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DEPARTMENT OF DEFENSE
HANDBOOK

TOLERANCES FOR INVESTMENT CASTINGS

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FOREWORD

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

2. This handbook is for guidance only. This handbook cannot be cited as a requirement. If it is, the contractor does not have to comply.

3. This handbook compiles widely used as-cast tolerances for investment castings. Variations from tolerance bands shown can be controlled by the casting source.

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

CONTENTS

CONTENTS

FIGURES PAGE

CONTENTS

FIGURES PAGE

TABLES PAGE

1. SCOPE

1.1 Scope. This handbook covers general tolerances applicable to ferrous and nonferrous as-cast investment castings.

1.2 Purpose. The purpose of this handbook is to provide design engineers with the tolerance capabilities of investment casting sources.

2. APPLICABLE DOCUMENTS

2.1 General. The documents listed below are not necessarily all of the documents referenced herein, but are the ones that are needed in order to fully understand the information provided by this handbook.

2.2 Non-Government publications. The following documents form a part of this handbook to the extent specified herein. Unless otherwise specified the issues of the documents which are DoD adopted are those listed in the latest issue of the Department of Defense Index of Specifications and Standards (DoDISS), and supplement thereto.

AMERICAN NATIONAL STANDARDS INSTITUTE (ANSI)

ANSI/ASME B46.1	- Surface Texture (Surface Roughness, Waviness, and Lay) (DoD Adopted).

(Application for copies should be addressed to the American National Standards Institute, 11 West 42nd Street, New York, NY 10036.)

SOCIETY OF AUTOMOTIVE ENGINEERS, INC. (SAE)

SAE AMS 4640	- Aluminum Bronze Bars, Rods, Shapes, Tubes, and Forgings 81.5 Cu - 10.0 A1 - 4.8 Ni - 3.0 Fe Annealed (DoD Adopted).
SAE J448	- Surface Texture, Standard.
SAE J449	- Surface Texture Control, Recommended Practice.

(Application for copies should be addressed to the Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, PA 15096.)

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

3. DEFINITIONS

3.1 Definitions. Definitions relating to investment castings not shown here may be found in the reference documents.

3.1.1 Draft. (1) The angle or taper on the surface of a die or the parts made with it which facilitates removal of the work. (2) Taper put on the surface of a pattern so that it can be successfully withdrawn from the mold.

3.1.2 Gate (ingate). The portion of the runner in a mold through which molten metal enters the mold cavity. Sometimes the generic term is applied to the entire network of connecting channels which conduct metal into the mold cavity.

3.1.3 Investment casting. Investment casting involves pouring metal into a mold produced by surrounding (investing) an expendable pattern with a refractory slurry that sets at room temperature. After this, the wax, plastic, or frozen mercury pattern is removed through the use of heat. This procedure is also known as precision casting or the lost wax process.

3.1.4 Investment compound. A mixture of a graded refractory filler, a binder and a liquid vehicle used to make molds for investment castings.

3.1.5 Parting line. A plane on a pattern or a line on a casting corresponding to the separation between the two portions of a mold.

3.1.6 Pouring basin. A basin on top of a mold to receive the molten metal before it enters the sprue or downgate.

3.1.7 Riser. A reservoir of molten metal connected to the casting to provide additional metal to the casting, required as a result of shrinkage before and during solidification.

3.1.8 Runner. (1) A channel through which molten metal flows from one receptacle to another. (2) The portion of the gate assembly that connects the downgate, sprue or riser with the casting. (3) Parts of patterns and finished castings corresponding to the described portion of the gate assembly.

3.1.9 Runner box. A distribution box that divides the molten metal into several streams before it enters the mold cavity.

3.1.10 Sprue (downsprue, downgate). (1) The channel that connects the pouring basin with the runner. (2) Sometimes used to mean all gates, risers, runners, and similar scrap.

4. GENERAL

4.1 Dimensional variations and tolerances. Unless otherwise specified, all dimensions and tolerances are in inches. Tolerances outlined in this handbook are general for the investment casting industry. Some foundries, depending upon their practice, may be able to incorporate more restrictive tolerancing and as a result their unit cost would reflect this improvement.

4.1.1 Variables affecting as-cast dimensional tolerances.

a. Contraction of the wax, plastic, or frozen mercury pattern material within the pattern mold cavity after injection.
b. Variation in the temperature and resulting expansion during heating of the investment mold just before the casting is poured.
c. Expansion and contraction of the ceramic mold as the hot metal is poured and begins to solidify.
d. Contraction of the cooling metal in the mold.

5. DETAIL

5.1 Tolerances.

5.1.1 Gates and risers.

a. Surfaces that require machining:

1. Flat or round surfaces, maximum protrusion 0.000 to 0.010 inch above adjacent surfaces in the same plane.
2. Irregular surfaces, maximum protrusion 0.000 to 0.030 inch above adjacent surfaces.
3. Intersection of planes, 0.25 inch fillet radius, maximum.

b. Unmachined surfaces. Maximum protrusion of 0.000 to 0.005 inch above surfaces in the same plane but not to exceed the drawing tolerance envelope.

5.1.2 Dimensional.

a. For all investment cast blades and vanes use table I.

TABLE I. Dimensional tolerances for blades and vanes.

Dimension	Tolerance
up to 0.999	± 0.005
1.000 to 1.999	± 0.010
2.000 to 3.999	± 0.015
4.000 to 5.999	± 0.020
6.000 to 11.999	± 0.030
12.000 and over	± 0.045

b. For all investment castings other than blades and vanes use table II.
c. Dimensions from cast surfaces to finished surfaces are subject to the tolerances specified in table II.

TABLE II. Dimensional tolerances for general category investment castings.

Dimension	Tolerance
up to 1.999	± 0.010
2.000 to 3.999	± 0.015
4.000 to 5.999	± 0.020
6.000 to 11.999	± 0.030
12.000 and over	± 0.045

5.1.3 Flatness (bow or dish). These tolerances apply regardless of feature size providing the form tolerance zone falls entirely within the tolerance zone for size. Each configuration must be evaluated in relation to alloy, total surface area, and volume of casting (see table III).

TABLE III. Flatness tolerances (bow or dish - plate).

Length	Tolerance
up to 0.999	± 0.005
1.000 to 1.999	± 0.008
2.000 to 3.999	± 0.012
4.000 to 6.000	± 0.015
6.000 and over	± 0.020

5.1.4 Shafts (solid).

5.1.4.1 Straightness. Straightness is the deviation of the cast axis from the true axis. The tolerances shown in table IV apply regardless of feature size.

TABLE IV. Straightness tolerances.

Length	Tolerance
up to 1.999	± 0.010
2.000 to 5.999	± 0.020
6.000 and over	± 0.030

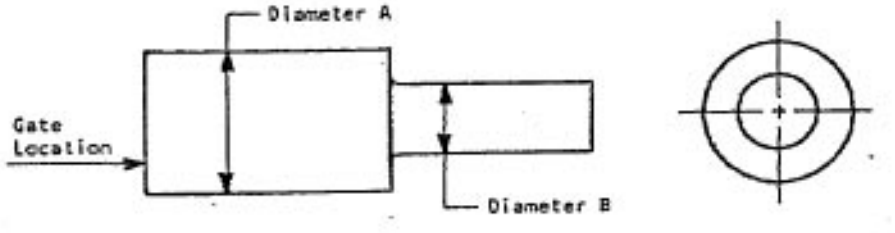
5.1.4.2 Roundness.

TABLE V. Out-of-roundness tolerances for solid shaft investment castings.

Diameter	TIR 1/
0.500	0.005
1.000	0.010
1.500	0.012
2.000	0.015

1/ Represents total indicator reading (TIR) and does not carry a plus (+) or minus (-) tolerance.

5.1.4.3 Concentricity. Limit is in relationship of diameters A and B. Gate location is a vital factor in maintaining concentricity (see figure 1).



Diameter A	Diameter B	TIR
0.500	0.250	0.005
1.000	0.500	0.008
2.000	1.000	0.012
2.500	1.250	0.015

FIGURE 1. Concentricity tolerances for solid shaft investment castings.

5.1.5 Angles. Tolerances for angles, as-cast, depend upon the location of angles in the casting. The tolerance may range from ± 0.5 degrees (°) for angles in well supported positions to ± 2° where inherent distortion could be expected (see figure 2).

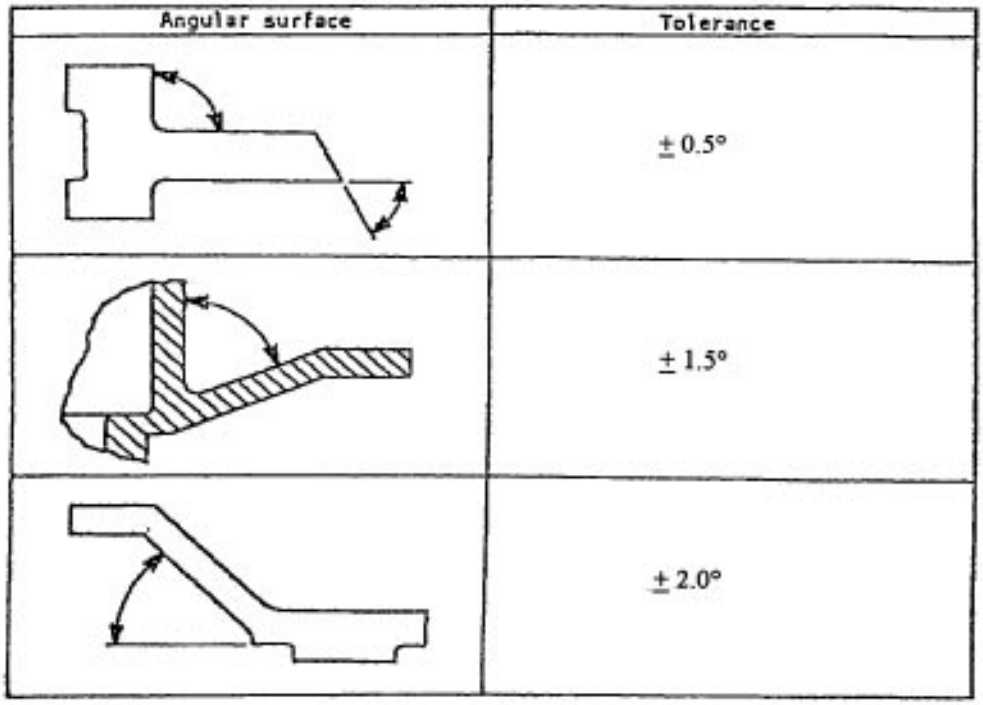


FIGURE 2. Tolerances for angular surfaces of as-cast investment castings.

5.1.6 Squareness (angular part). Control of tolerance on flat, angular-type parts is difficult. Redesigning incorporating brace reinforcements or straightening, if feasible and permitted, are alternative solutions. The amount of straightening should be a function of section thickness, variation, and support ribs. Where straightening is feasible and permitted, a tolerance of ± 0.5° should be maintained.

5.1.7 Surface texture (finish). The height of roughness should be expressed in microinches Arithmetic Average (μin. AA) as defined in SAE J448a, section 4.1. This value is used to describe surface texture of as-cast investment castings after cleaning in accordance with the engineering requirement, i.e., sand blast, and should be in accordance with values specified in table VI.

TABLE VI. Surface texture for as-cast and sand blasted investment castings. 1/

Material/product	Roughness (µin. AA)	Material/product	Roughness (µin. AA)
Airfoil contours	63	Cobalt-chromium alloy	100
Aluminum alloy	100	Magnesium alloy	100
Aluminum bronze 2/	100	Nickel base superalloy	125
Beryllium copper	100	Stainless, 300 series	125
Carbon steel	125	Stainless, 400 series	125

1/ Method of measuring and controlling surface texture should be in accordance with SAE J448 and SAE J449 respectively, or ANSI/ASME B46.1.
2/ SAE AMS 4640.

5.1.8 Draft. Draft is normally not specified except in special applications on deep perpendicular draws or in long untapered cored holes. The amount of draft required will depend upon the pattern material used, length (depth of draw), and wall thickness. The need for draft should be resolved between the casting source and engineering design. When required, draft should be specified in degrees or in taper per inch. A taper of 1° is considered acceptable in most instances (see figure 3).

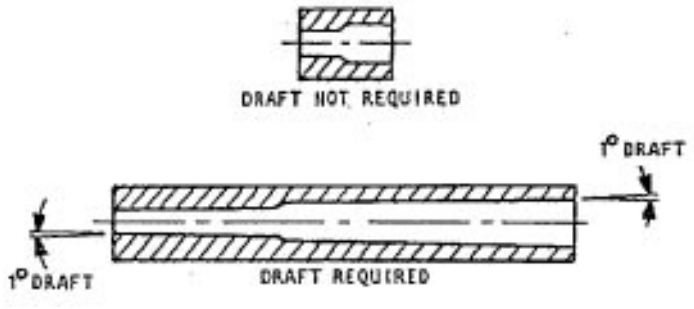
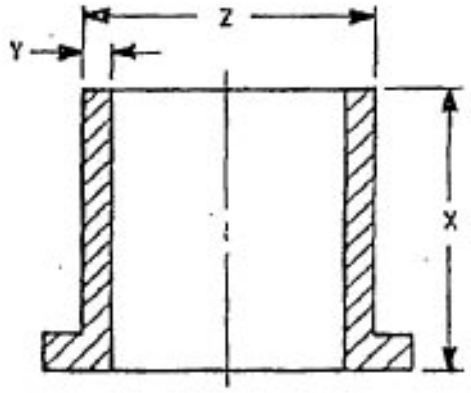


FIGURE 3. Examples of draft applications.

5.1.9 Wall thickness. Designing for minimum wall thickness depends upon:

a. Fluidity of the alloy and its ability to flow in the mold, i.e., a function of metal and mold temperature.
b. Solidification range of the alloy in relation to proper feeding of the section.
c. Surface area or exposed metal and feeding distance.

Minimum wall thickness for cored cavities are shown in figure 4.



X	Z	Y - minimum
0.250	0.125	0.030
0.500	0.250	0.040
0.750	0.375	0.050
1.000	0.500	0.060
1.250	0.750	0.060
1.500	1.000	0.060
2.000	1.500	0.060
2.500	1.750	0.060

FIGURE 4. Minimum wall thickness in relation to cored cavity for investment castings.

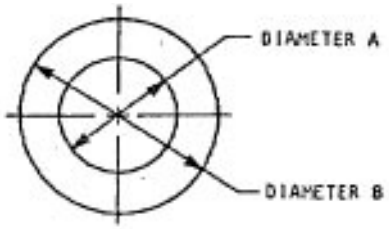
5.1.10 Radii and fillets. Sound casting design necessitates incorporating proper tolerancing of radii and fillets to minimize stress concentrations, tooling costs (internal coring), turbulence and wear, etc. Suggested minimum tolerance on all radii is ± 0.016 inch. Where smaller tolerances are absolutely necessary, see table VII.

TABLE VII. Radii and fillet tolerances for investment castings.

Radii	Minimum tolerance for fillet and external radii
0.031	± 0.004
0.062	± 0.004
0.125	± 0.004
0.250	± 0.004
0.500	± 0.005
1.000	± 0.005
over 1.000	± 0.005 inch/inch

5.1.11 Holes (cast or cored).

5.1.11.1 Concentricity. Limit in the relation of one diameter to another (see figure 5).



Diameter A	Diameter B	TIR
0.250	0.750	0.005
0.500	1.000	0.005
0.750	1.500	0.010
1.000	2.000	0.010

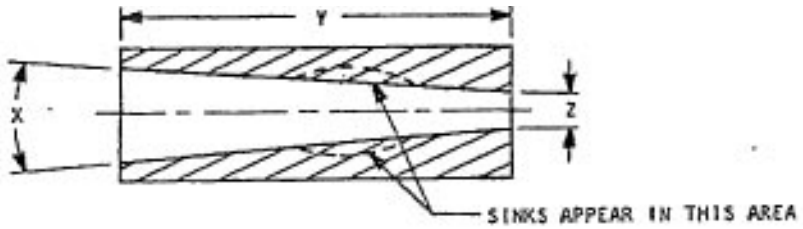
FIGURE 5. Concentricity tolerances for investment castings with holes.

5.1.11.2 Roundness. Holes, depending upon casting stresses, may be cast “egg-shaped” as indicated in table VIII.

TABLE VIII. Out-of-roundness tolerances for investment castings with holes.

Diameter	TIR
0.500	0.005
1.000	0.010
1.500	0.012
2.000	0.050

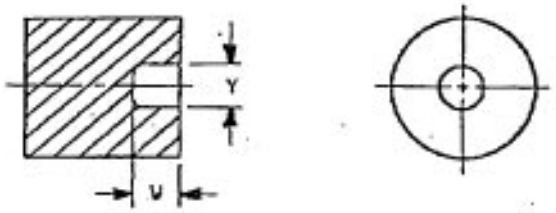
5.1.11.3 Tapered holes. Castings with tapered holes may, depending upon size, exhibit some shrinkage (sink) (see figure 6).



Z	Y	X	Tolerance for X
0.250	0.500	15°	± 0° 30'
0.500	0.750	30°	± 0° 30'
0.250	0.500	60°	± 0° 30'
0.500	0.750	90°	± 0° 45'
0.750	1.500	120°	± 1°

FIGURE 6. Angular tolerances for investment castings with tapered holes.

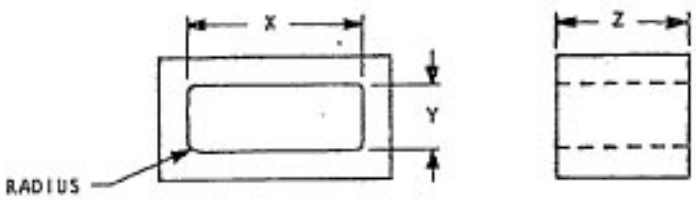
5.1.11.4 Blind holes. Blind holes are recommended for nonferrous alloys only. Blind holes can be cast in ferrous alloys, but no “rule of thumb” applies. See figure 7 for dimensional limits.



W - length	Y - minimum diameter	Draft
0.250	0.187	0°
0.500	0.250	0°
0.750	0.500	0°
1.000	0.625	0°
1.250	0.750	0° 15'
1.500	1.000	0° 15'
2.000	1.000	0° 15'
2.500	1.000	0° 15'

FIGURE 7. Blind hole limits for investment castings.

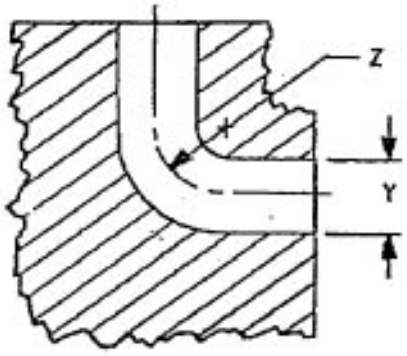
5.1.11.5 Rectangular holes. Tolerances for rectangular holes are shown in figure 8.



Radius	Z	X	Tolerance for X	Y	Tolerance for Y
0.016	0.125	0.250	±0.004	0.125	±0.003
0.031	0.250	0.500	±0.005	0.250	±0.004
0.063	0.125	0.750	±0.005	0.500	±0.005
0.063	0.250	1.000	±0.005	0.750	±0.005
0.063	0.500	0.500	±0.005	0.150	±0.004
0.063	1.000	0.500	±0.005	0.250	±0.004
0.125	2.000	2.500	±0.015	1.500	±0.010

FIGURE 8. Tolerances for investment castings with rectangular holes.

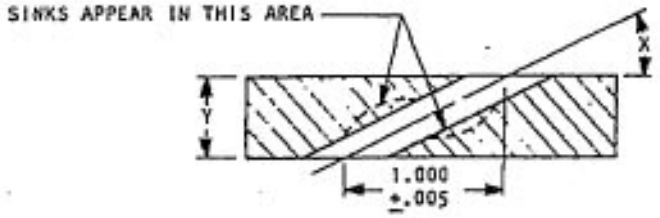
5.1.11.6 Curved holes. Size of opening and radius of curved passages take a different set of tolerances. Figure 9 covers the tolerances for the radius of a curve. See table II for tolerances applicable to openings.



Y	Z	Tolerance for Z
0.250	0.500	± 0.005
0.500	0.750	± 0.005
0.750	1.000	± 0.008
1.000	1.500	± 0.010
1.000	2.000	± 0.014
1.000	2.500	± 0.016
1.000	3.000	± 0.018

FIGURE 9. Tolerances for investment castings with curved holes.

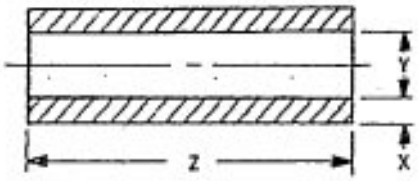
5.1.11.7 Angular cored holes. Tolerances for angular cored holes are shown in figure 10.



Y	X	Tolerance for X
0.250	15°	± 1°
0.500	30°	± 1°
1.000	45°	± 1°

FIGURE 10. Tolerances for investment castings with angular holes.

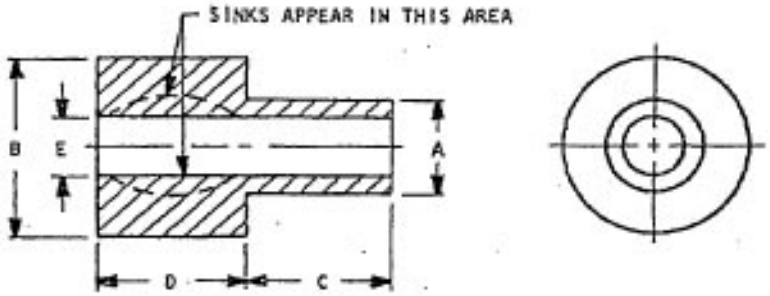
5.1.11.8 Through-hole limits. Limits for through-holes are shown in figure 11.



X - minimum wall	Z - length	Y - minimum diameter	Draft
0.030	0.250	0.093	0°
0.040	0.500	0.125	0°
0.050	0.750	0.187	0°
0.060	1.000	0.250	0°
0.060	1.250	0.312	0°
0.060	1.500	0.437	0° 15'
0.060	2.000	0.500	0° 15'
0.060	2.500	0.625	0° 15'

FIGURE 11. Through-hole limits for investment castings.

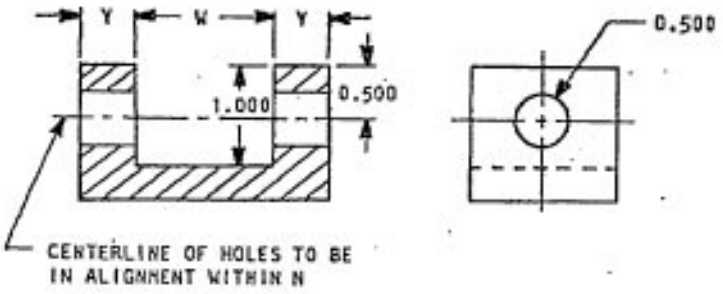
5.1.11.9 Non-uniform wall sections. Recommended tolerances for investment castings with non-uniform wall sections are shown in figure 12.



A	B	C	D	E	Tolerance for E
0.500	1.000	0.250	0.750	0.375	± 0.004
0.750	1.500	0.500	1.000	0.500	± 0.006
1.000	2.000	0.750	1.500	0.750	± 0.008
1.250	2.500	1.000	2.000	1.000	± 0.010

FIGURE 12. Tolerances for investment castings with non-uniform wall sections.

5.1.11.10 In-line holes. Centerline of holes should be held to hole alignment tolerance as specified in figure 13.



W	Z	Y	Hole alignment tolerance
0.250	0.500	0.125	± 0.003
0.375	0.750	0.187	± 0.004
0.500	1.000	0.250	± 0.005
0.750	1.500	0.375	± 0.005
1.000	2.000	0.500	± 0.010
1.250	2.500	0.625	± 0.012
1.500	3.000	0.750	± 0.015

FIGURE 13. Tolerances for investment castings with in-line holes.

5.1.11.11 Finish stock in hole. Finish stock allowance of 0.010 to 0.015 inch per side is required for grinding or reaming a hole, provided that the section around the hole is uniform. For holes over 1 inch in diameter, sufficient stock should be allowed to maintain required tolerance and also guarantee “clean-up”. If section around hole is not uniform, more finish stock will be required as heavier section tends to pull hole out of round (see figure 14).

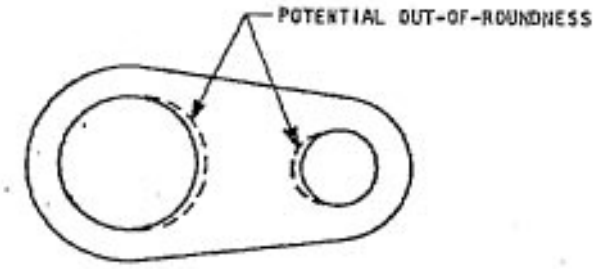
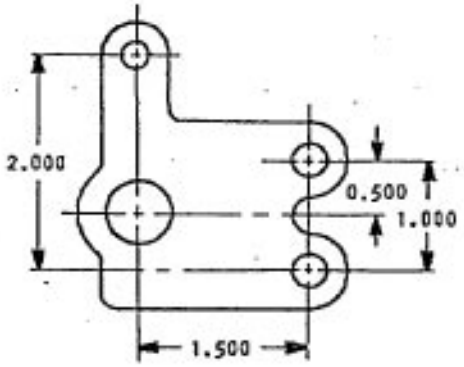


FIGURE 14. Potential out-of-roundness in an irregular mass.

5.1.11.12 Hole relationships.

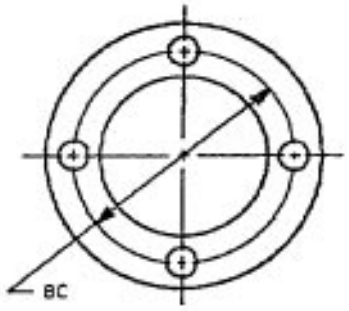
5.1.11.12.1 Distance between holes. Tolerances for various interhole distances are shown in figure 15.



Distance between holes	Tolerance
0.500	± 0.004
1.000	± 0.005
1.500	± 0.008
2.000	± 0.010

FIGURE 15. Tolerances between holes in investment castings.

5.1.11.12.2 Positioning. Holes (or bosses) should be located within tolerances of true position on line BC as specified in figure 16.



BC diameter	Tolerance
0.500	± 0.005
1.000	± 0.005
1.500	± 0.009
2.000	± 0.010
2.500	± 0.015
5.000	± 0.025
8.000	± 0.040
10.000	± 0.050

FIGURE 16. Hole positioning tolerances for investment castings.

5.1.11.12.3 Parallelism. Centerlines of cored holes should be held to parallelism tolerances as specified in figure 17.

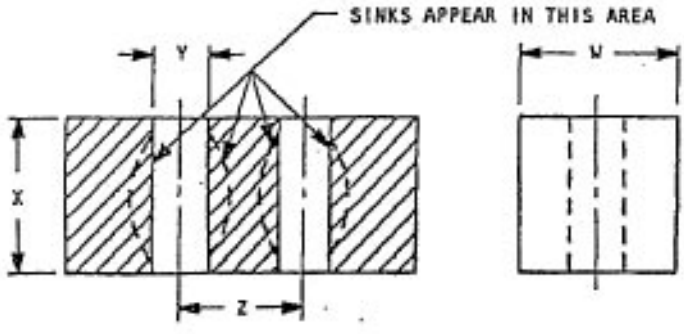
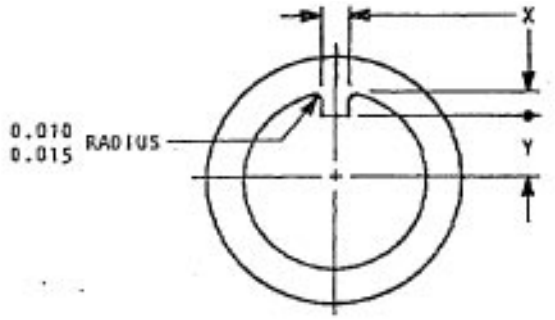


FIGURE 17. Hole parallelism tolerances for investment castings.

W	X	Y	Z	Parallelism tolerance
0.375	0.250	0.125	0.500	± 0.003
0.500	0.500	0.250	0.750	± 0.005
0.625	0.750	0.375	1.000	± 0.005
0.875	1.000	0.500	1.250	± 0.008
1.000	1.250	0.625	1.500	± 0.008
1.250	1.500	0.750	1.750	± 0.010
1.375	2.000	0.875	2.000	± 0.010
1.500	2.500	1.000	2.250	± 0.015

FIGURE 17. Hole parallelism tolerances for investment castings - Continued.

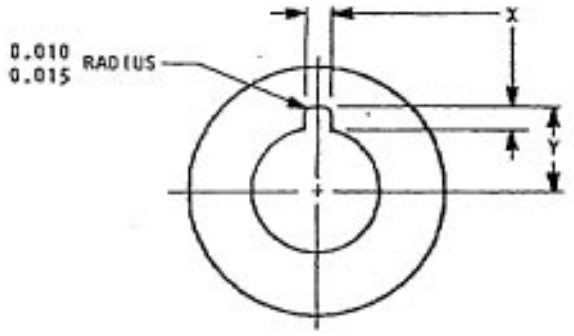
5.1.12 Keyways. Tolerances for investment cast keyways are shown in figure 18.



X	Tolerance for X	Y	Tolerance for Y
0.031	± 0.003	0.500	± 0.005
0.046	± 0.003	0.750	± 0.005
0.062	± 0.003	1.000	± 0.005
0.125	± 0.003	1.500	± 0.008
0.250	± 0.003	2.000	± 0.010

FIGURE 18. Keyway tolerances for investment castings.

5.1.13 Keyslots. Recommended for non-ferrous alloys only. A key slot can be cast in ferrous alloys, but no “rule of thumb” applies. When a closer tolerance is required, broaching stock and/or ream stock is allowed or keyslot is omitted entirely. For recommended tolerances see figure 19.



X	Tolerance for X	Y	Tolerance for Y
0.062	± 0.003	0.500	± 0.005
0.093	± 0.003	0.750	± 0.005
0.125	± 0.003	1.000	± 0.005
0.250	± 0.003	1.500	± 0.008
0.500	± 0.004	2.000	± 0.010

FIGURE 19. Keyslot tolerances for investment castings.

6. NOTES

6.1 Distortion. Problems involving distortion and the closely related casting defect, hot tearing, are conditions that can be eliminated or minimized by proper casting design. Distortion can result from:

a. Differences in solidification times.
b. Restraint imposed by the mold as the casting cools and contracts.
c. Stresses generated during heat treatment.
d. Differences in alloy composition.

6.2 Subject term (key word) listing.

Draft
Gate
Lost wax
Mold
Riser
Runner
Sprue

CONCLUDING MATERIAL

Custodian:
Army - AT

Preparing activity:
Army - AT

(Project MECA-0576)