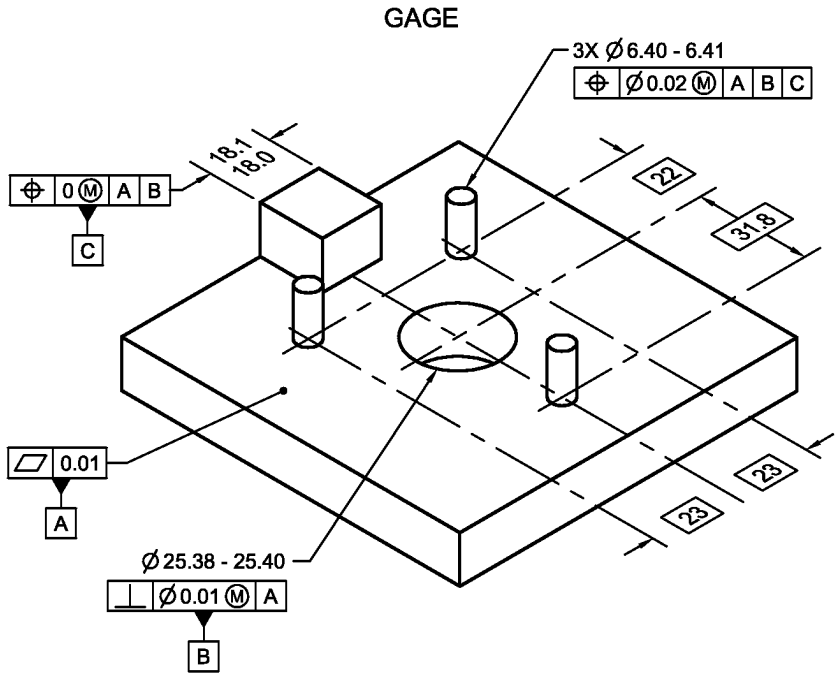


Fig. B4(b)

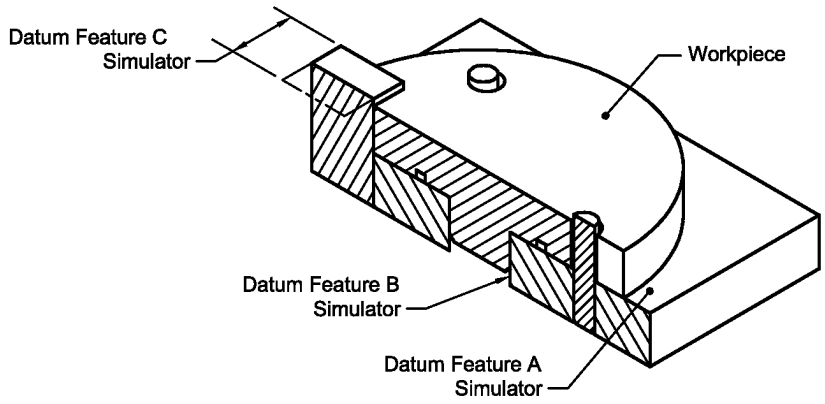


Fig. B4 Cylindrical and Rectangular Datum Features of Size (Cont'd)

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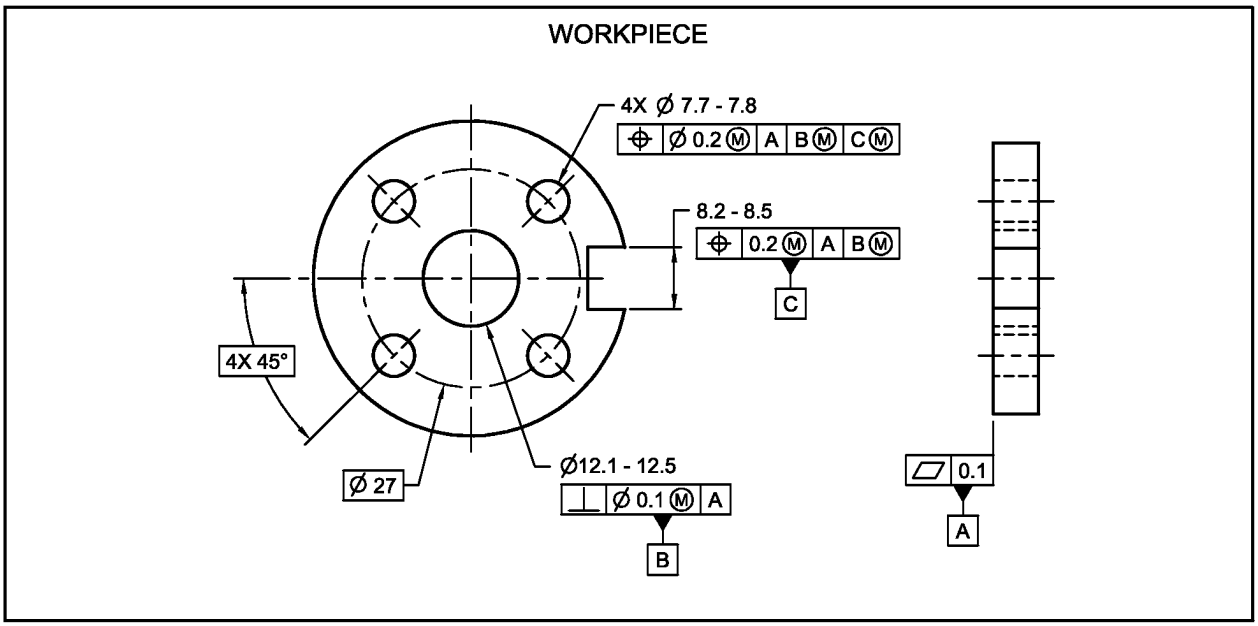


Fig. B5 Internal Cylindrical and Rectangular Datum Features of Size

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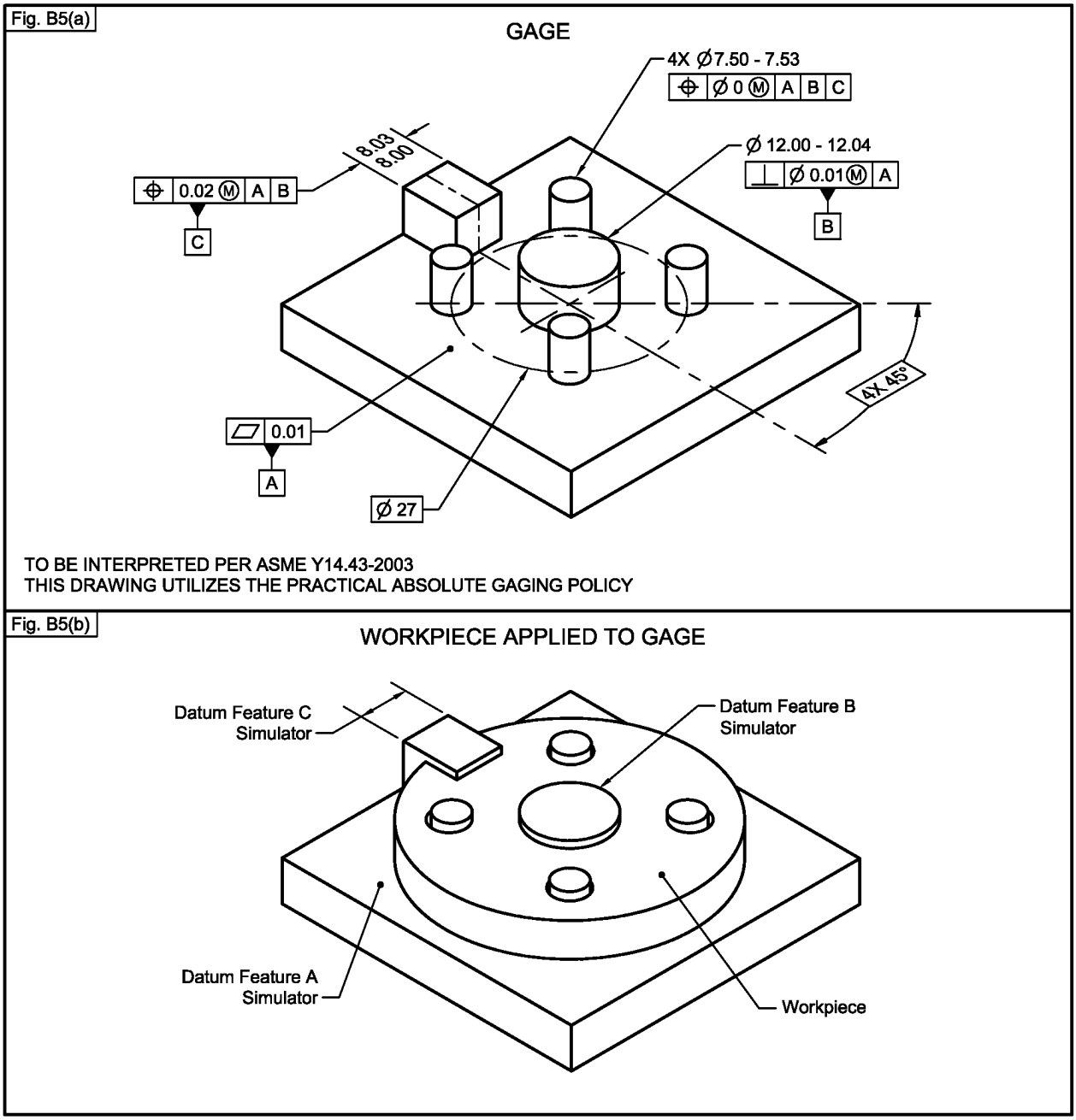


Fig. B5 Internal Cylindrical and Rectangular Datum Features of Size (Cont'd)

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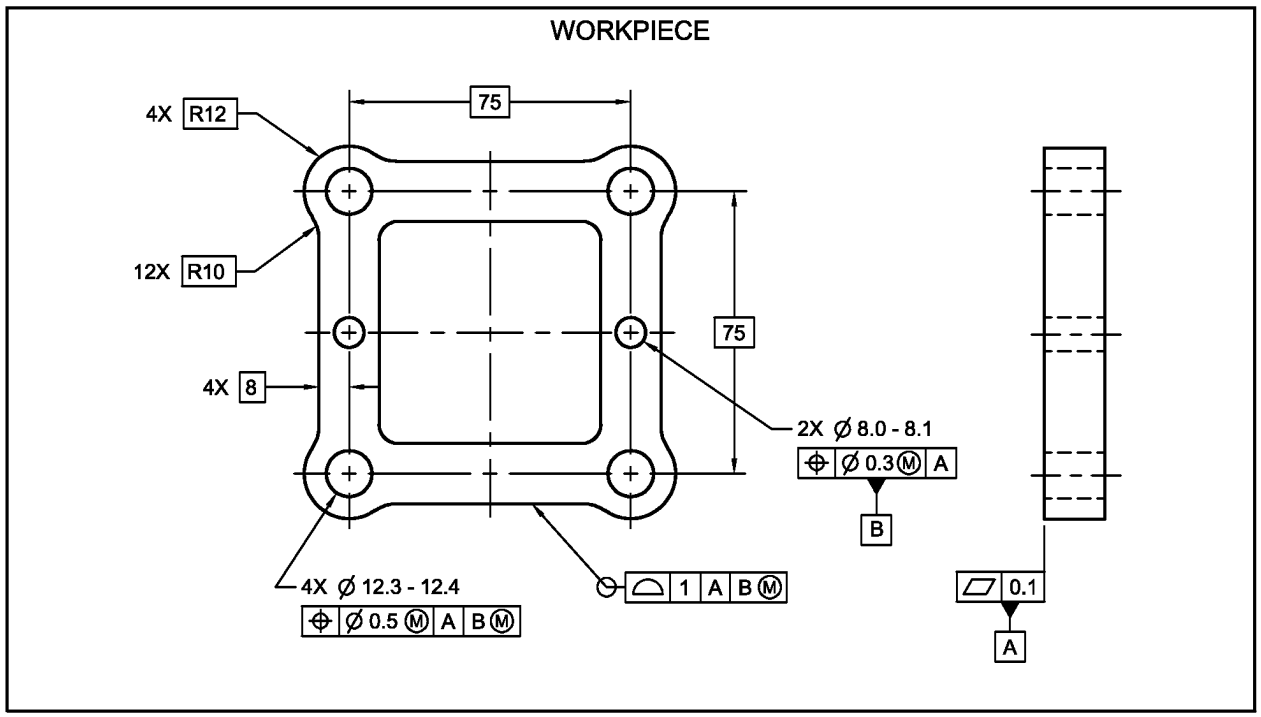
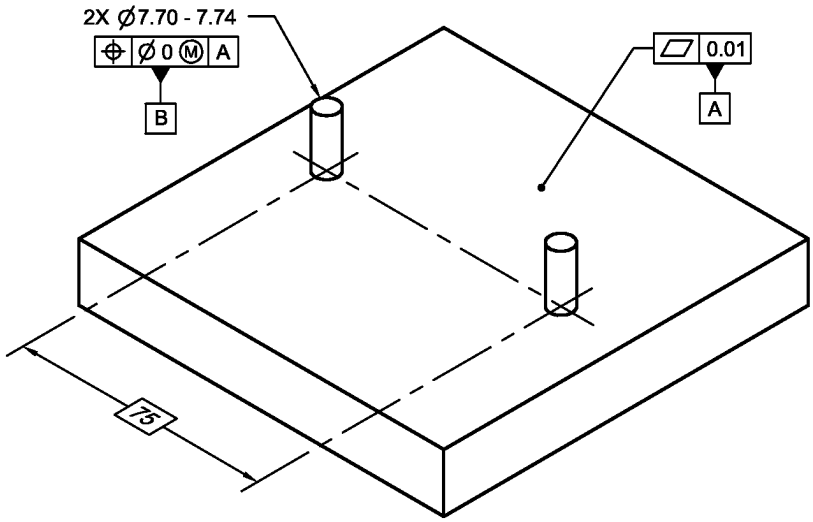


Fig. B6 Simultaneous Position and Profile Tolerances

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Fig. B6(a)

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Fig. B6(b)

WORKPIECE APPLIED TO GAGE

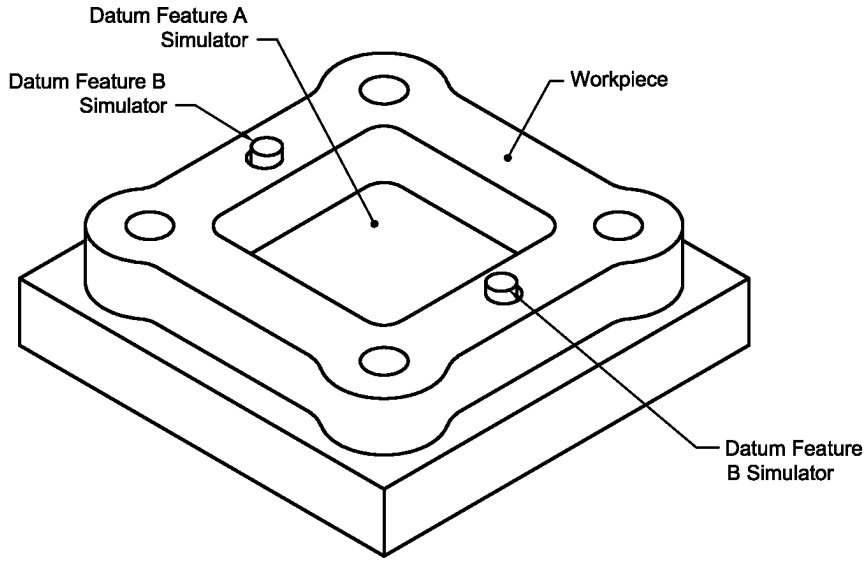
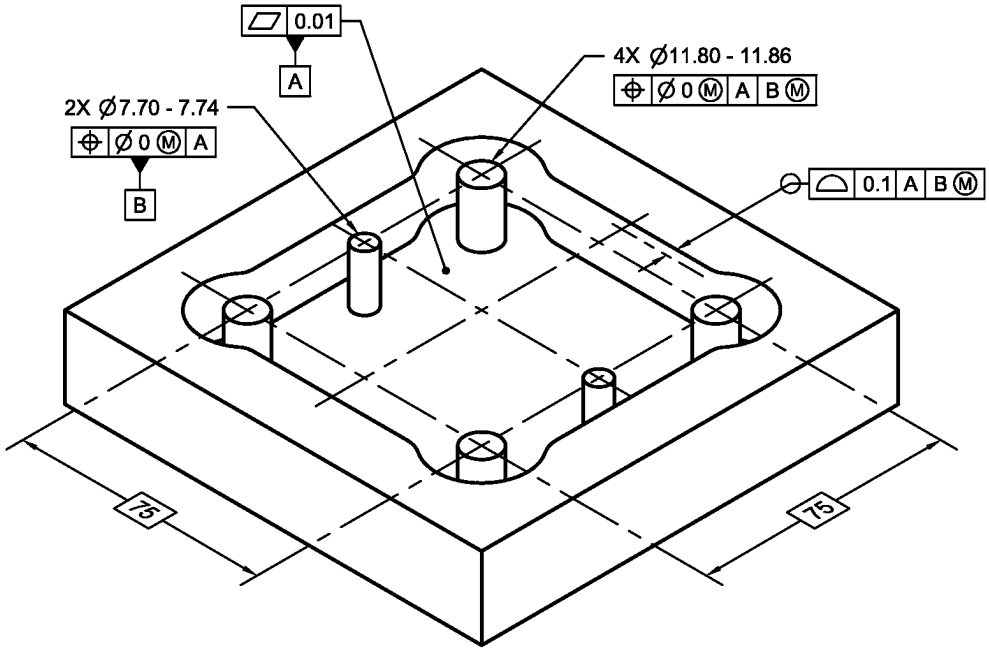


Fig. B6 Simultaneous Position and Profile Tolerances (Cont'd)

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Fig. B6(c)

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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. B6(d)

WORKPIECE APPLIED TO GAGE

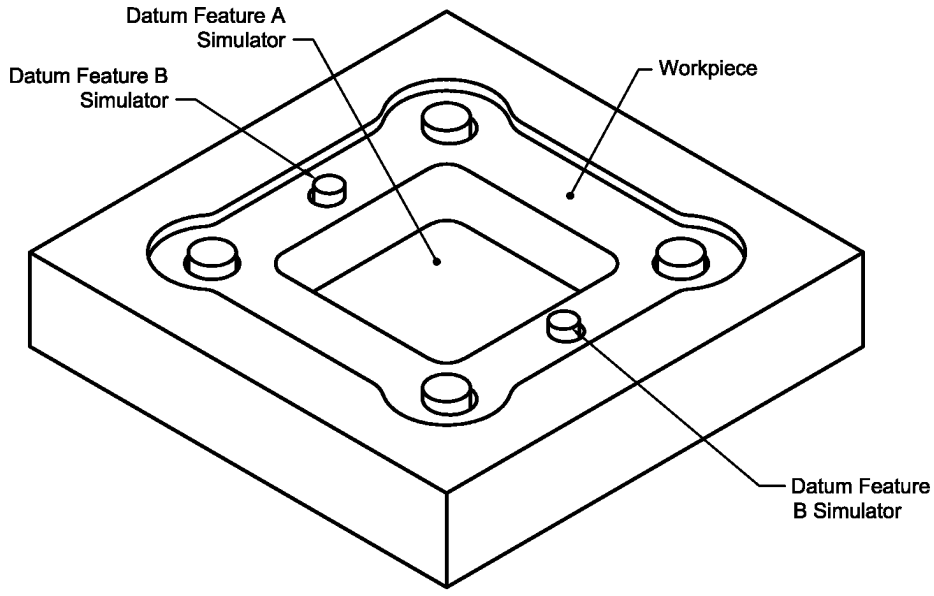


Fig. B6 Simultaneous Position and Profile Tolerances (Cont'd)

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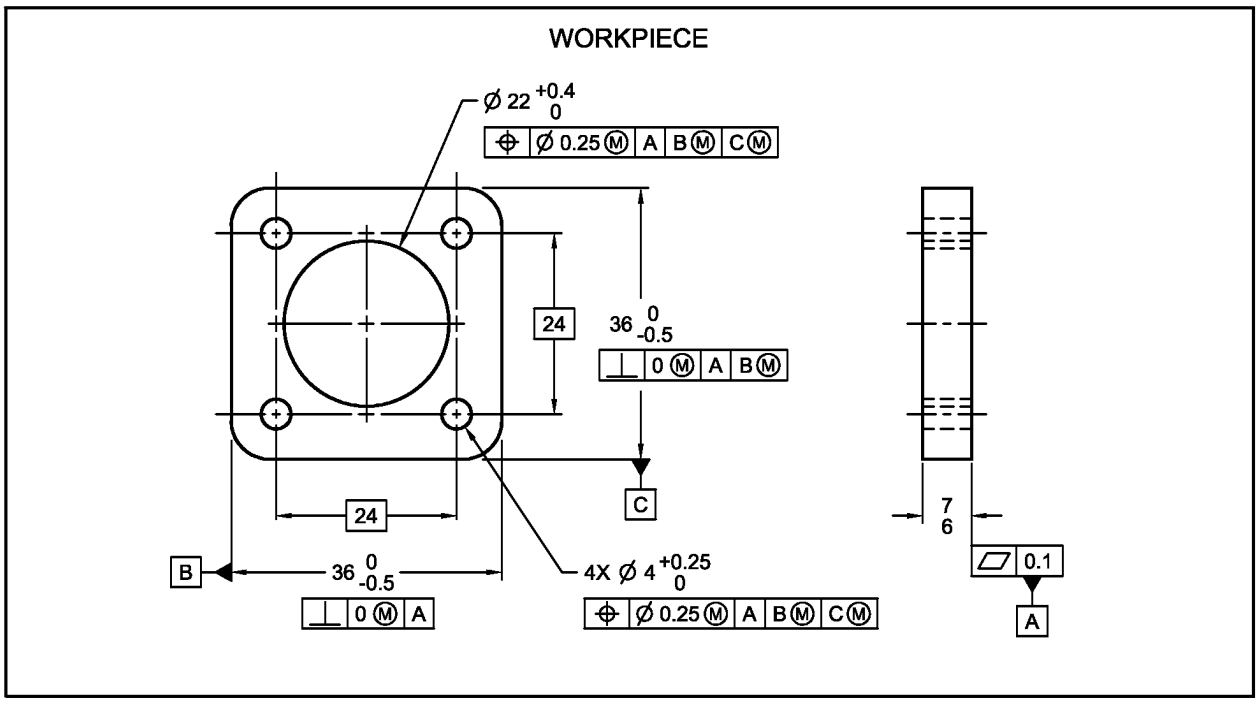
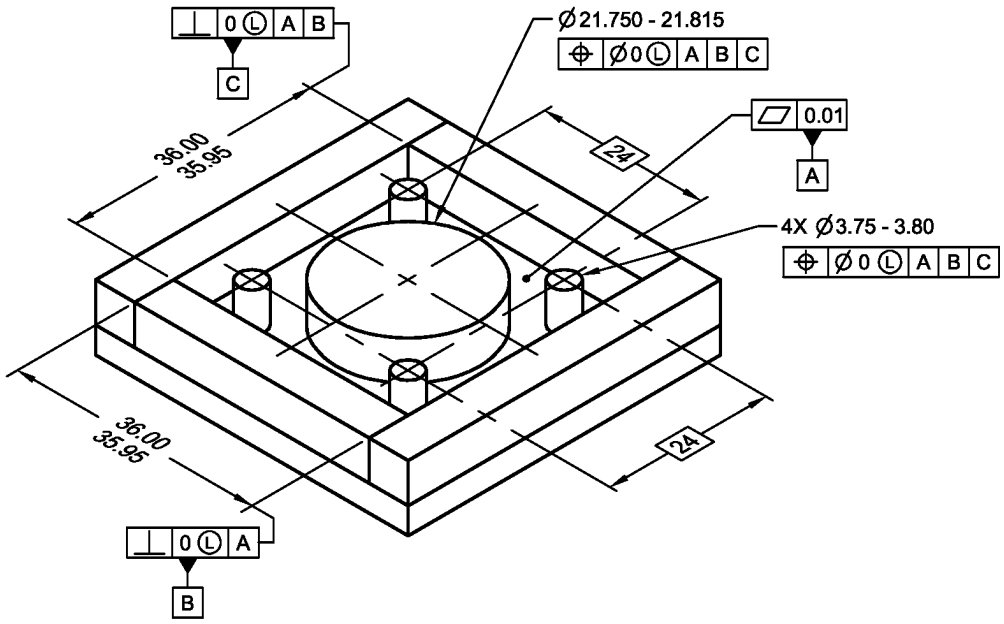


Fig. B7 Two Rectangular Datum Features of Size at MMC

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Fig. B7(a)

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Fig. B7(b)

WORKPIECE APPLIED TO GAGE

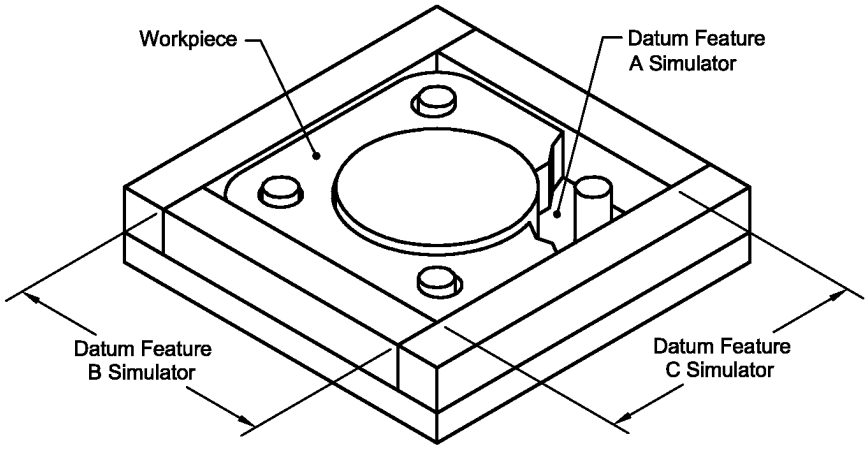


Fig. B7 Two Rectangular Datum Features of Size at MMC (Cont'd)

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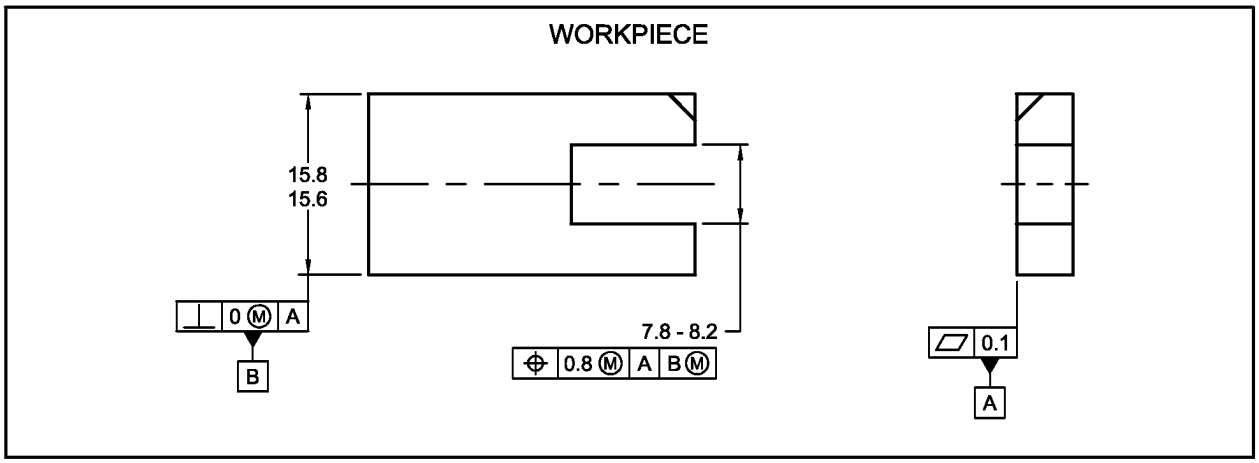
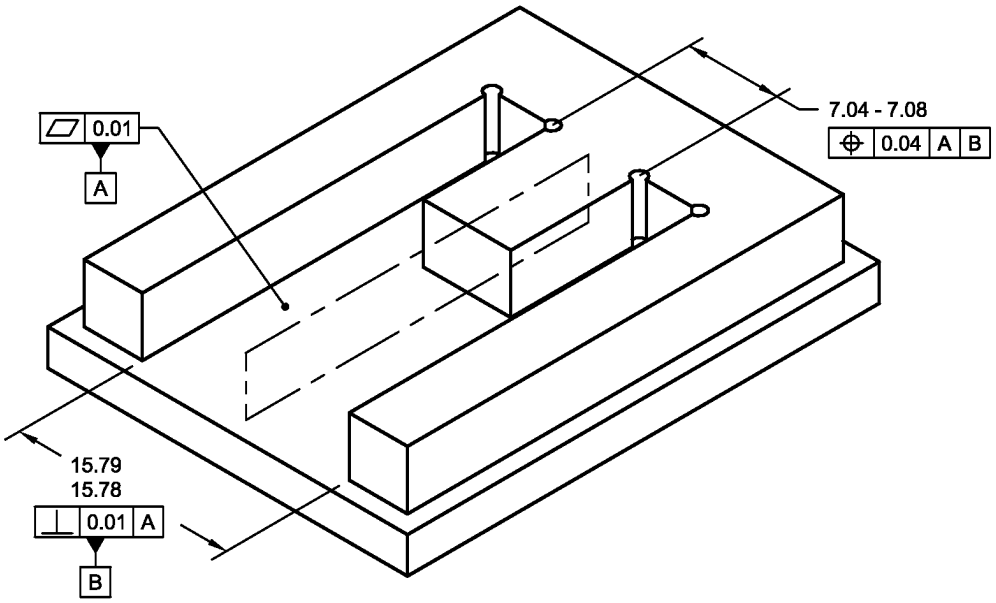


Fig. B8 Rectangular Features of Size at MMC

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Fig. B8(a)

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Fig. B8(b)

WORKPIECE APPLIED TO GAGE

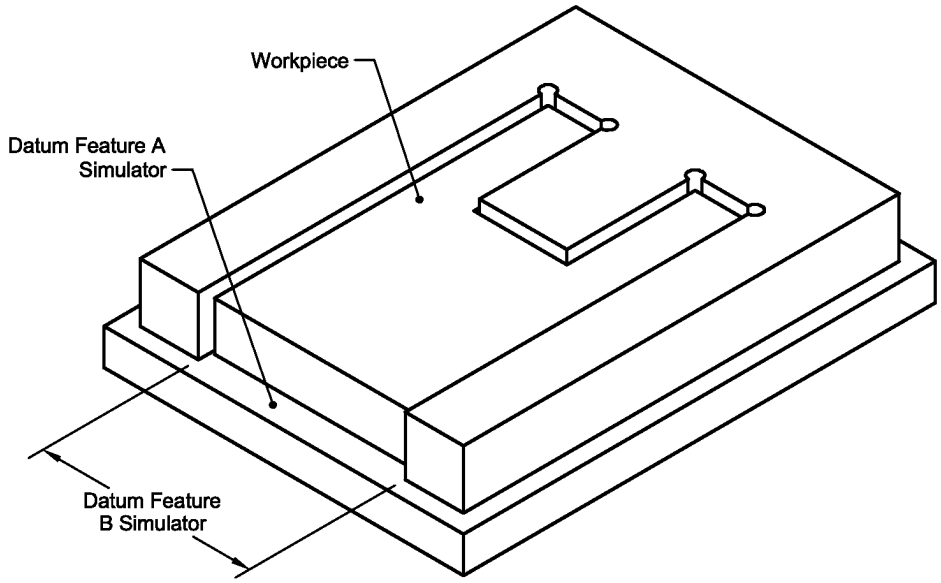


Fig. B8 Rectangular Features of Size at MMC (Cont'd)

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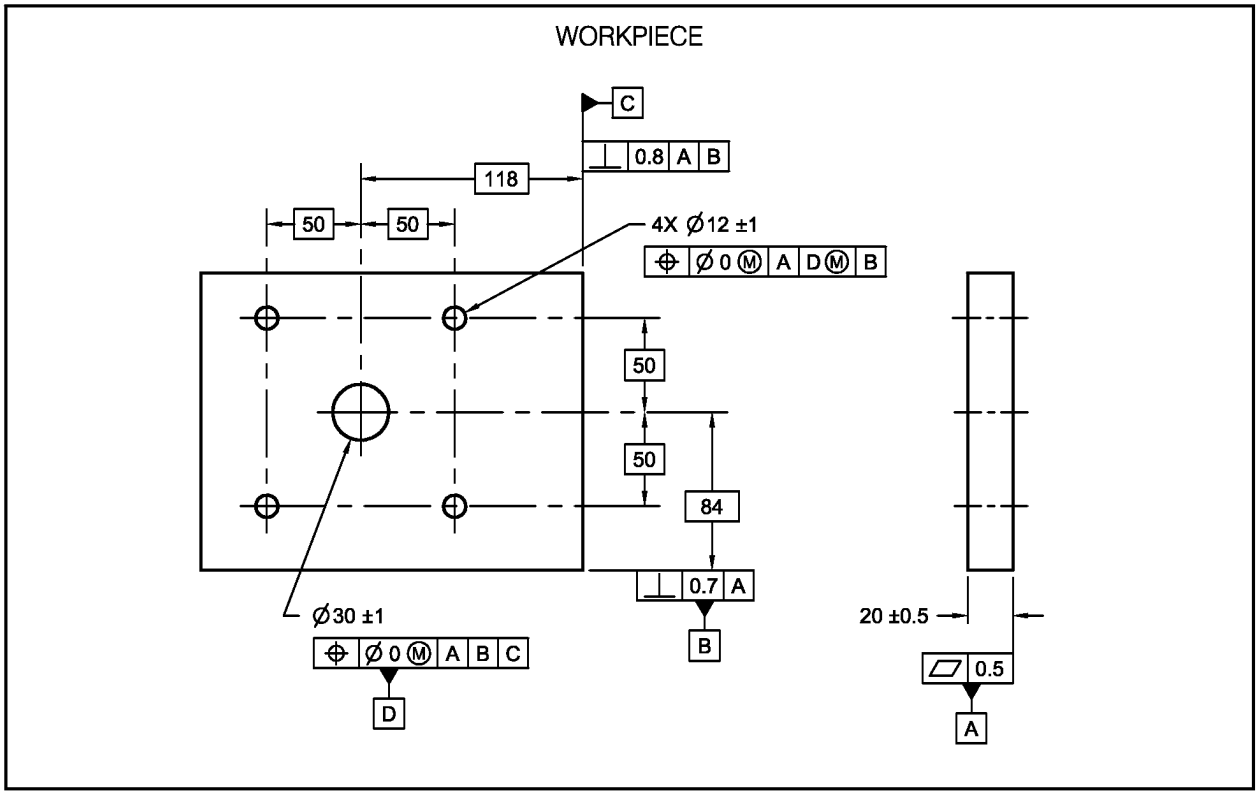
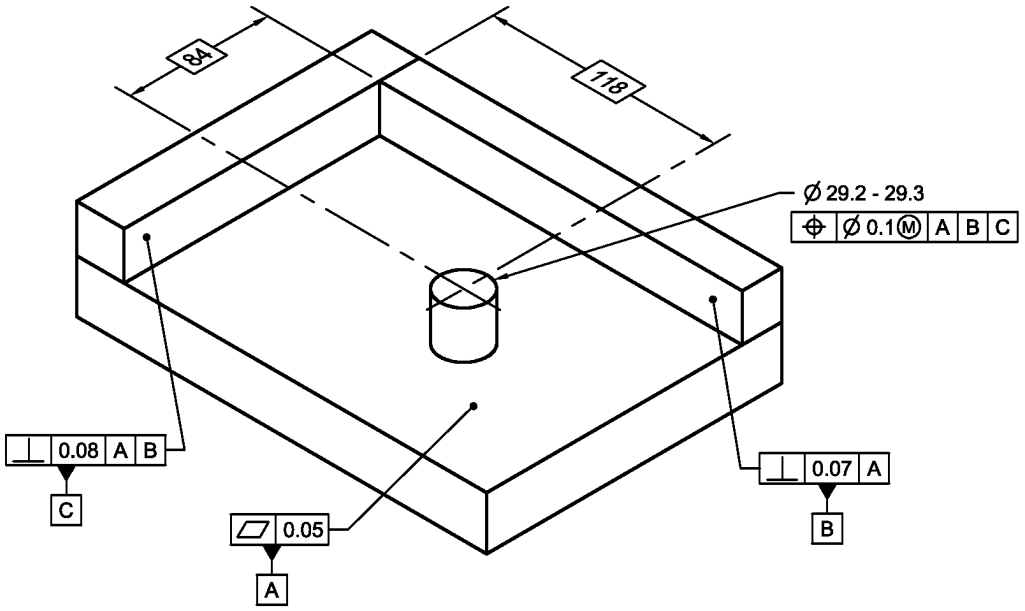


Fig. B9 Size and Planar Datum Features

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Fig. B9(a)

GAGE TO VERIFY DATUM FEATURE D



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Fig. B9(b)

WORKPIECE APPLIED TO GAGE

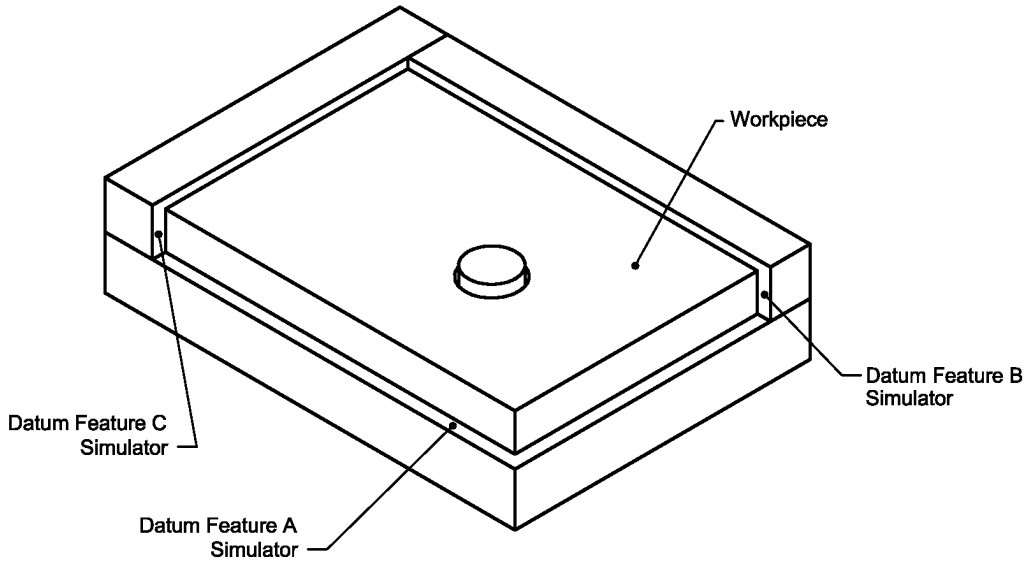
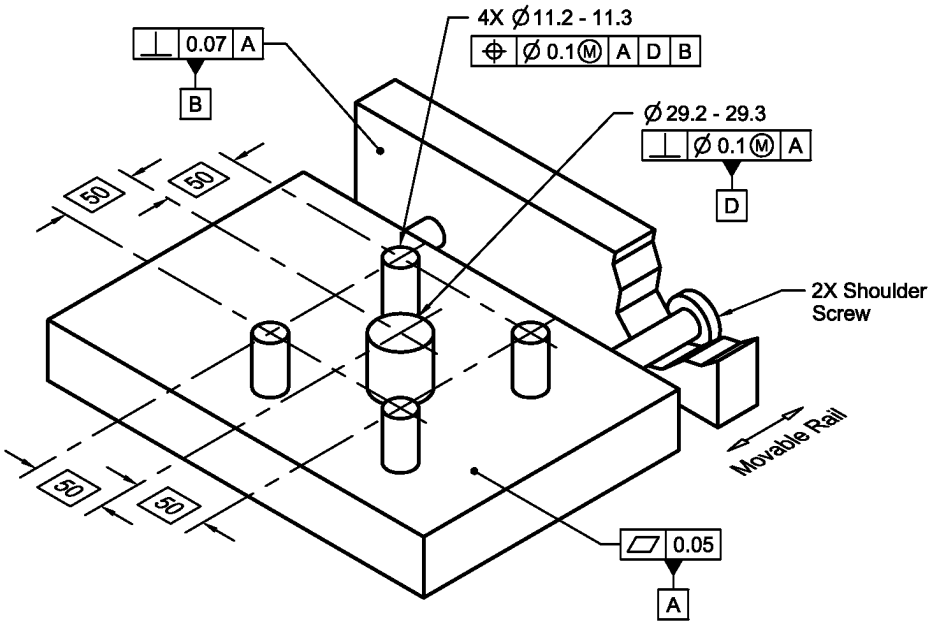


Fig. B9 Size and Planar Datum Features (Cont'd)

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Fig. B9(c)

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Fig. B9(d)

WORKPIECE APPLIED TO GAGE

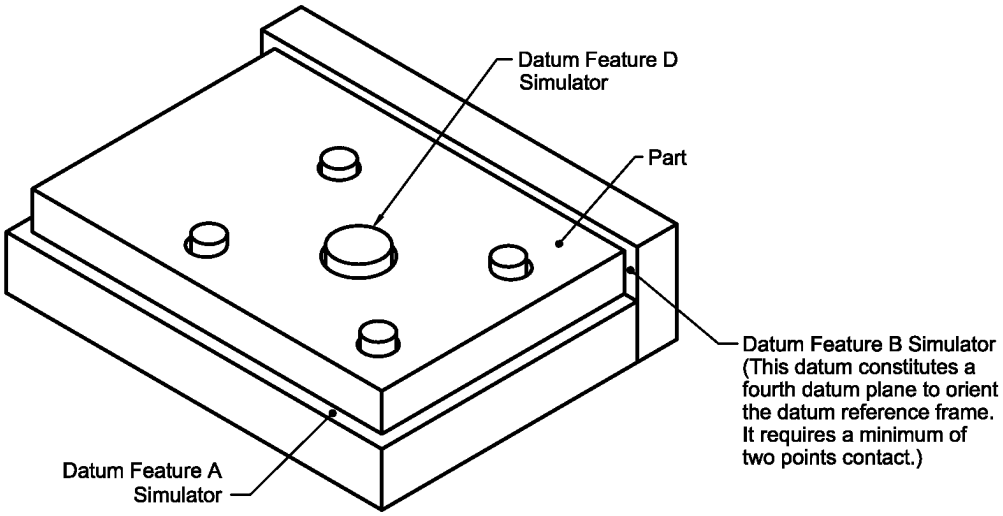


Fig. B9 Size and Planar Datum Features (Cont'd)

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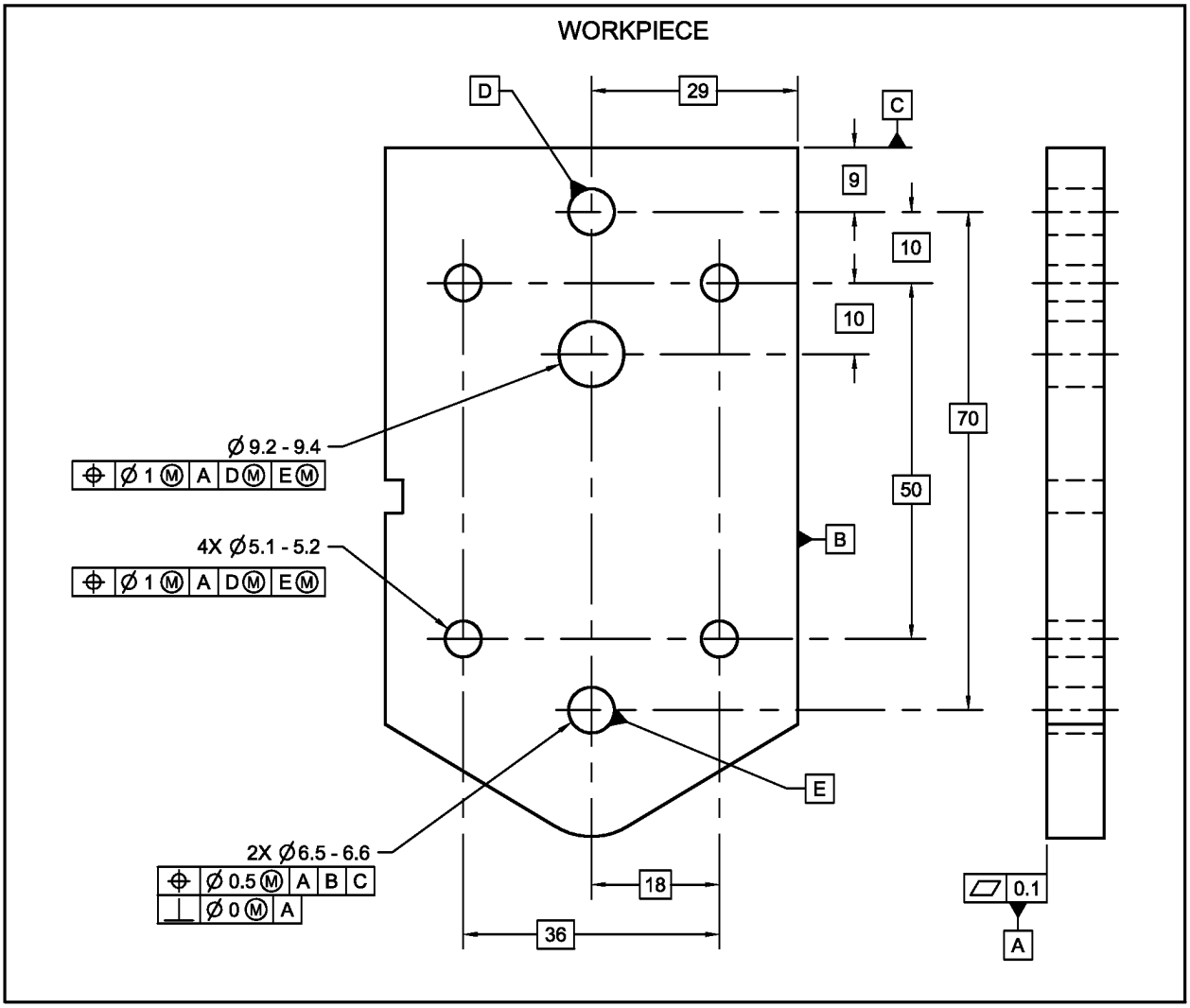
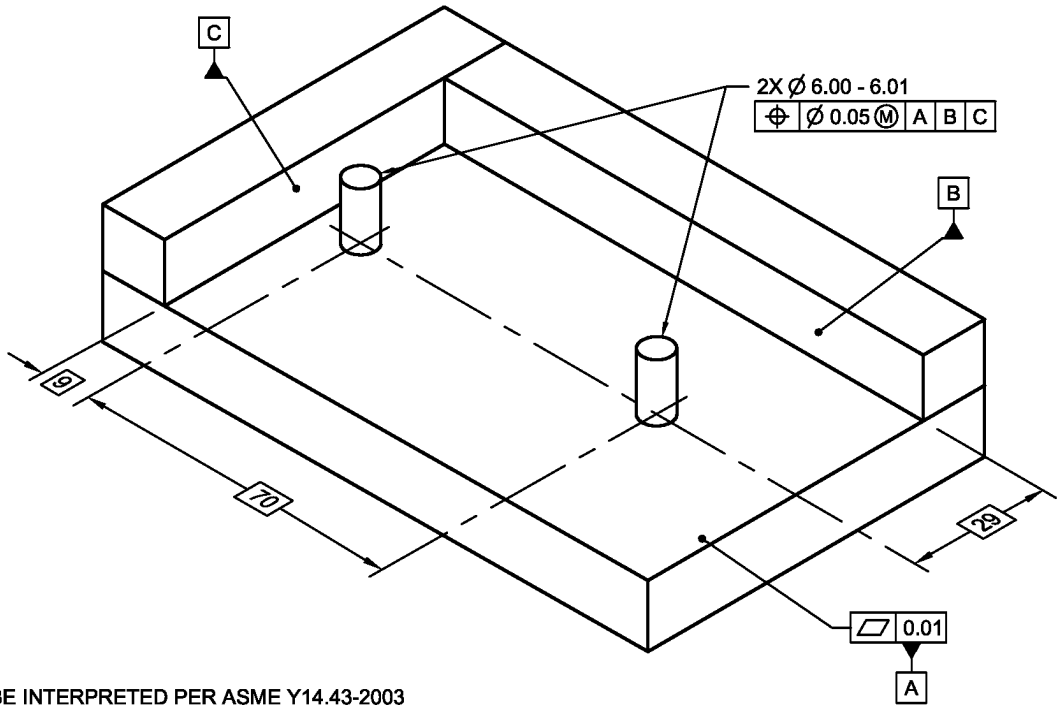


Fig. B10 Controlling Rotation With Datum Features of Size

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Fig. B10(b)

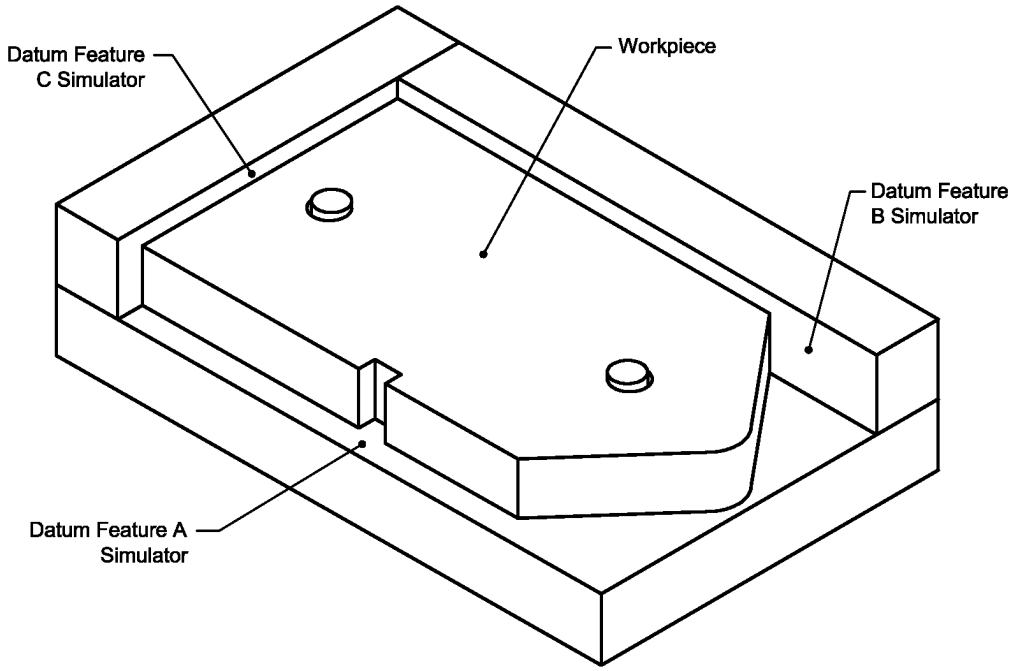


Fig. B10 Controlling Rotation With Datum Features of Size (Cont'd)

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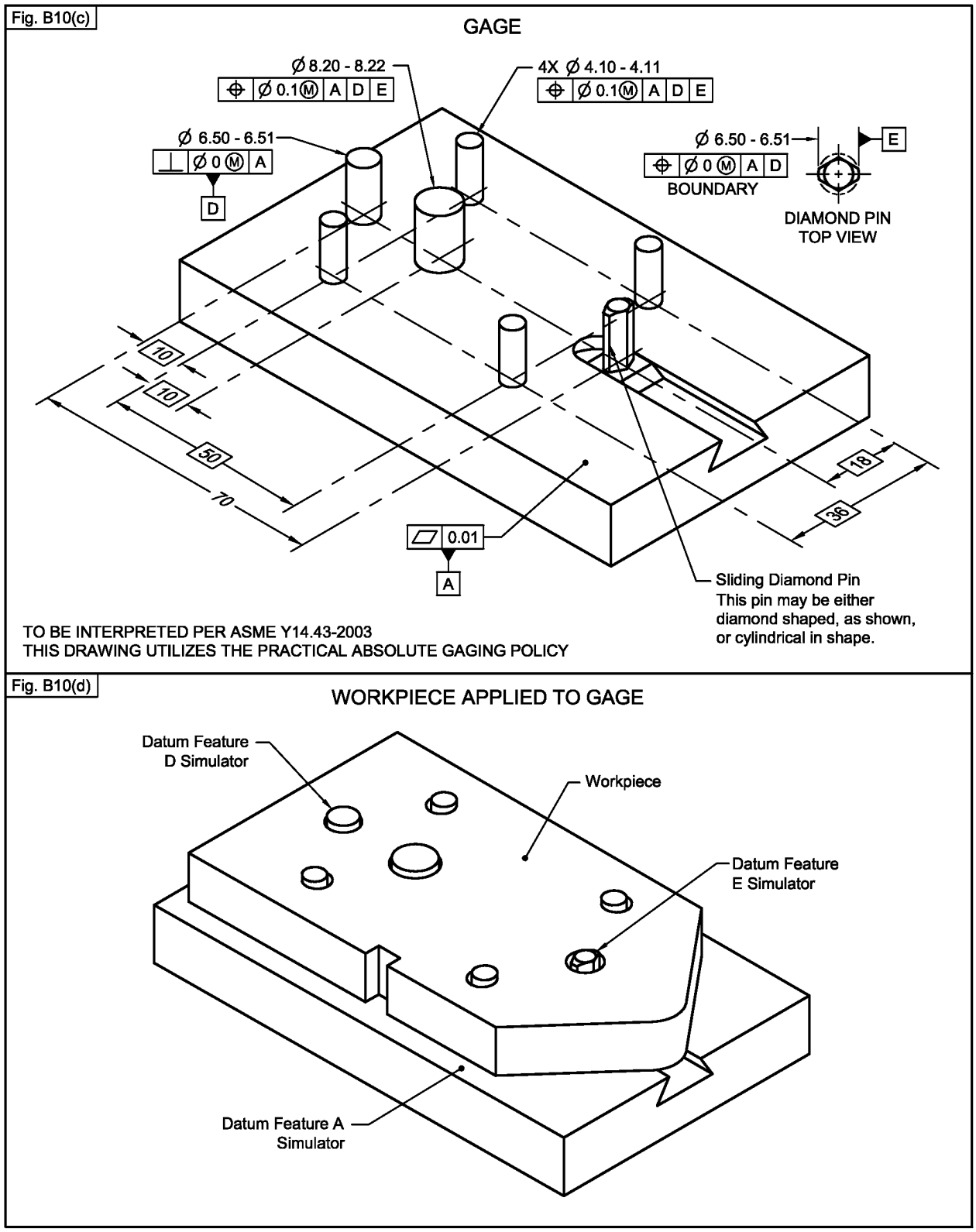


Fig. B10 Controlling Rotation With Datum Features of Size (Cont'd)

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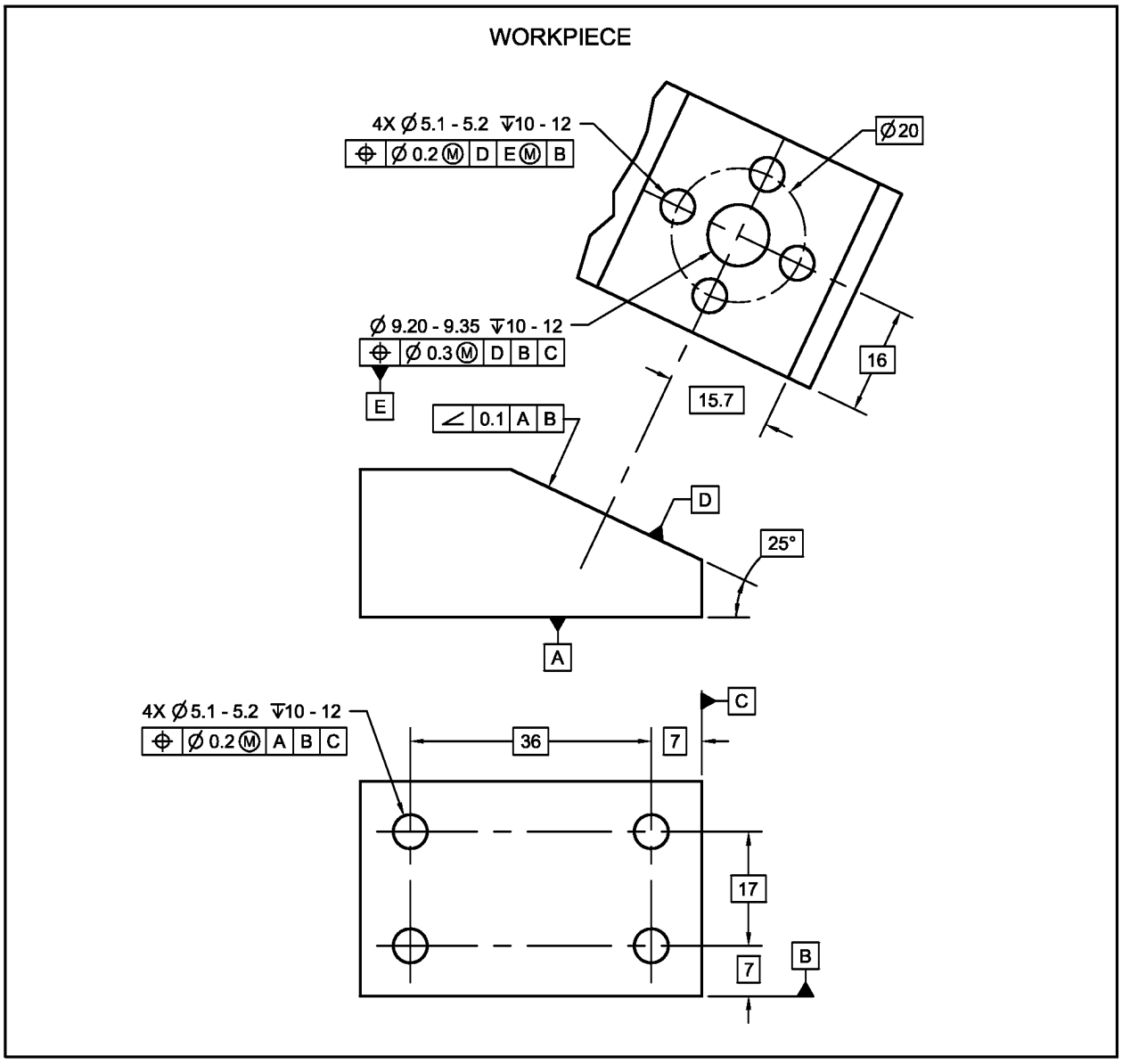
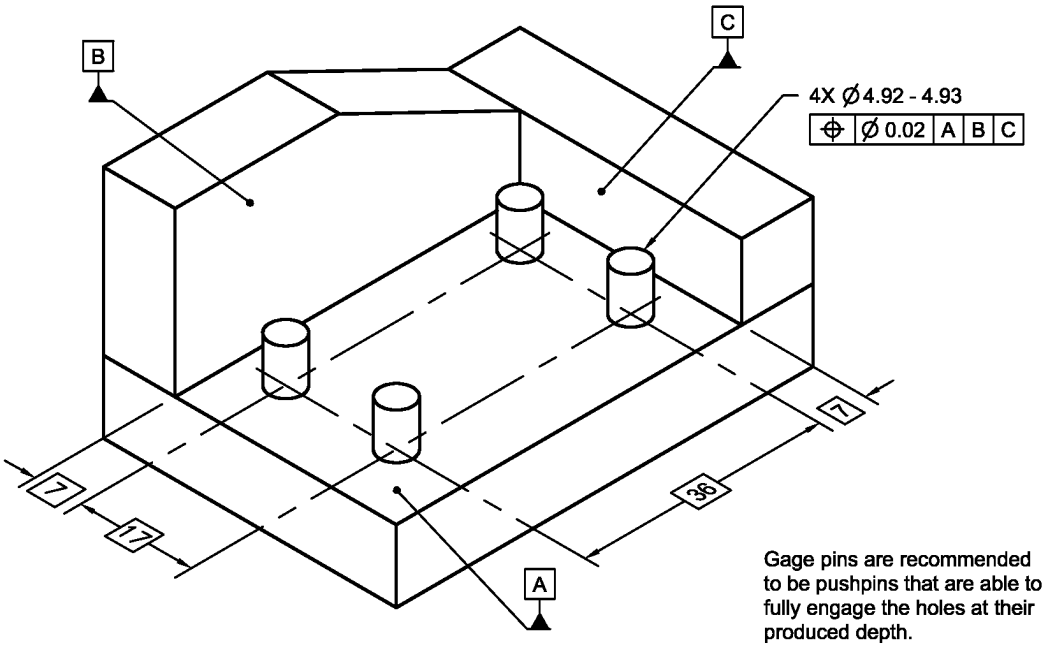


Fig. B11 Interrelated Datum Reference Frames

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Fig. B11(a)

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Fig. B11(b)

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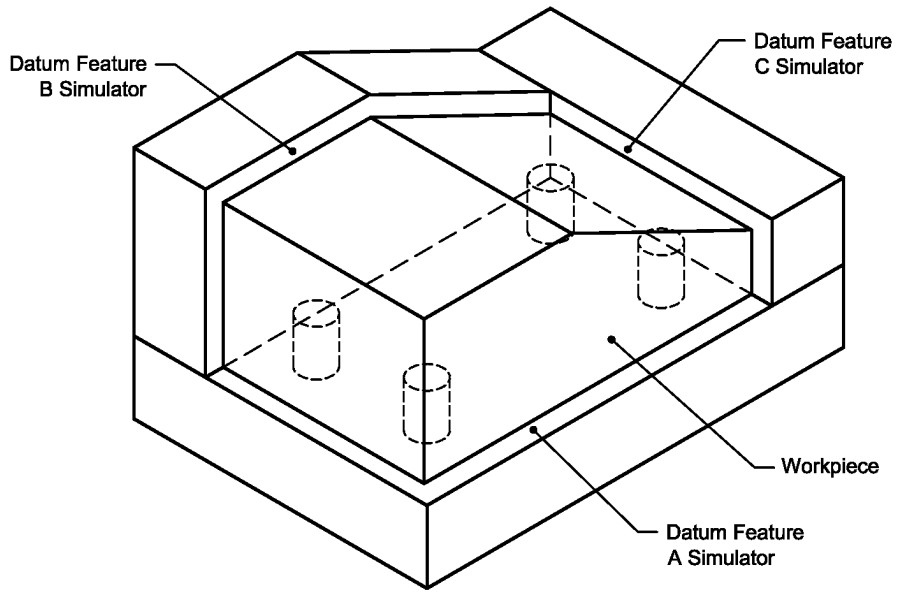
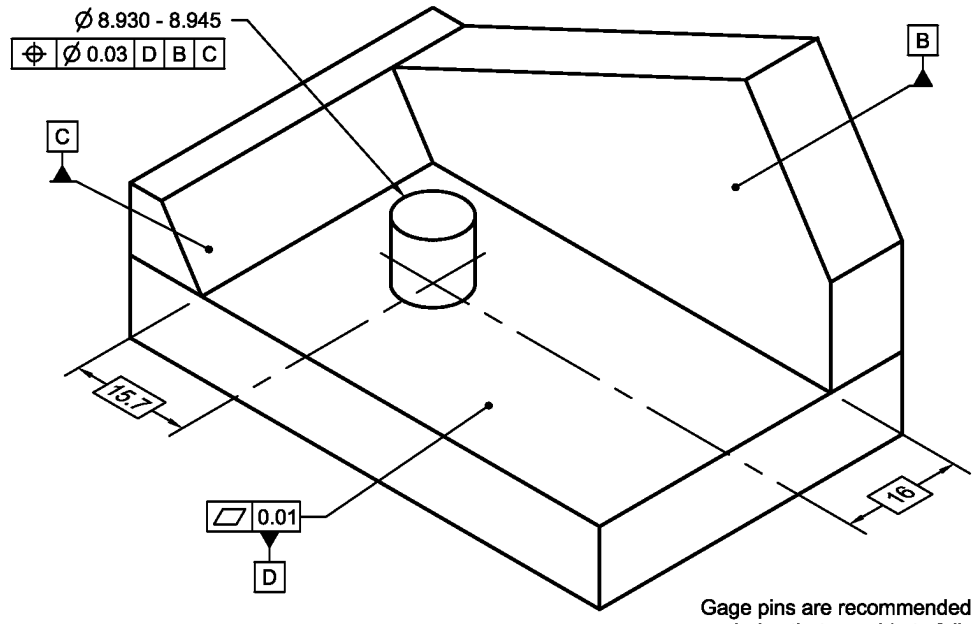


Fig. B11 Interrelated Datum Reference Frames (Cont'd)

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Fig. B11(c)

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

Fig. B11(d)

WORKPIECE APPLIED TO GAGE

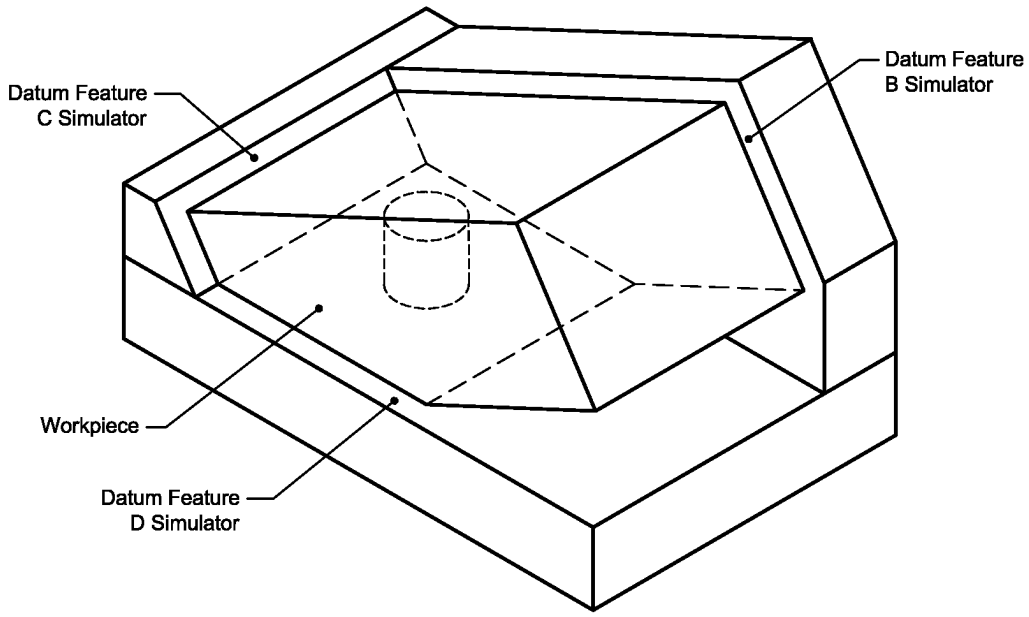
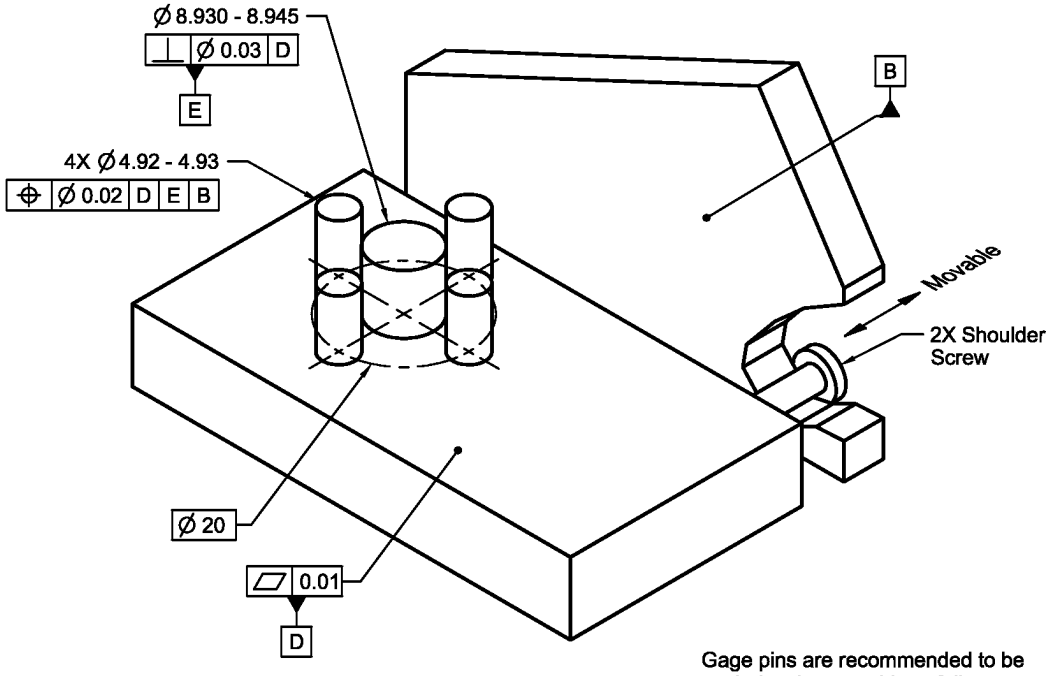


Fig. B11 Interrelated Datum Reference Frames (Cont'd)

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Fig. B11(e)

GAGE



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Fig. B11(f)

WORKPIECE APPLIED TO GAGE

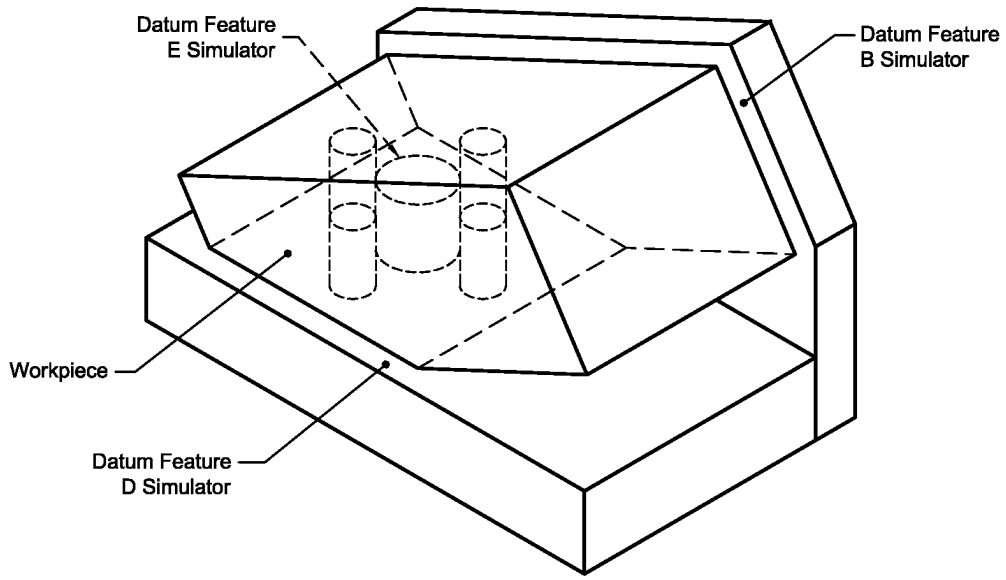


Fig. B11 Interrelated Datum Reference Frames (Cont'd)

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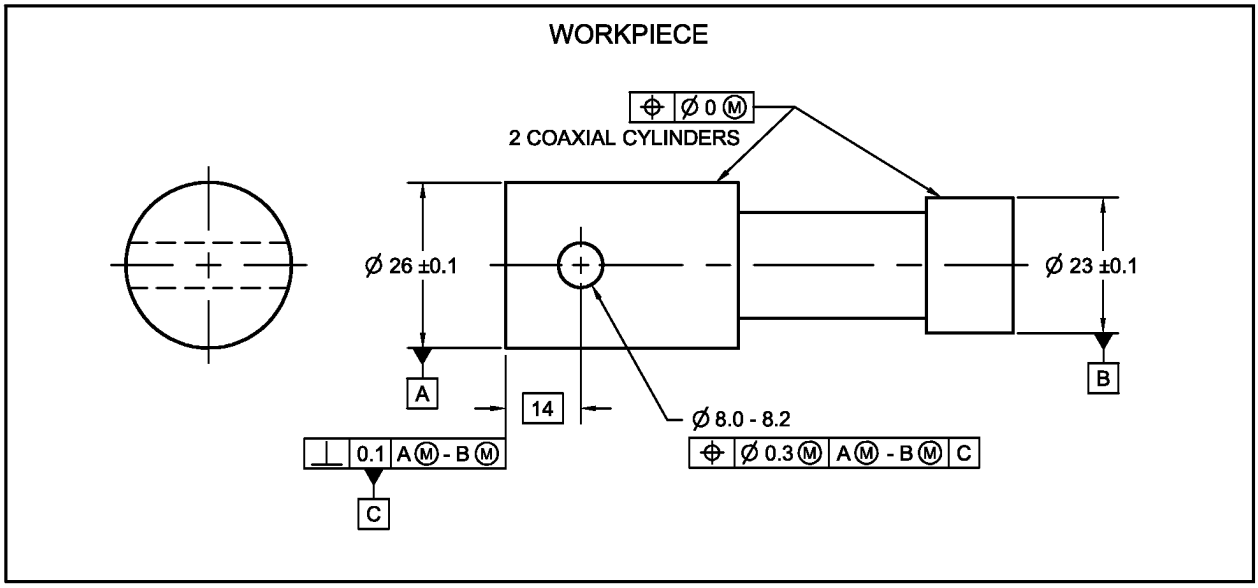


Fig. B12 Two Datum Features — Single Datum Axis

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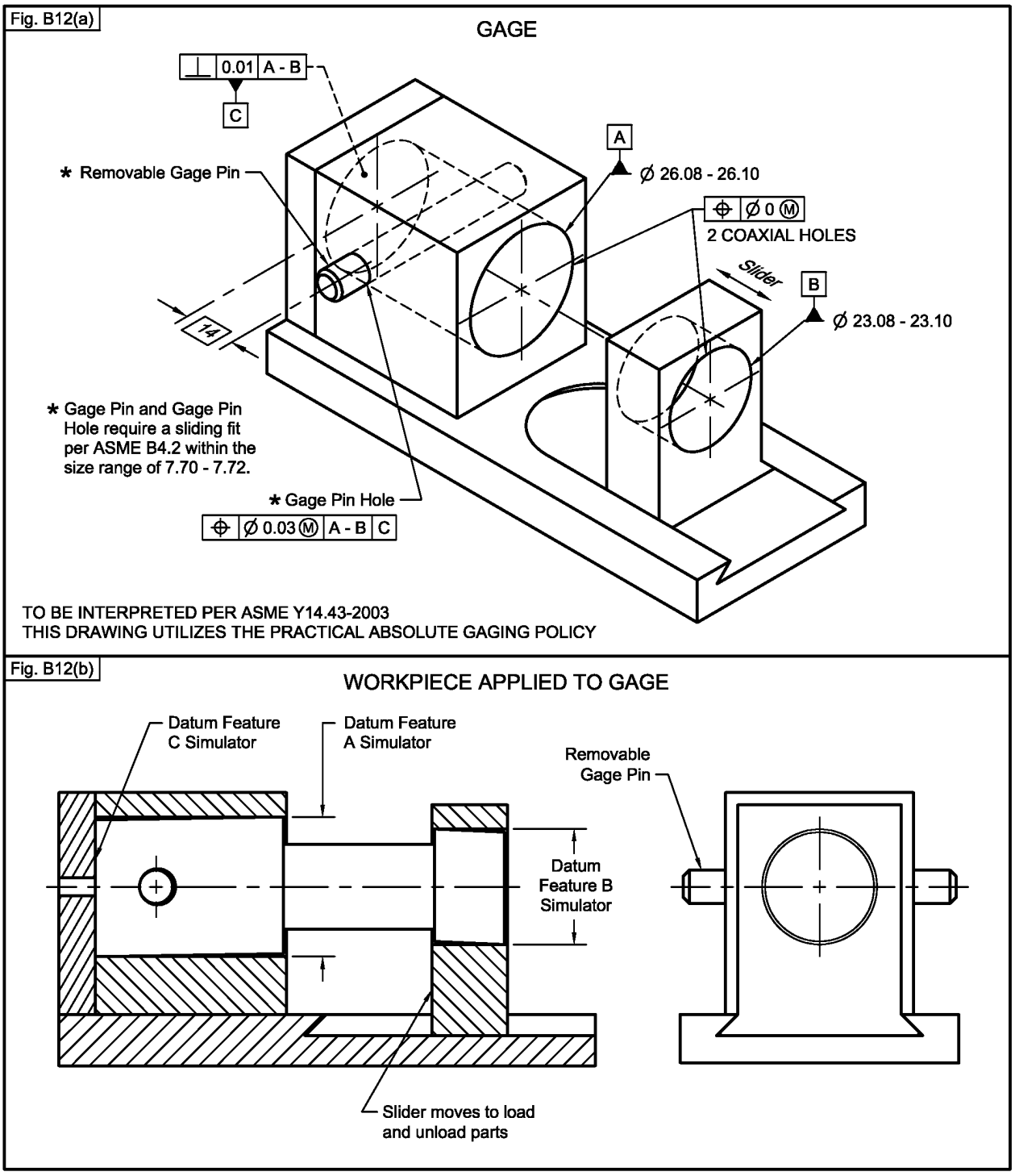


Fig. B12 Two Datum Features — Single Datum Axis (Cont'd)

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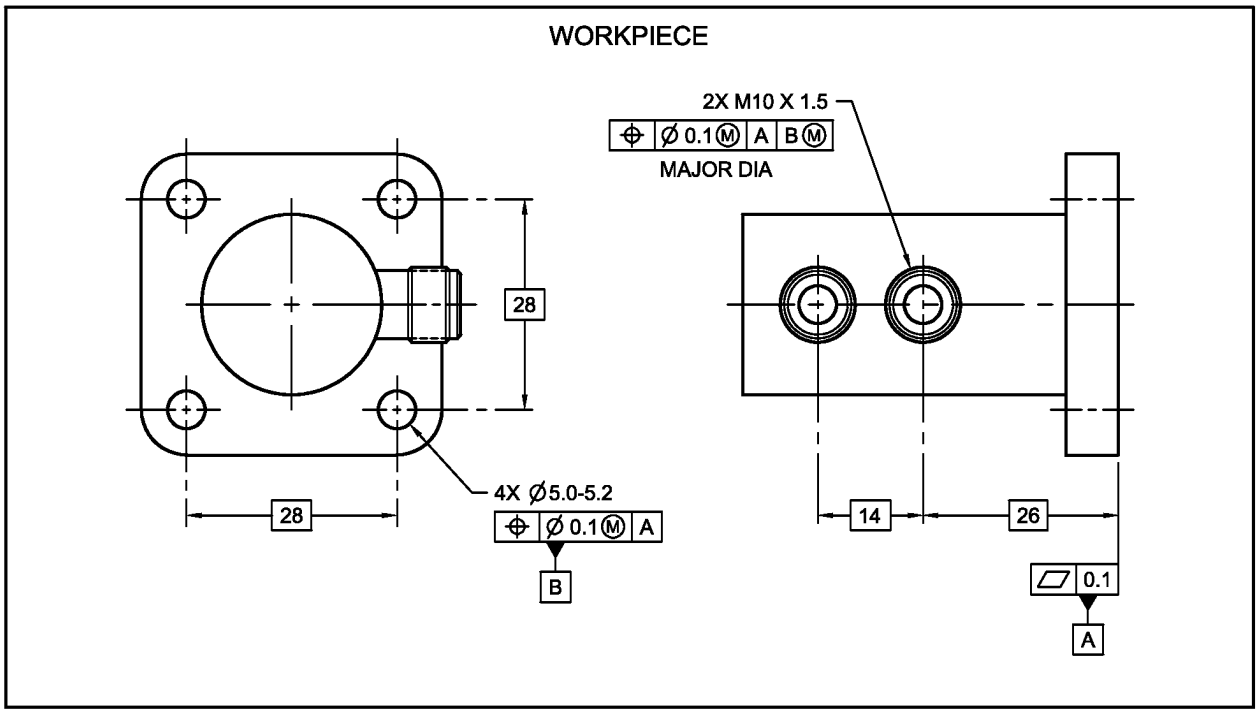
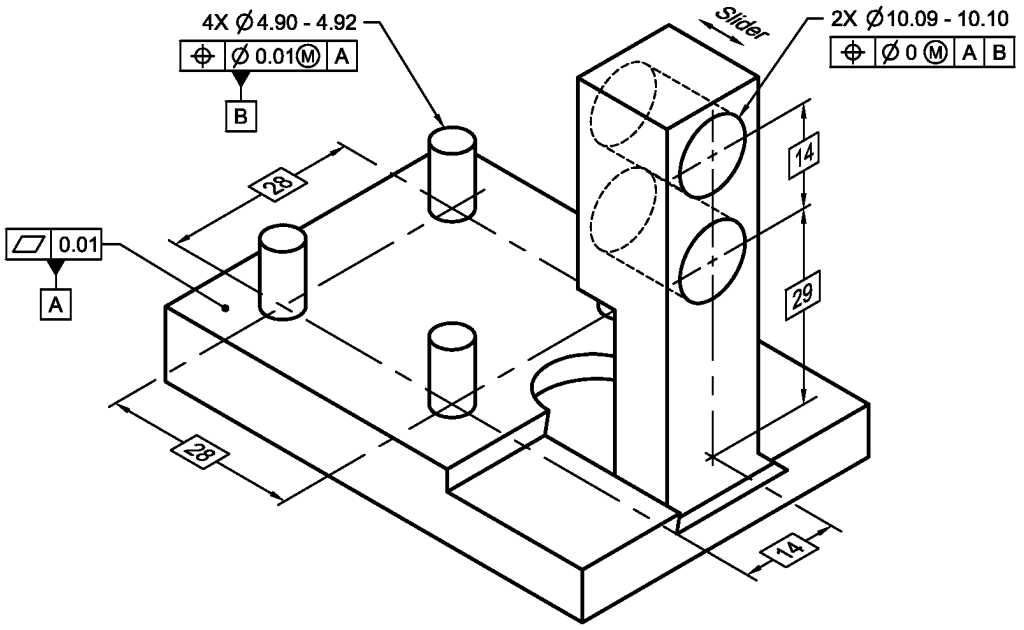


Fig. B13 Hole Pattern as a Datum

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Fig. B13(a)

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Fig. B13(b)

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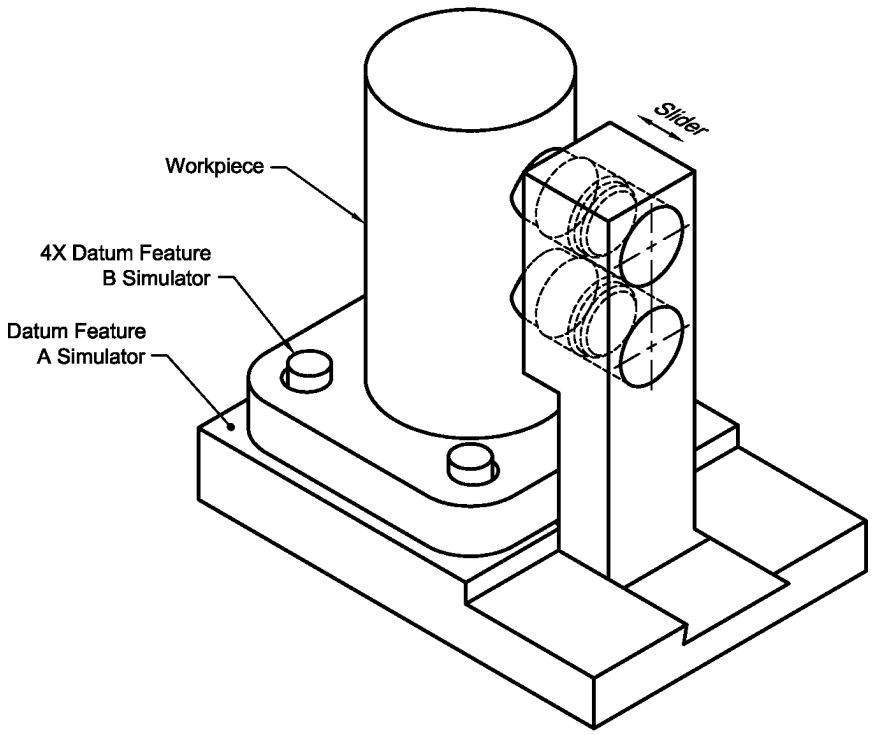


Fig. B13 Hole Pattern as a Datum (Cont'd)

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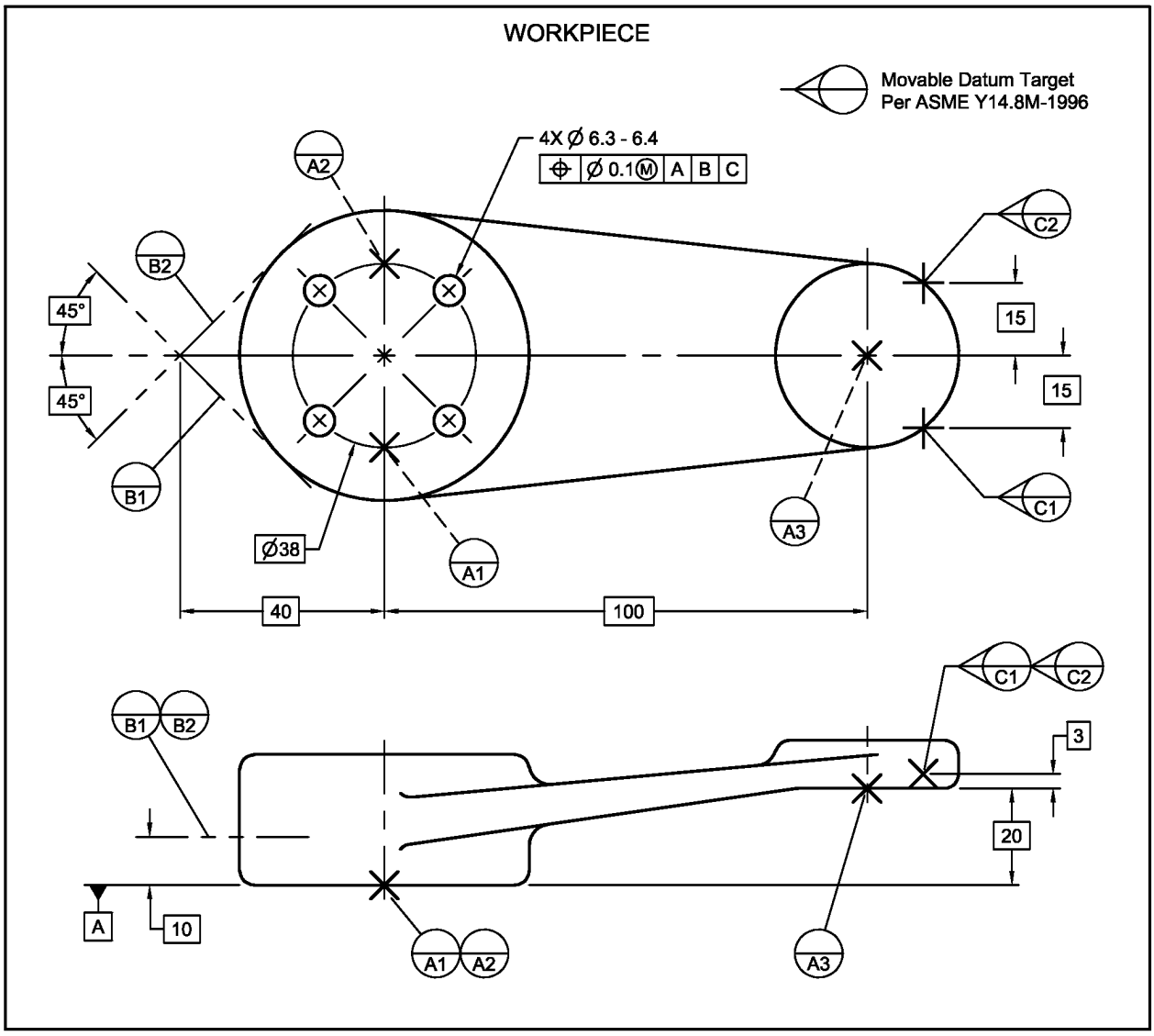


Fig. B14 Equalizing Datums

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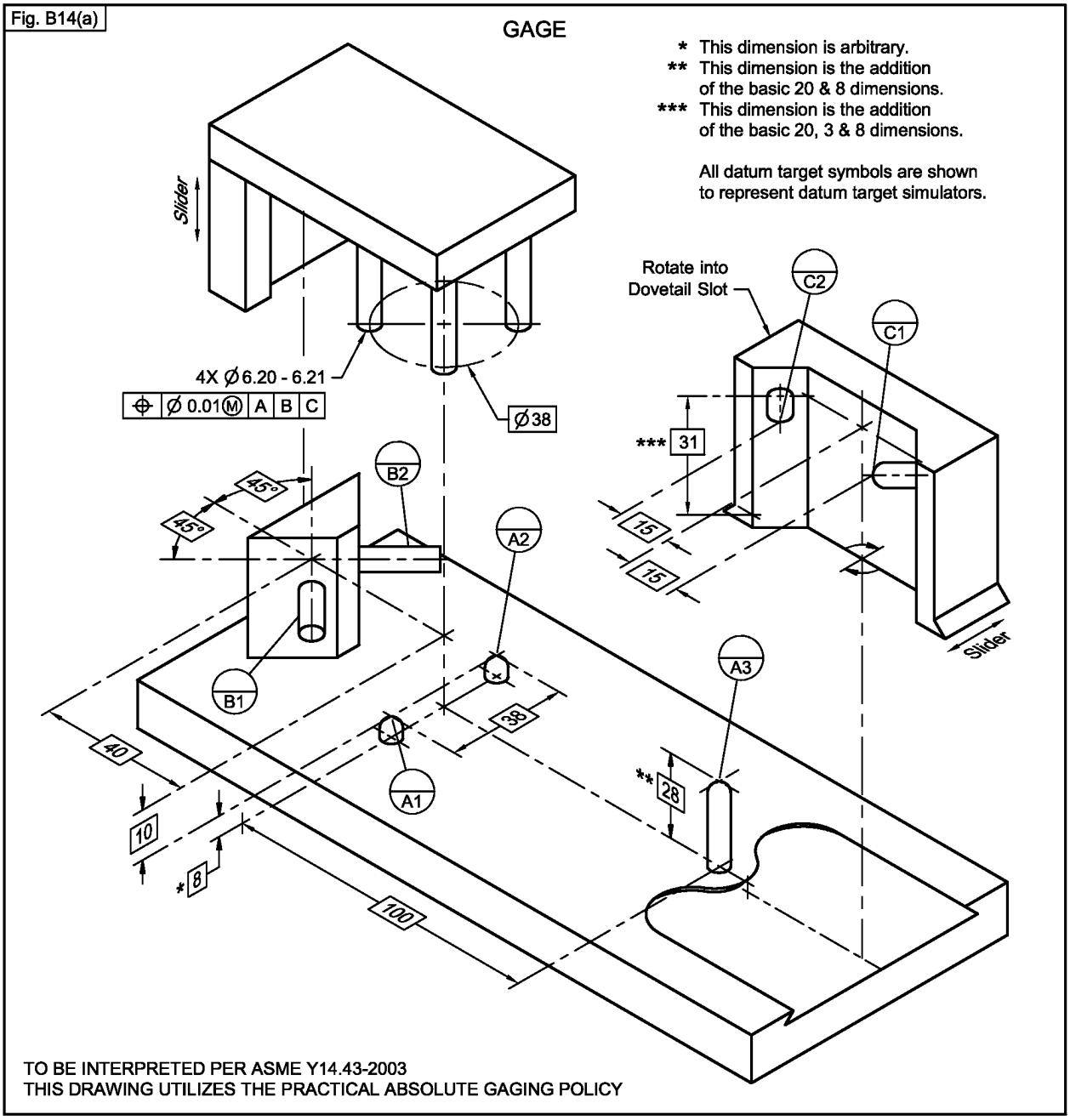


Fig. B14 Equalizing Datums (Cont'd)

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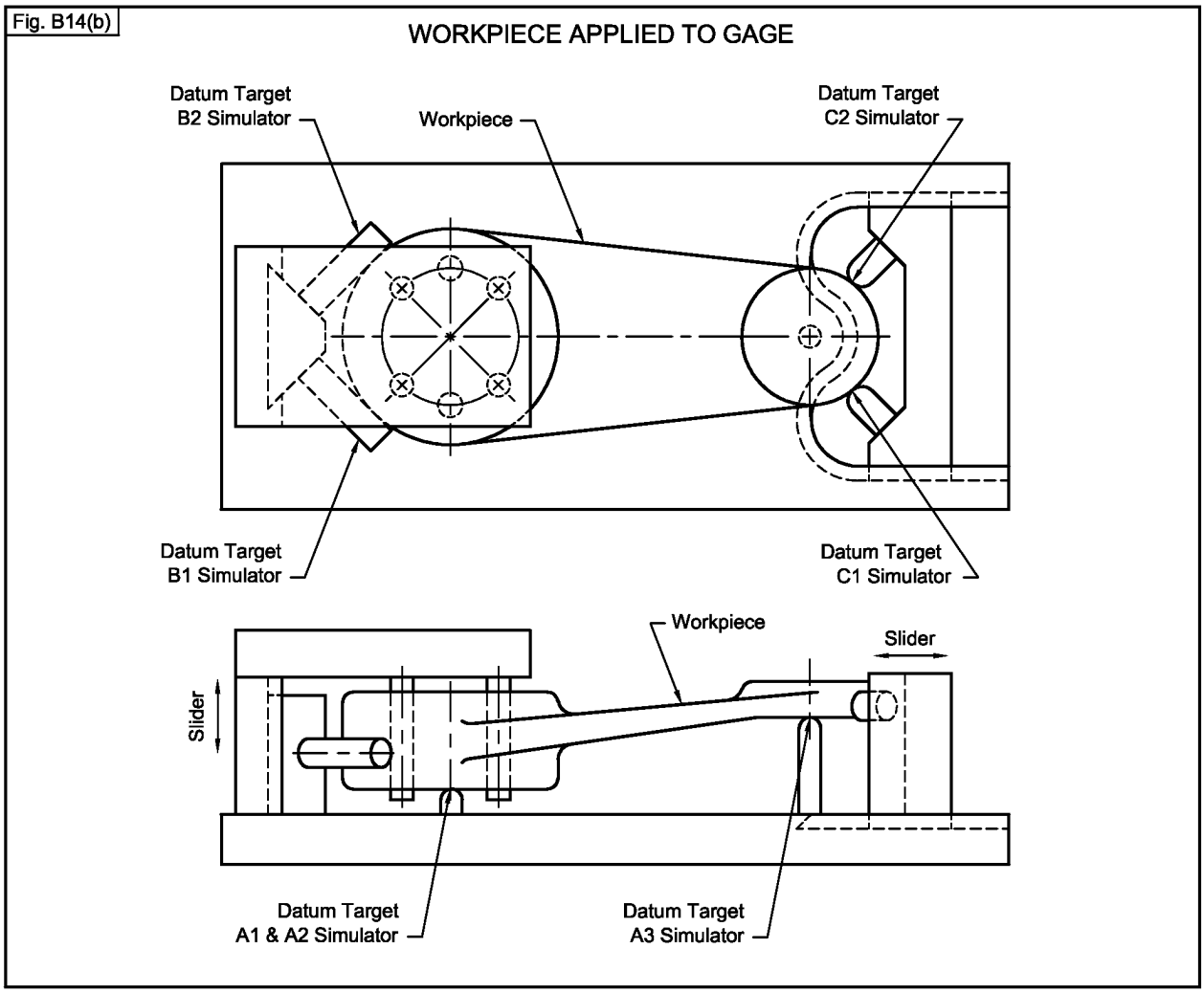


Fig. B14 Equalizing Datums (Cont'd)

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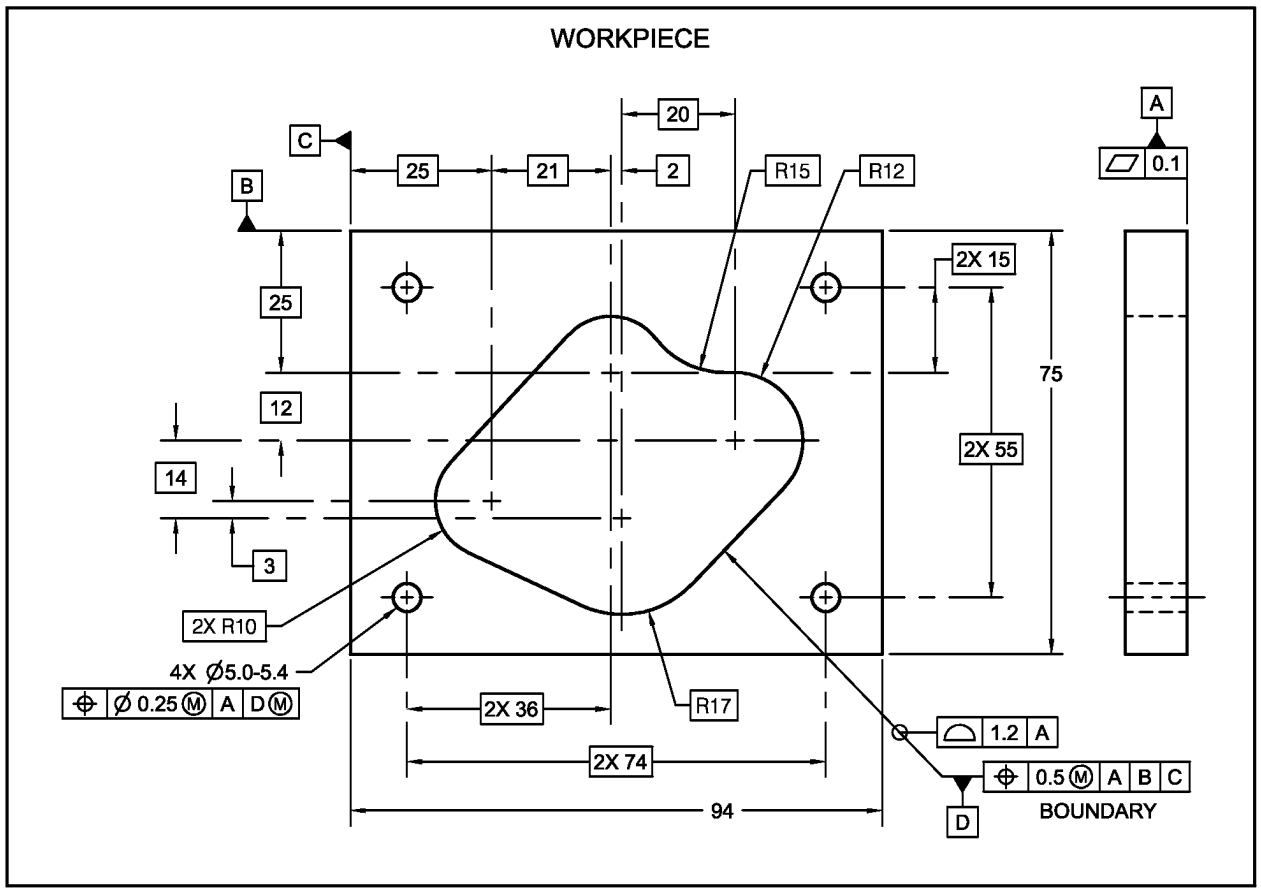
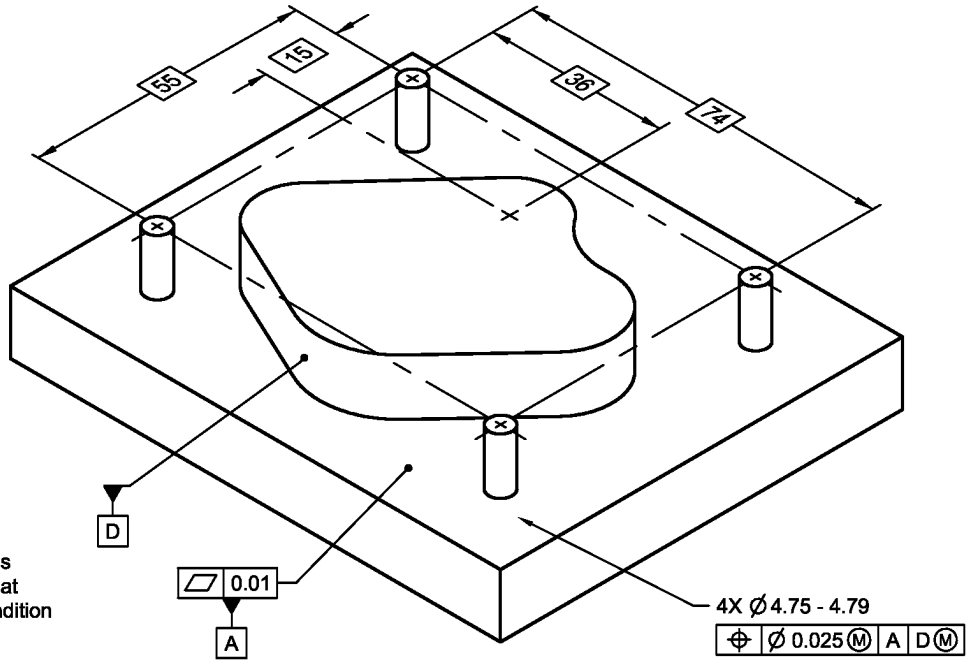


Fig. B15 Irregular Closed Feature Used as a Datum Feature

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Fig. B15(a)

GAGE



Datum D is produced at virtual condition relative to Datum A.

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Fig. B15(b)

WORKPIECE APPLIED TO GAGE

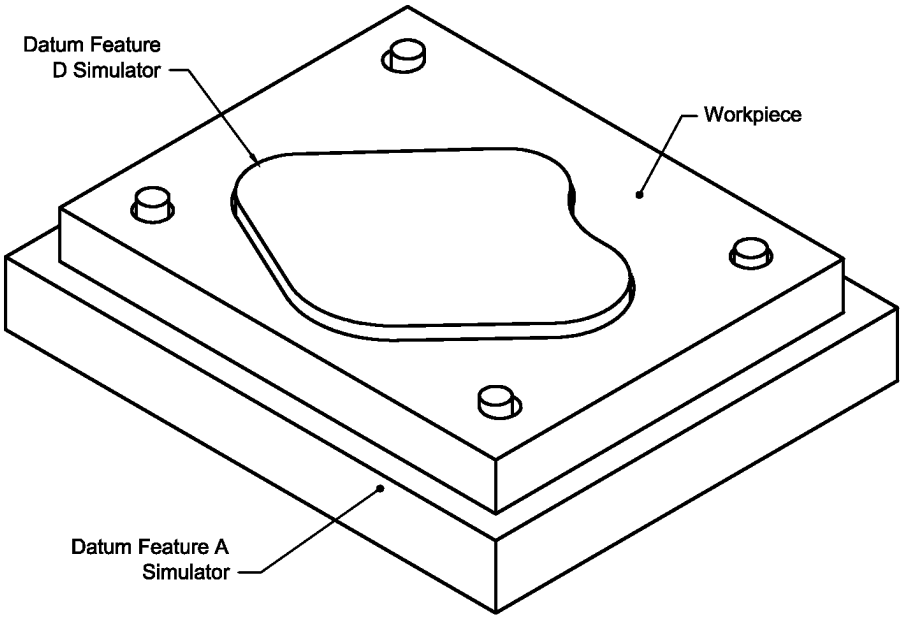


Fig. B15 Irregular Closed Feature Used as a Datum Feature (Cont'd)

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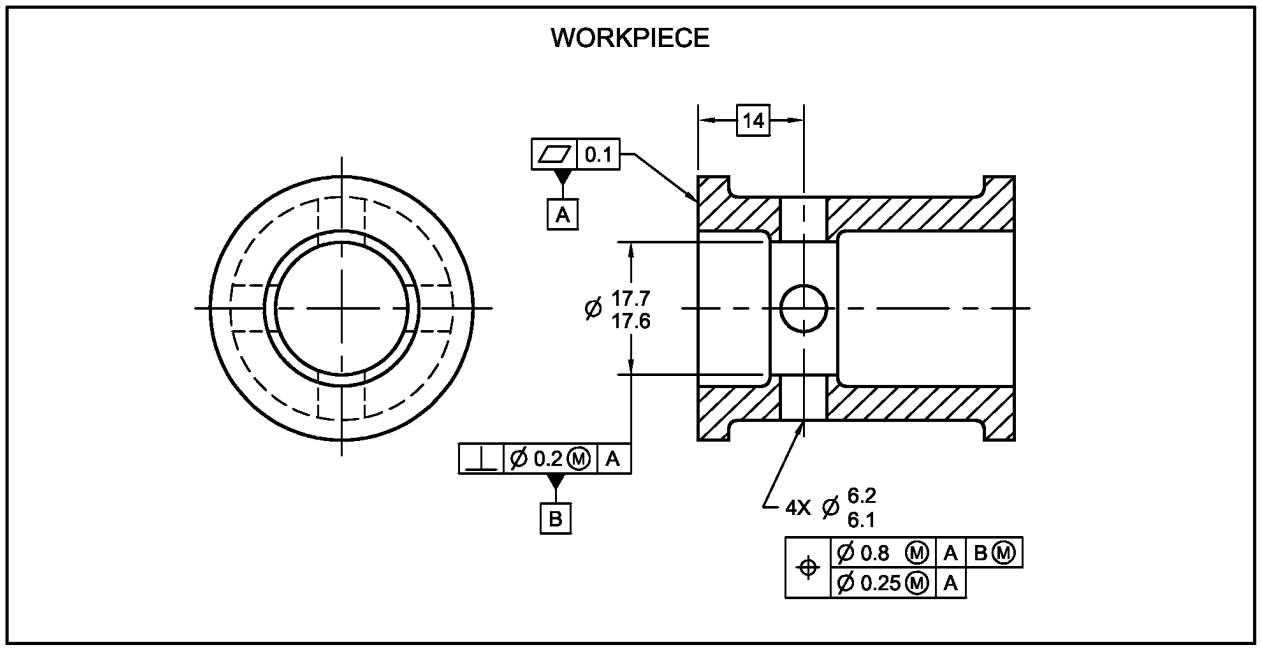
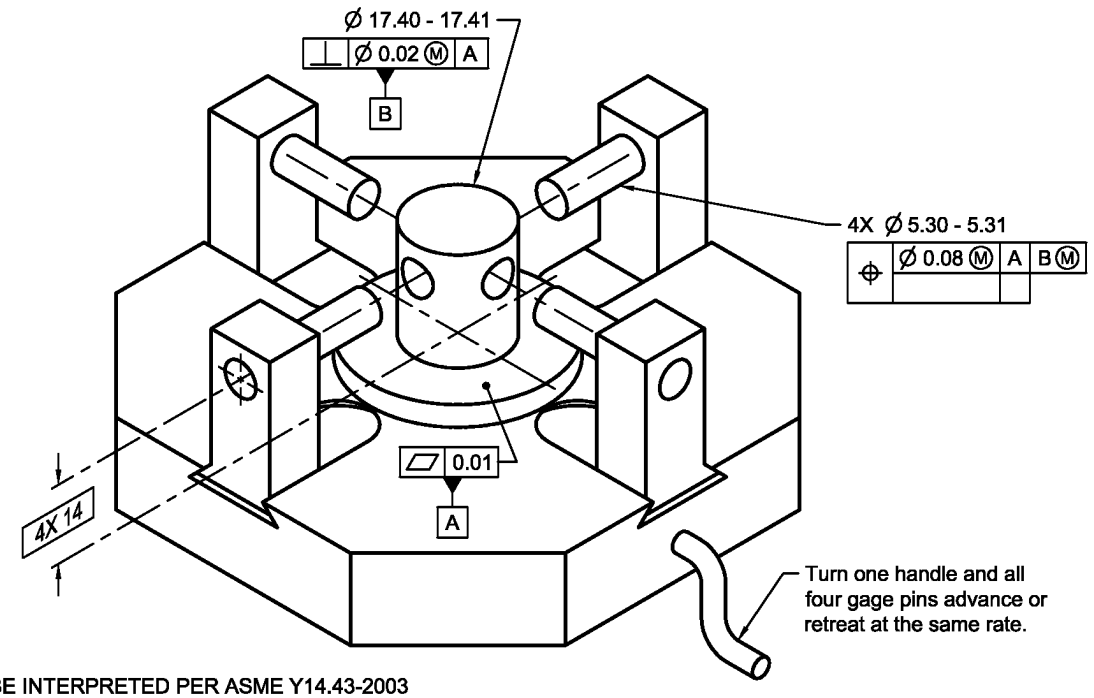


Fig. B16 Radial Hole Pattern Located by Composite Position

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Fig. B16(a)

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Fig. B16(b)

WORKPIECE APPLIED TO GAGE

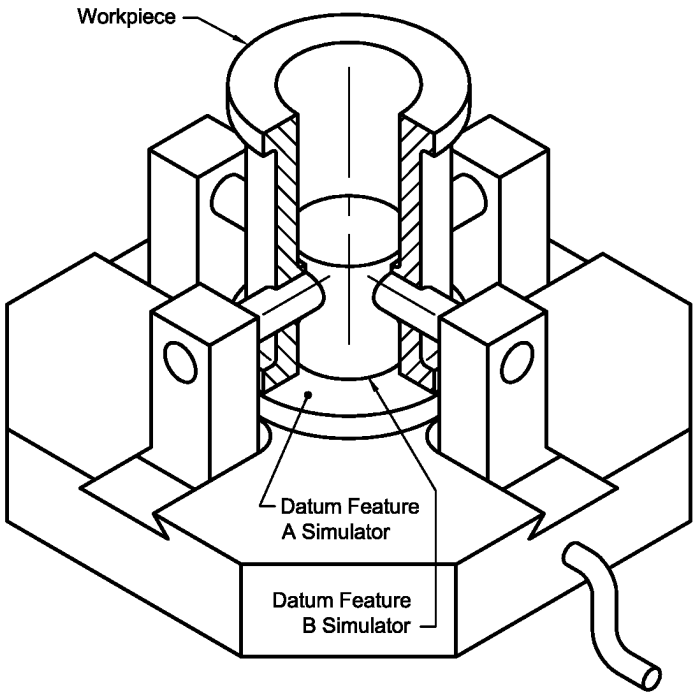
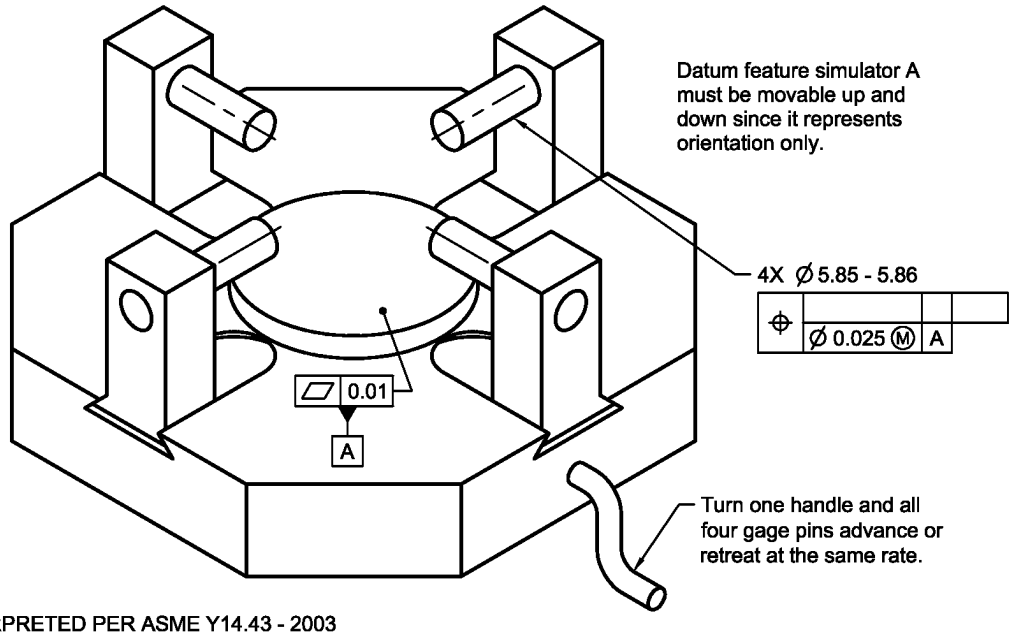


Fig. B16 Radial Hole Pattern Located by Composite Position (Cont'd)

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Fig. B16(c)

GAGE



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Fig. B16(d)

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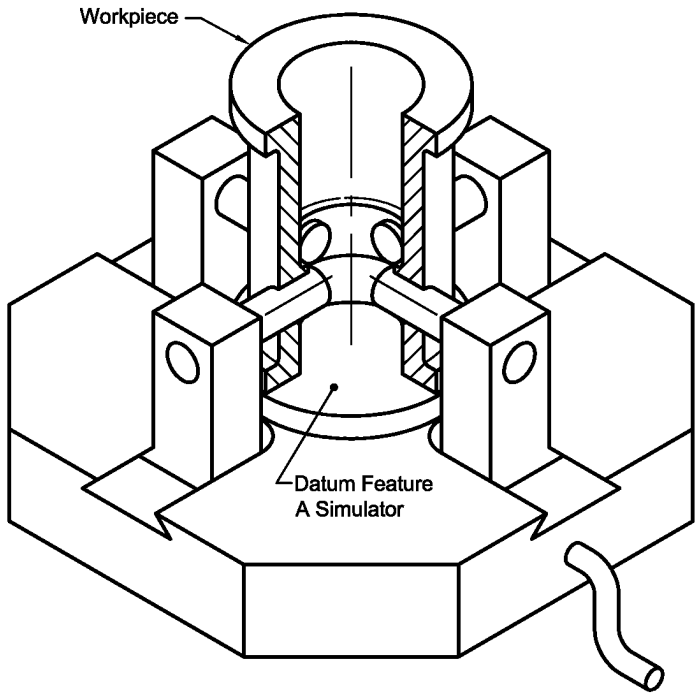


Fig. B16 Radial Hole Pattern Located by Composite Position (Cont'd)

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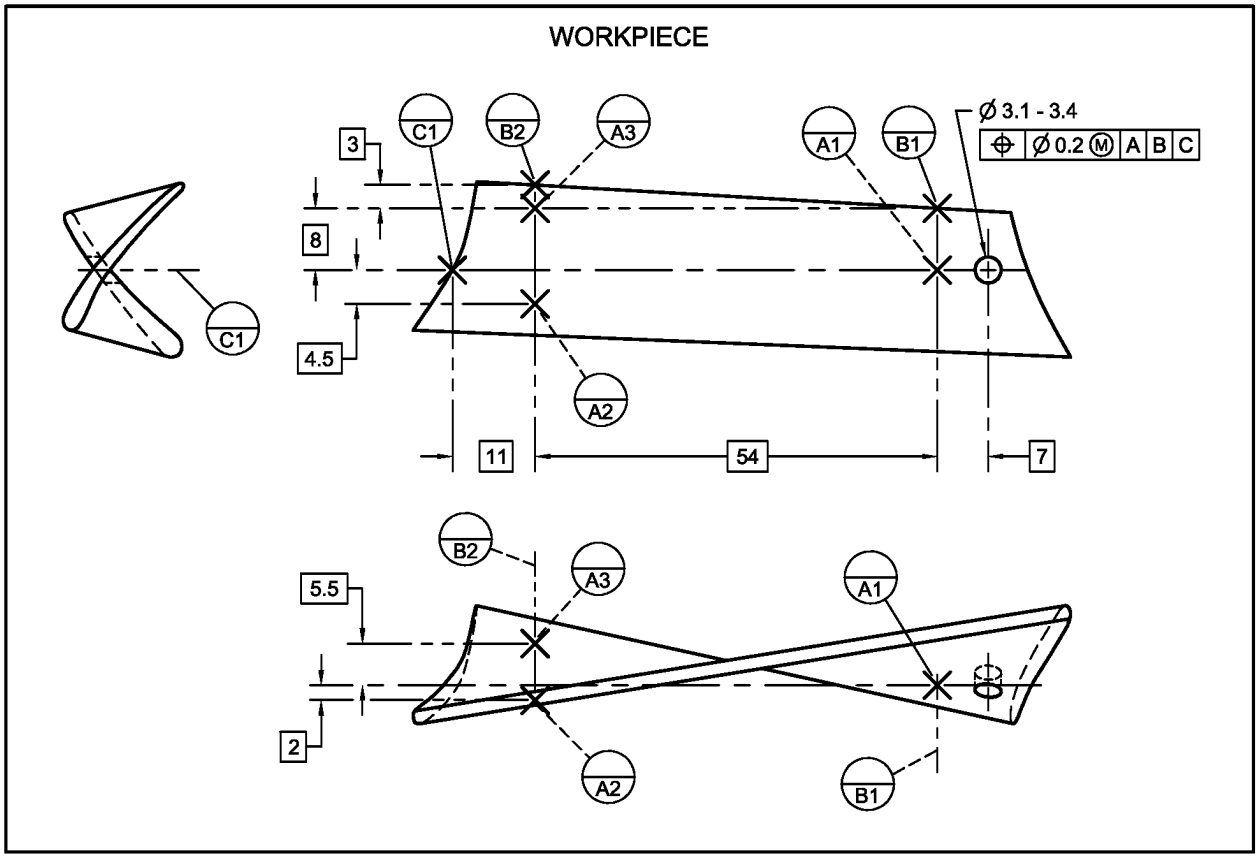
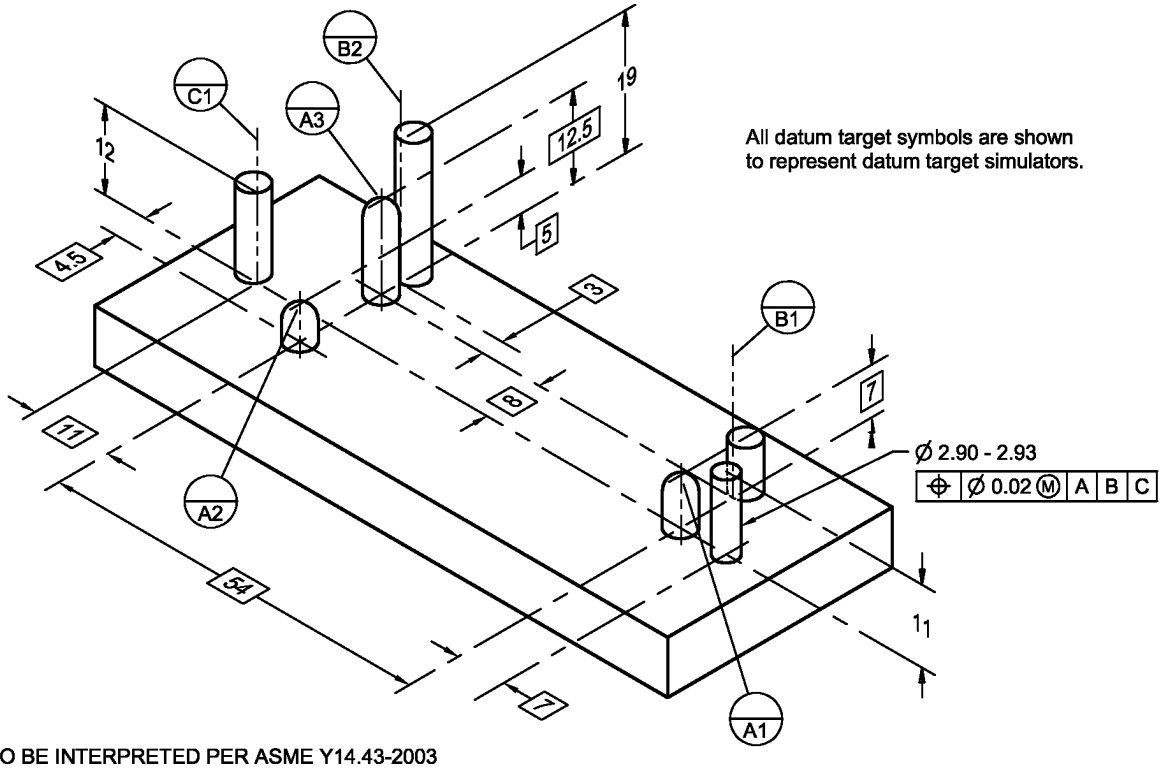


Fig. B17 Datum Targets on a Complex Part

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Fig. B17(a)

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Fig. B17(b)

WORKPIECE APPLIED TO GAGE

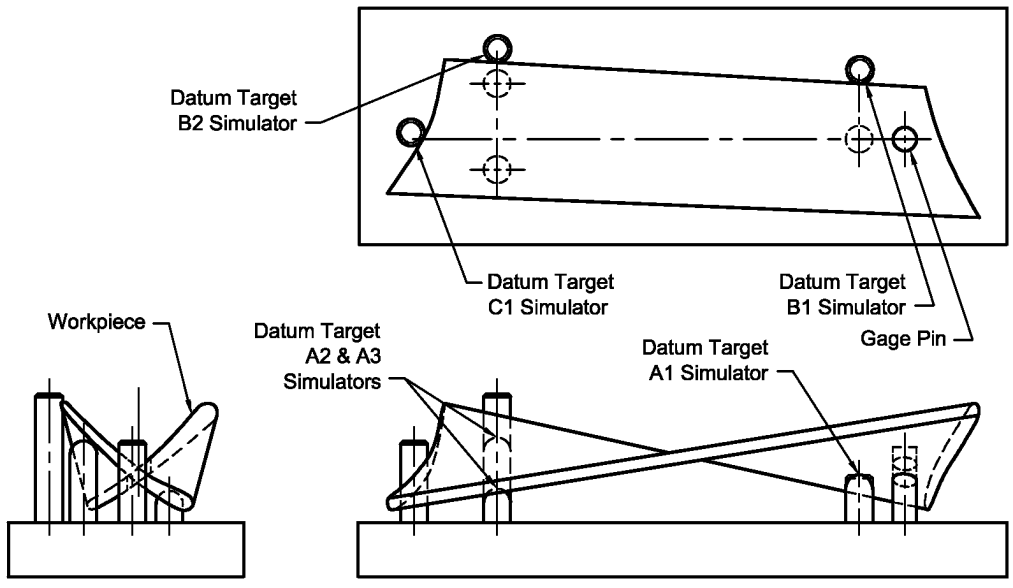


Fig. B17 Datum Targets on a Complex Part (Cont'd)

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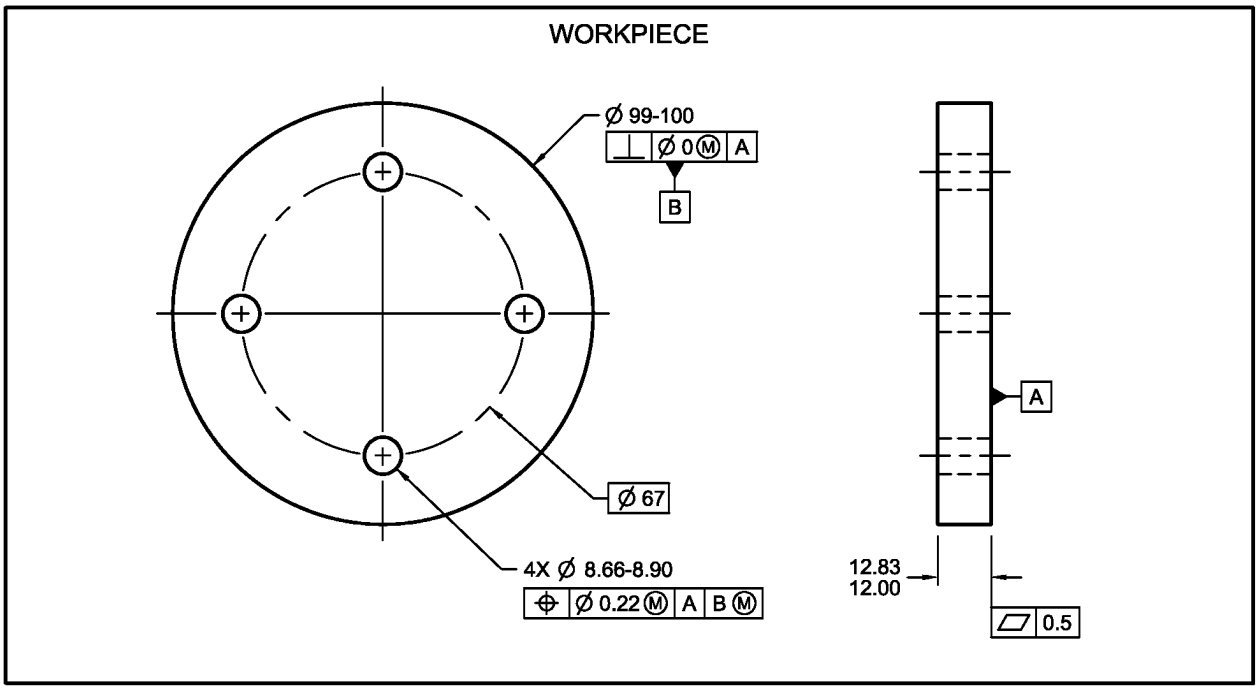


Fig. B18 Pushpin Gages for Part Clearance Holes

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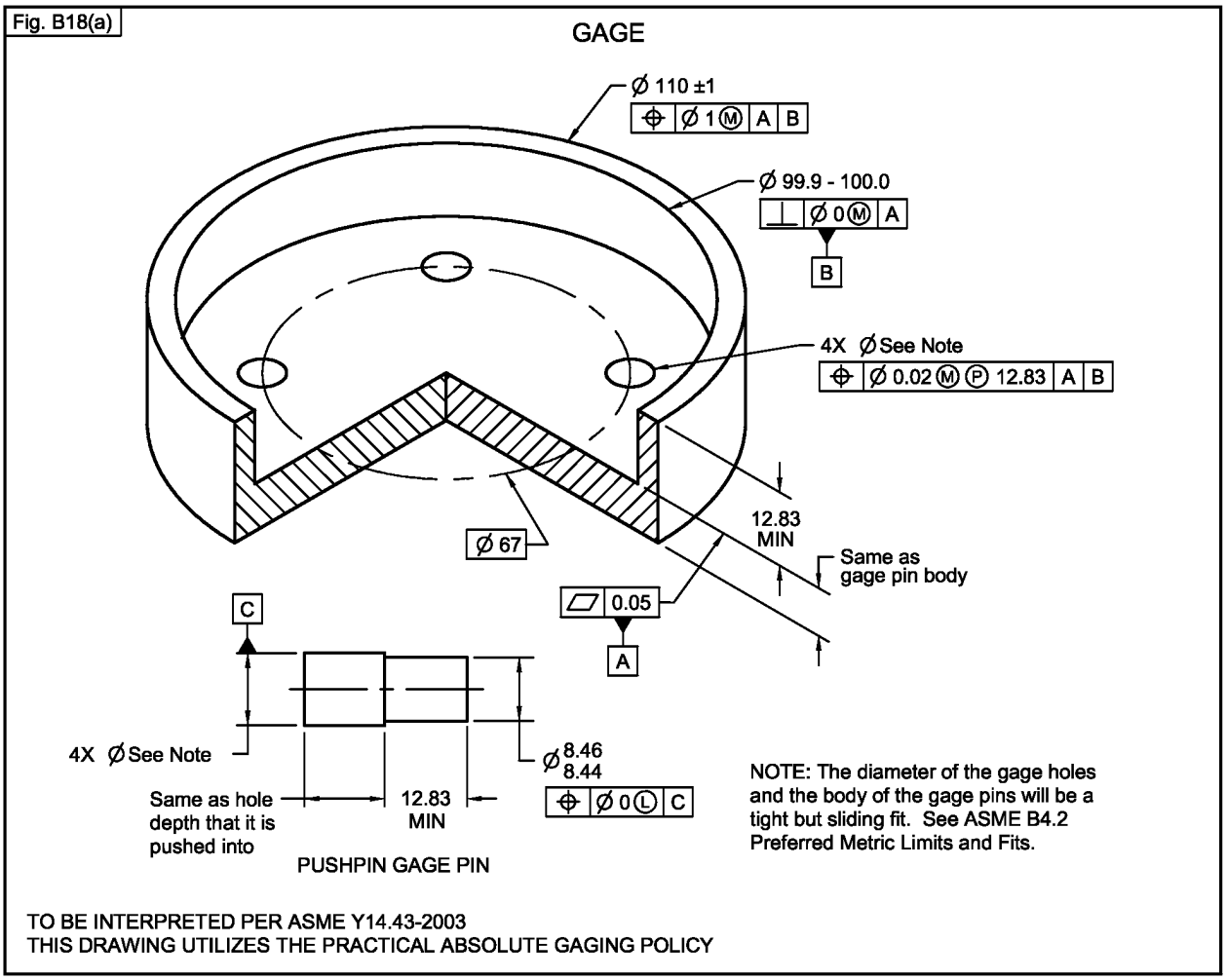


Fig. B18 Pushpin Gages for Part Clearance Holes (Cont'd)

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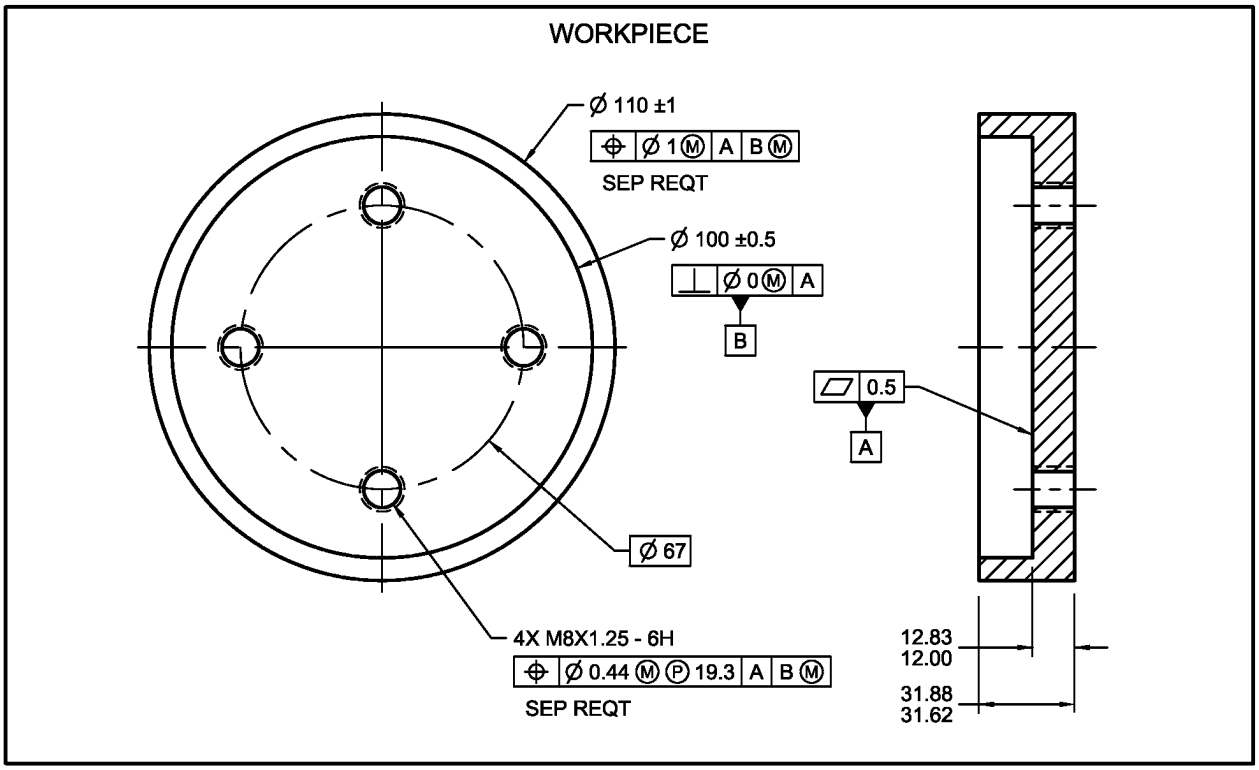


Fig. B19 Pushpin Gages for Part Threaded Holes

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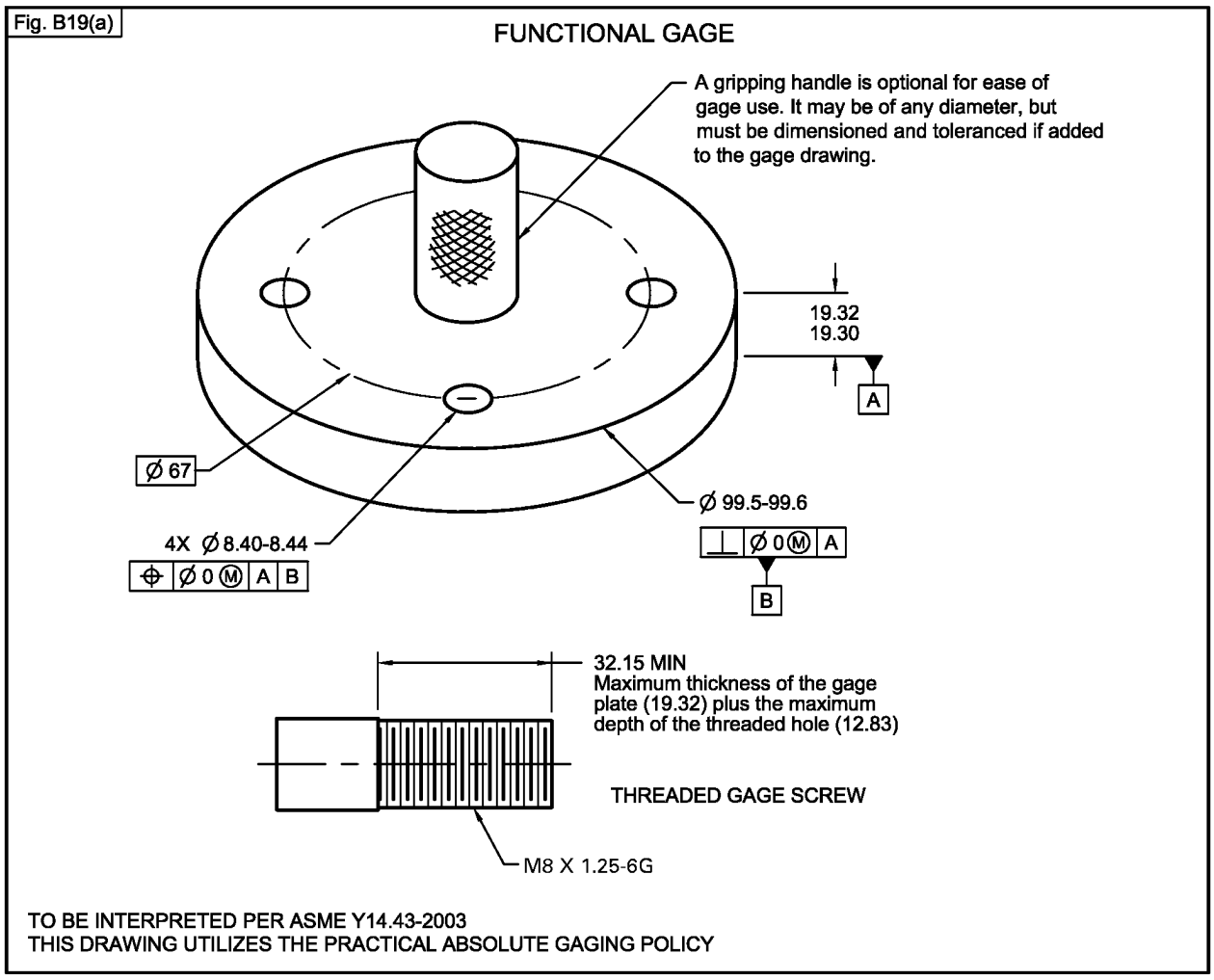
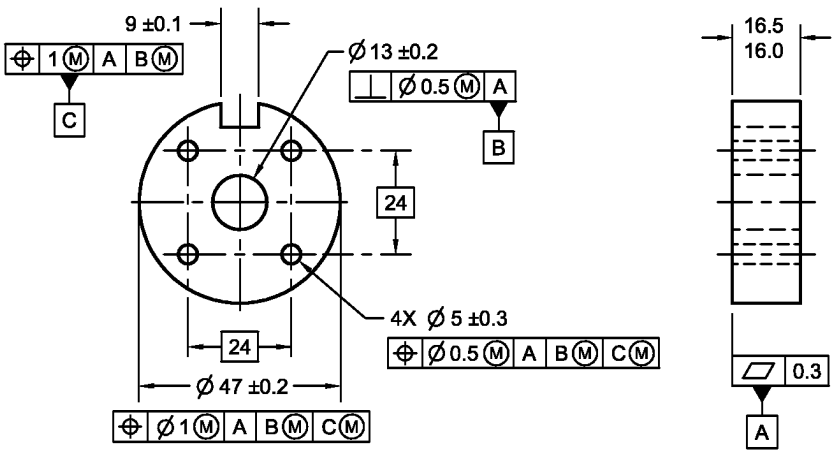


Fig. B19 Pushpin Gages for Part Threaded Holes (Cont'd)

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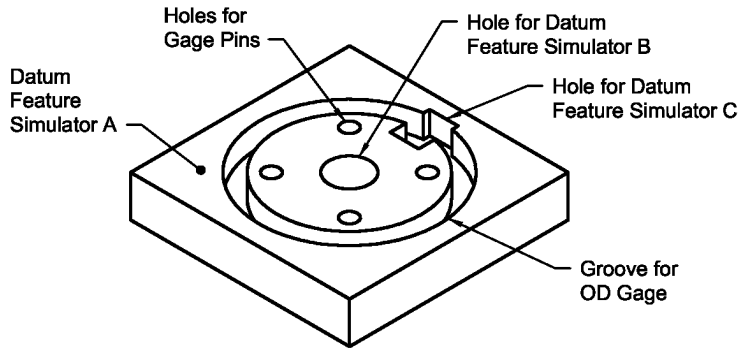
The Primary Datum Feature is a flat surface, the Secondary Datum Feature is a cylindrical feature of size, and the Tertiary Datum Feature is a width feature of size. In this example the keyway is used as Datum Feature C. The part is staged against Datum Feature Simulator A and over Datum Feature Simulators 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 MMC and C at MMC.

Fig. B20 Sequential Gaging

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Fig. B20(a)

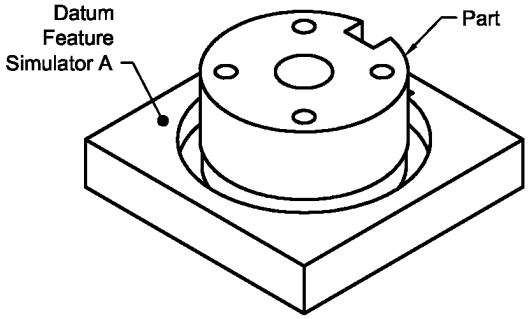
GAGE BODY



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

Fig. B20(b)

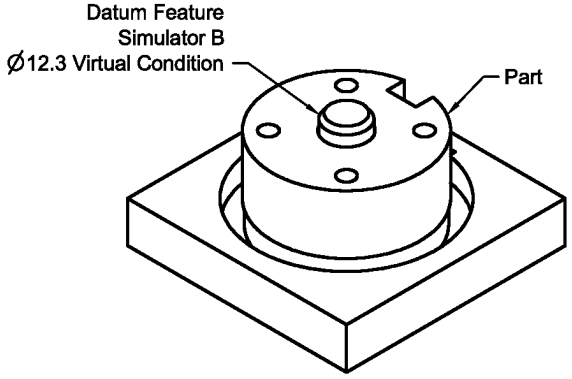
WORKPIECE APPLIED TO GAGE



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. B20(c)

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 Ø12.3 Virtual Condition Simulator.

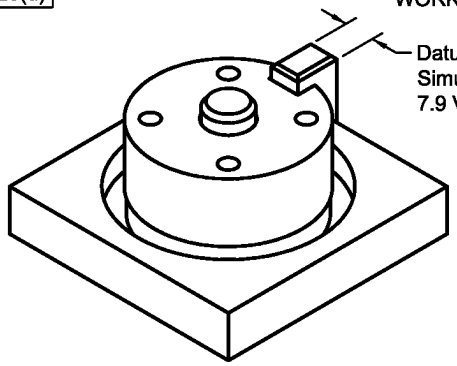
Fig. B20 Sequential Gaging (Cont'd)

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Fig. B20(d)

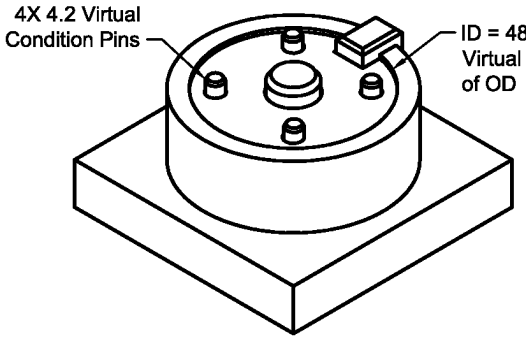
WORKPIECE APPLIED TO GAGE



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. B20(e)

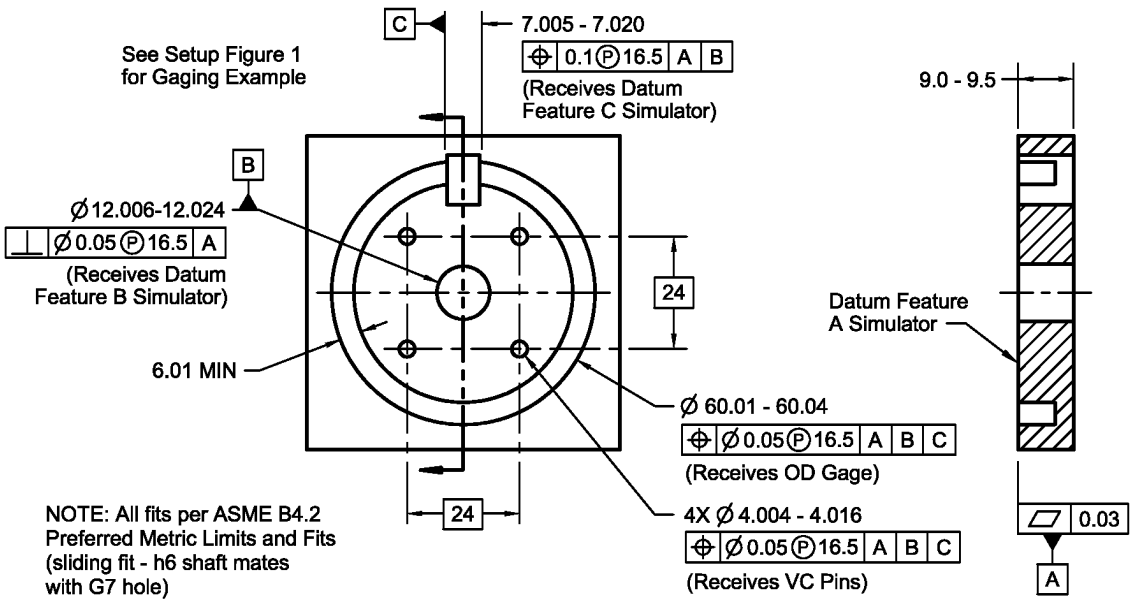
WORKPIECE APPLIED TO GAGE



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 MMC, and C at MMC. The size of Datum Feature B, Datum Feature C, the holes, and the OD must be verified separately.

Fig. B20(f)

GAGE BASE



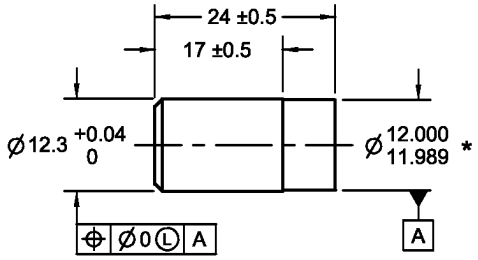
Datum Feature A on the Gage is the simulator for Datum Feature A on the part. The Gage also contains receivers (holes and slots) for pins that simulate Datum Features B and C on the part as well as receivers for the Virtual Condition pins and OD Gage. Gage feature tolerances are 10% of the associated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

Fig. B20 Sequential Gaging (Cont'd)

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Fig. B20(g)

DATUM FEATURE B SIMULATOR

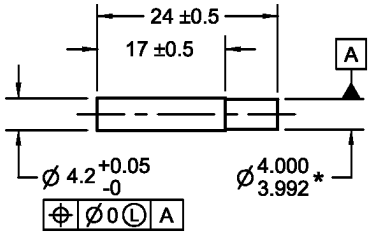


The Ø12.3 cylinder is the Virtual Condition Simulator for Datum Feature B of the part.

See Fig. B20(c) for application.

Fig. B20(h)

HOLE GAGE PINS

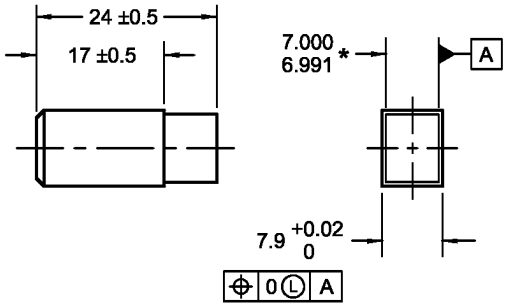


The Ø4.2 cylinder is the Virtual Condition Simulator for the 4X Ø4 ±0.3 holes on the part.

See Fig. B20(e) for application.

Fig. B20(i)

DATUM FEATURE C SIMULATOR

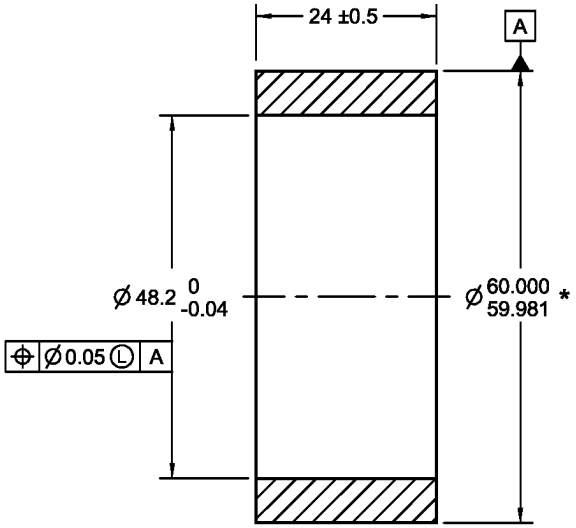


The 7.9 width is the Virtual Condition Simulator for Datum Feature C of the part.

See Fig. B20(d) for application.

Fig. B20(j)

OUTSIDE DIAMETER GAGE



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

See Fig. B20(e) for application.

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

Fig. B20 Sequential Gaging (Cont'd)

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NONMANDATORY APPENDIX C
REGARDLESS OF FEATURE SIZE

C1 RFS GAGING

Regardless of feature size (RFS) is a term used to indicate that a geometric tolerance or datum reference applies at any increment of the feature size within its size tolerance. As such, the geometric tolerance is independent of the finished size of the feature. RFS can be applied to the datum feature surfaces and to the 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 datum feature. Fixed-size elements are not appropriate for ascertaining the compliance of controlled features. Therefore, when a geometric tolerance is independent of feature size, the design frequently uses dial indicators or other devices capable of variables measurement.

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

The basic advantage of the RFS type of inspection equipment design is its ability to perform a measurement accurately and independently of feature size variations. In some cases, RFS is the only functional inspection method. Gage designs for inspecting RFS callouts often employ dial indicators, which provide easy recalibration. Wear adjustments are an inherent part of the design. This ease of recalibration also provides an easy means of compensating for revisions in product size or tolerance requirements. When dial indicators or similar units are incorporated into the design, RFS inspection equipment can determine not only whether or not 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 can be a desirable tolerancing concept.

The disadvantage of the RFS concept 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 an RFS modifier, as this modifier does not allow use of fixed-size gaging elements.

(a) Gage Example With Both RFS and MMC References. See Fig. C1. This example shows a workpiece that has two rectangular size datum features referenced at RFS, with round considered features referenced at MMC. While the gage has a complex datum feature simulator for the RFS datums, it has a conventional set of fixed-size gaging 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 ability of assembling the feature relationship. In Fig. C1, sketches (a) and (b) show the gage and describe its features.

(b) Gage Example With All RFS References. See Fig. C2 (Fig. 5-60 of ASME Y14.5M-1994). This example shows a workpiece that has a single size datum feature and considered feature, both 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) In Fig. C2, sketch (b) shows the workpiece restrained to simulated datum features as specified by the workpiece shown in Fig. C2.

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 sketch (a).

Datum A feature of the workpiece makes contact on the datum A simulator. Clockwise rotation of the crank causes the 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 3. See sketch (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, which 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 Fig. C2, sketches (c) and (d) were taken from the gage shown in sketch (b). The dial indicator shall be set to zero using the

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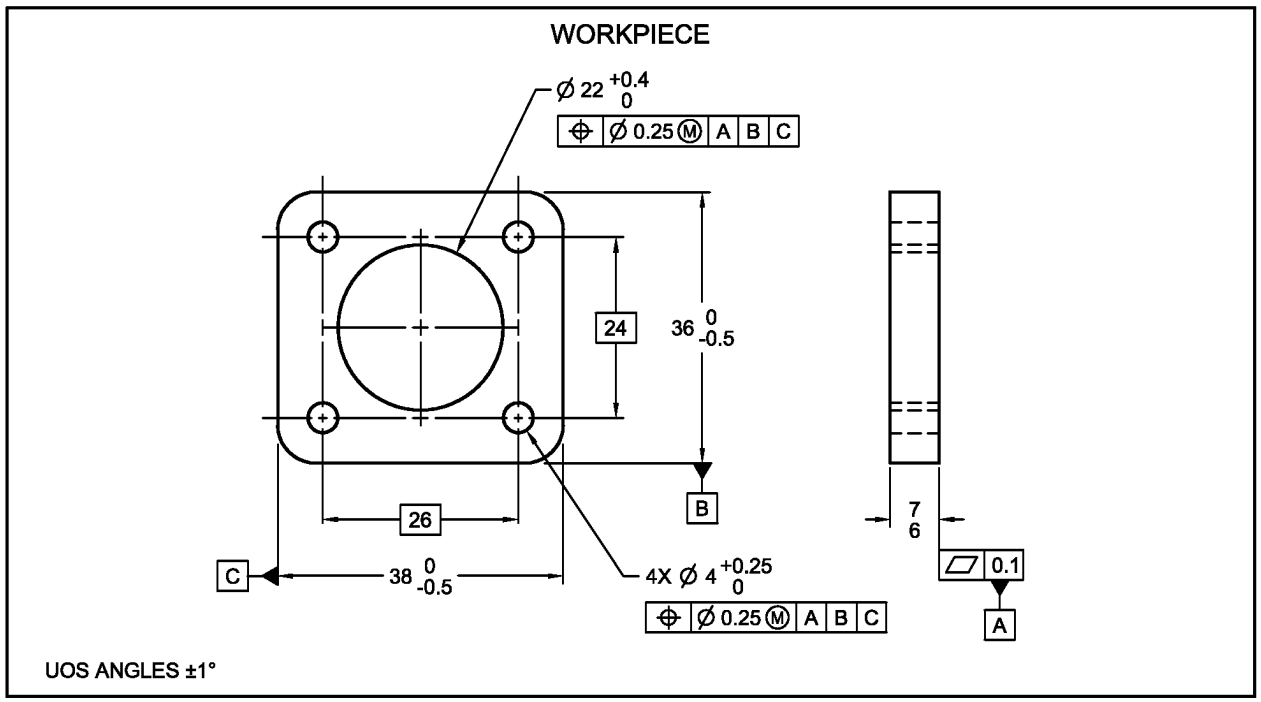


Fig. C1 Two Rectangular Size Datum Features at RFS

calibration gage shown in sketch (e) prior to taking any measurements.

Sketch (c) shows the slot at near-ideal location and orientation. Sketch (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 would be 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.

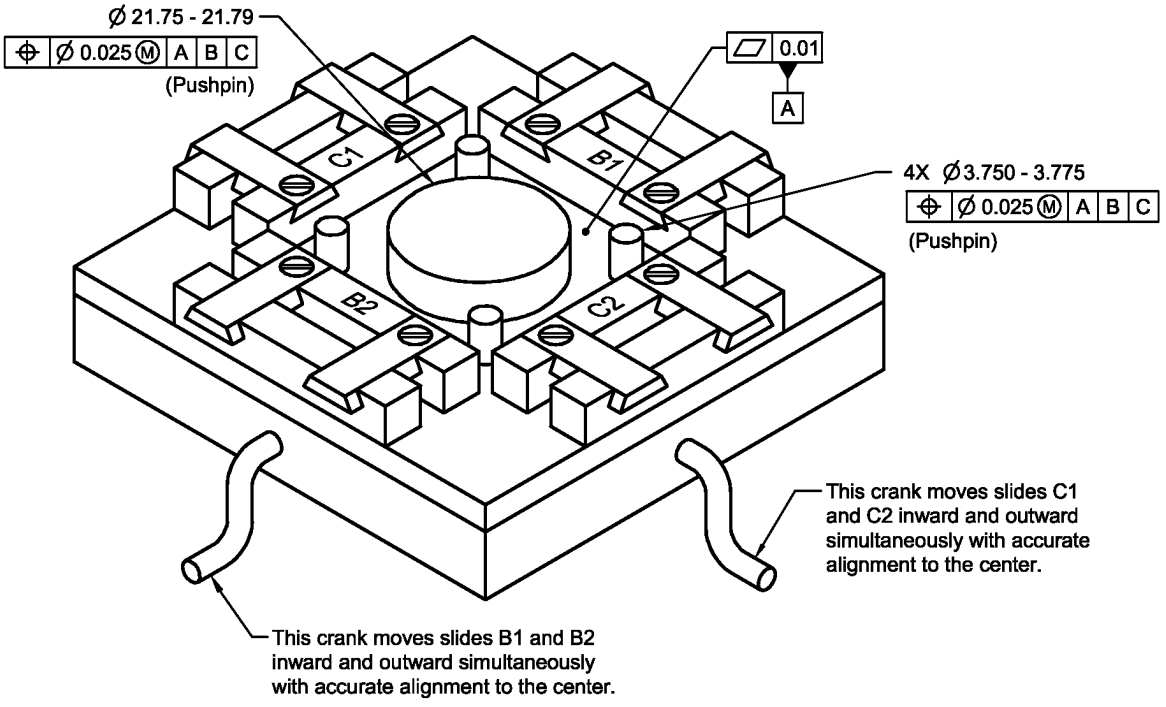
The guide block for position 3 is brought into contact with the surface of the workpiece. The dial indicator is inserted into the inspection bore and the dog-legged inspection probe contacts the expanding block with the knife edge of the probe on the same plane as the contact surface of the workpiece. 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 C2, sketch (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 in Fig. C2. Checking the various lengths of the slots would add 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 sketch (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.

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Fig. C1(a)

GAGE WITH PUSHPINS INSERTED



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Fig. C1(b)

WORKPIECE APPLIED TO GAGE

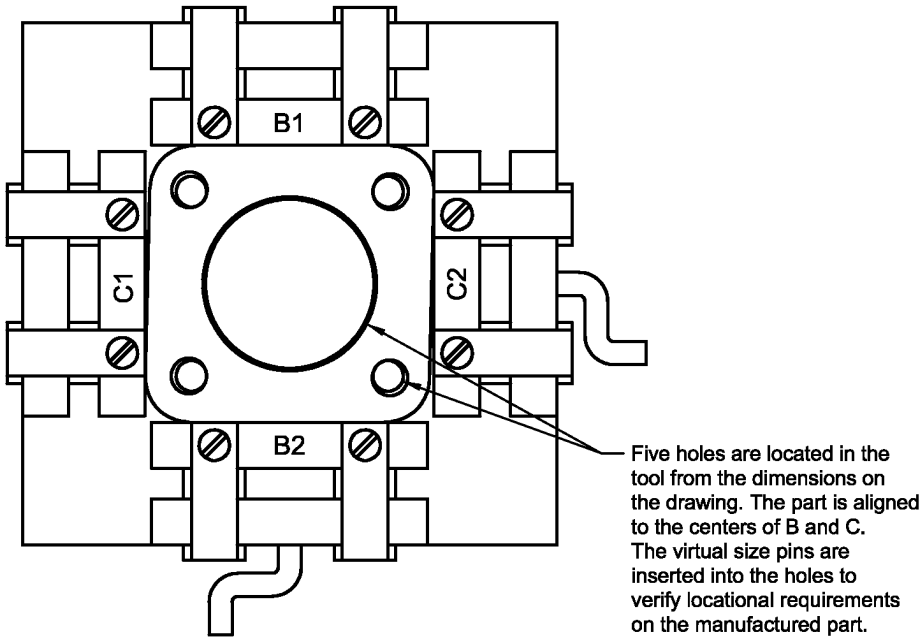


Fig. C1 Two Rectangular Size Datum Features at RFS (Cont'd)

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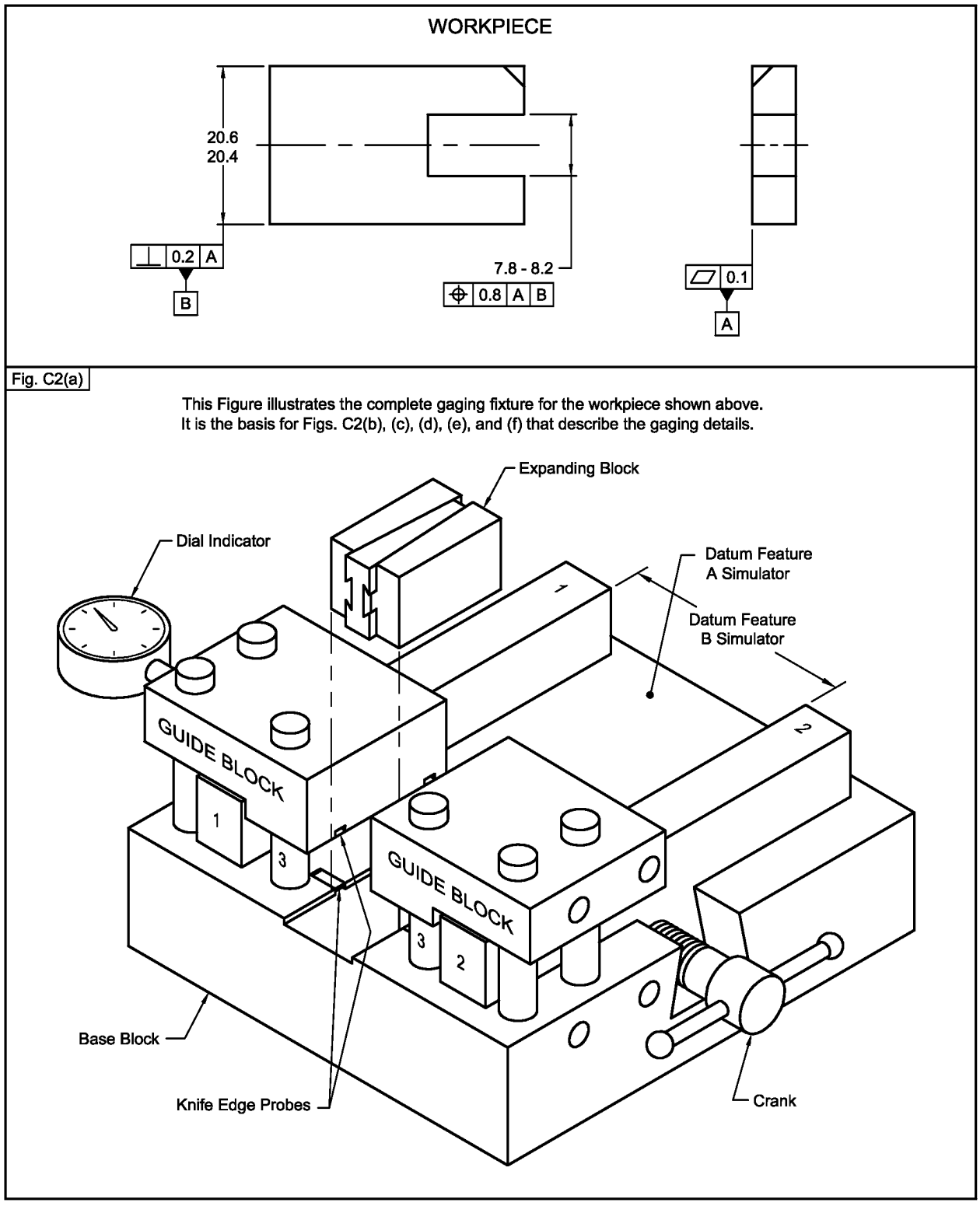


Fig. C2 Rectangular Size Feature at RFS

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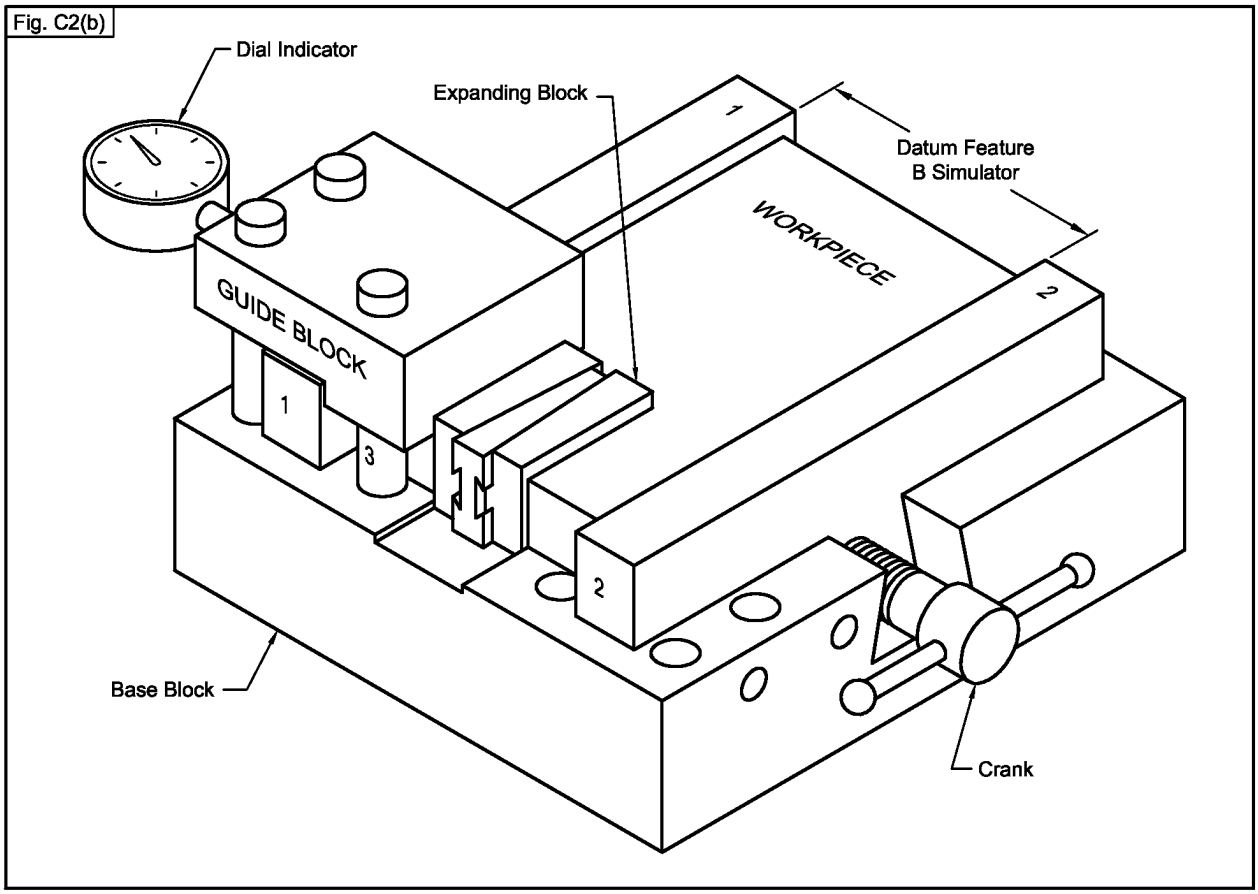


Fig. C2 Rectangular Size Feature at RFS (Cont'd)

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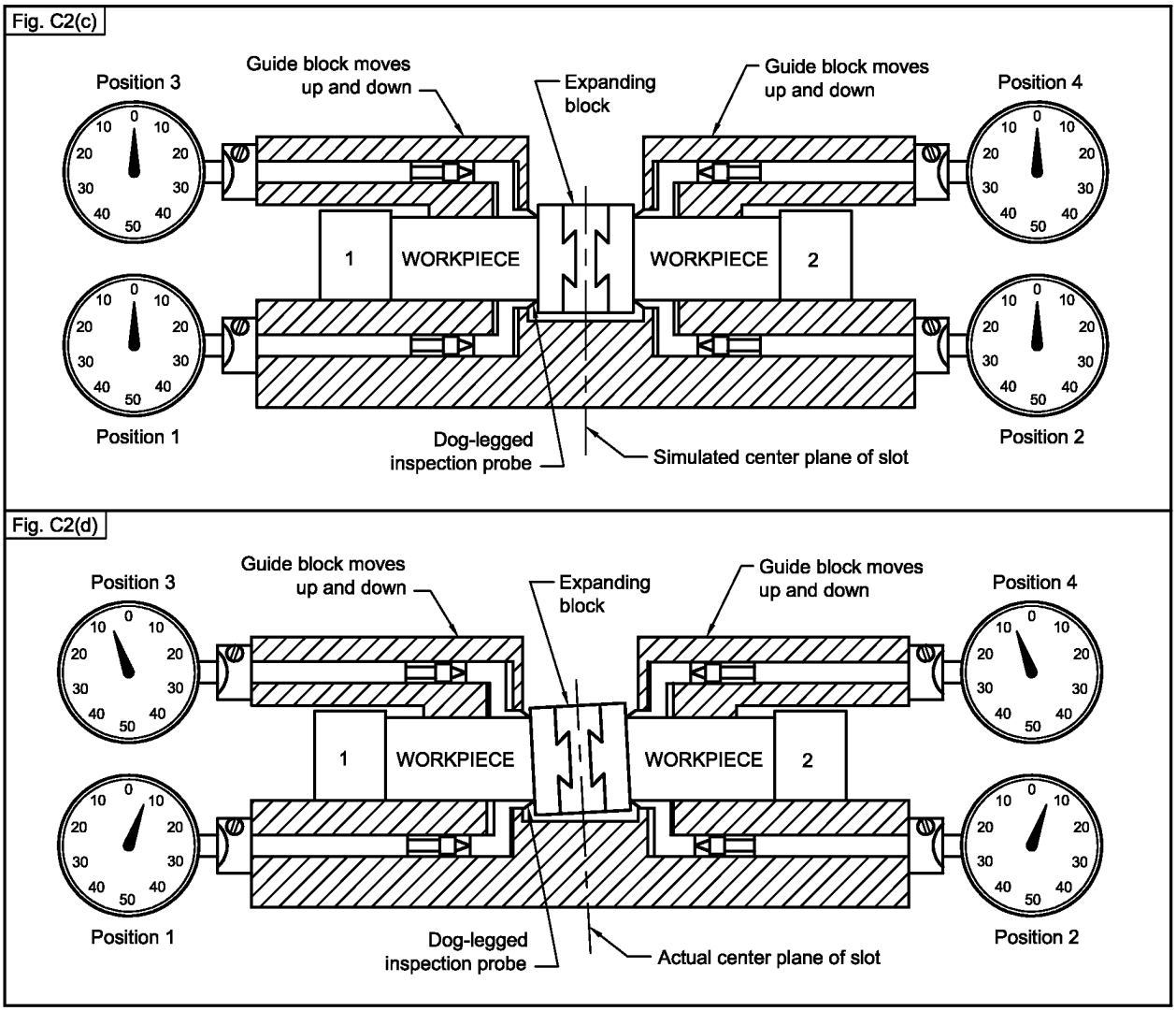
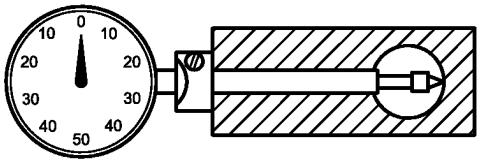


Fig. C2 Rectangular Size Feature at RFS (Cont'd)

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Fig. C2(e)



The dial indicator calibration gage used to zero the indicator is built into the base block.

Fig. C2(f)

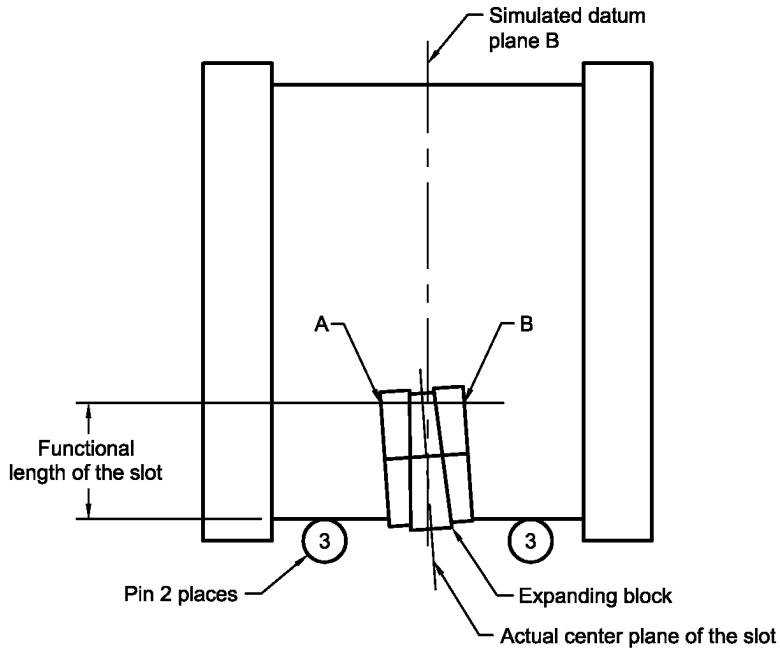


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