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JSC FABRICATION TOLERANCES AND PRACTICES

Engineering Directorate
Office of Primary Responsibility: EX / Project Management and Systems Engineering Division

Compliance is Mandatory

National Aeronautics and Space Administration

Change Record

Revision /DCN	Date	Originator	Approvals	Description
Basic	25 April 2024	Beth Sheridan / EX5	Per EA MRCB CR/D EA-0288	Initial Release. This document supersedes JSC Standard SKZ36103755, JSC Fabrication Tolerances and Practices (a book-form reference drawing) due to the retirement of the JSC Engineering Drawing Control Center (EDCC) drawing repository.
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Prepared by: Elizabeth Sheridan Digitally signed by Elizabeth Sheridan Date: 2024.05.02 14:22:57 -05'00'

Beth Sheridan, Change / Document / Records Management — Date
EX5 / Applied Systems Engineering Branch

Concurred by: Erick Ordonez Digitally signed by Erick Ordonez Date: 2024.05.14 13:43:21 -05'00'

Erick Ordonez, Branch Chief — Date
EX5 / Applied Systems Engineering Branch

Concurred by: Jesse Leggett Digitally signed by Jesse Leggett Date: 2024.05.14 15:03:51 -05'00'

Jay Leggett, Division chief — Date
EX / Project Management and Systems Engineering Division

Approved by: GERALD LEBEAU Digitally signed by GERALD LEBEAU Date: 2024.05.14 21:42:50 -05'00'

Julie Kramer White, Director — Date
EA / Engineering Directorate

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1 PURPOSE

This document contains tolerance and dimension limits for human spaceflight equipment design based on JSC lessons learned, best practices, and industry standards. This document is to replace the long-time JSC standard SKZ36103755, JSC Fabrication Tolerances and Practices (a book-form reference drawing) due to the retirement of the JSC Engineering Drawing Control Center (EDCC) drawing repository.

2 SCOPE

When this document is referenced, the tolerances and limits herein are the maximum permissible for applicable, un-toleranced dimensions shown on the drawing, and unless otherwise specified, the practices herein are required where applicable.

Note: The phrase “unless otherwise specified” applies to all sections of this document.

3 APPLICABLE AND REFERENCE MATERIAL

(All citations are presumed to be the latest unless otherwise noted)

3.1 APPLICABLE DOCUMENTS AND WEB RESOURCES

TABLE 3-1 APPLICABLE DOCUMENTS AND WEB RESOURCES

Document Number or Resource Name	Document Title or Web Location
ASME Y14.5	Dimensioning and Tolerancing
ASME B46.1	Surface Texture (Surface Roughness, Waviness and Lay)
FED-STD-H28	Federal Standard Screw-Thread Standards for Federal Services

3.2 REFERENCE DOCUMENTS AND WEB RESOURCES

TABLE 13-2 REFERENCE DOCUMENTS AND WEB RESOURCES

Document Number or Resource Name	Document Title or Web Location
SKZ36103755	JSC Fabrication Tolerances and Practices

4 DIMENSIONS INTERPRETATION

a. All dimensions are per the international inch, which equals 2.54 centimeters.

b. All limits are considered to be absolute and shall be interpreted in accordance with ASME Y14.5.

   1. Finished parts exceeding specified limits to any degree, regardless of magnitude, shall be considered as not meeting drawing requirements.

c. Dimensions and tolerances of form and position and dimensional terminology shall be interpreted in accordance with ASME Y14.5.

d. All requirements of detail and assembly drawings apply after all processes employed to produce the items are completed. Where dimensional and other requirements are not specified for an assembly, the requirements specified for the detail shall still apply at assembly.

e. All dimensions apply when parts or assemblies are free from external force(s) except that when parts or assemblies are subject to free state variations (are non-rigid) the dimensions shall be interpreted in accordance with ASME Y14.5.

f. Dimensions of a part to which inorganic finishes such as plating's and oxides, or other similar finishes are applied, shall be finished product requirements.

g. Dimensions of a part to which phosphates or organic finishes such as paints, lacquers, other similar finishes applied, shall be the requirements before application of the finishes.

h. Dimensions shall apply at a part and measuring instrument temperature of 68° F (20° C)

i. There shall be no repair or restoration of material by any process without prior approval from the organization initiating the fabrication request.

5 SURFACE TEXTURE

a. Interpretation of surface texture symbols shall be in accordance with ASME B46.1.

b. On drawings that do not show a texture symbol for surfaces, the values shown apply.

TABLE 5-1 MAX ROUGHNESS FOR SURFACES

SURFACE	MAX ROUGHNESS
PRECISION HOLES (Section 9.7)	63√
THREAD SURFACES	63√
DRILLED HOLES OR COUNTERBORES	250√
CUT-OFF ENDS OF BAR STOCK	250√
ALL OTHER SURFACES	125√

c. Surfaces may be produced by any process that will create the surface texture specified.

6 DEFINITIONS OF TERMS AS USED IN THIS STANDARD OR ON DRAWINGS THAT REFERENCE THIS STANDARD

a. Axis – The real or imaginary straight line through the center of a part.

b. Burr – Any displaced base material extending beyond either of two machined or formed intersecting surfaces.

c. Camber – The greatest deviation of the side edge (bar, strip, sheet) from a straight line.

d. Deep Hole Drilling – The drilling of a hole to a depth exceeding five times the nominal diameter of the drill.

e. Machining – The removal of material from a rigid or semi rigid part by any means (e.g., mechanical, chemical, or electrical (excluding flame cutting)).

f. Re-entrant Angle – An angle of less than 180° whose vertex penetrates into the material. The angle may be on either an external or an internal surface.

g. Runout, Axial – The deviation of the actual centerline from a theoretically straight line.

h. Runout, Face – The total axial readings shown when the indicator contacts the face through 360° revolution. It is generally read relative to some “trued” portion of the part (e.g., when other means of checking squareness are not practical). This face is sometimes called “lateral runout”.

NOTE: A face runout check does not measure concavity and convexity, which comes under the term flatness.

i. Surface Defects – Irregularities that occur at one place or at relatively infrequent or widely varying intervals in a surface. Defects include but are not limited to scratches, nicks, gouges, dents, ridges, prick punch marks, weld spatter, and tool chatter marks.

j. Surface of Revolution – A surface, either external or internal, generated during a machining or forming process when either the work piece or the tool is revolved about an axis, which is stationary relative to the opposing tool or work piece.

k. TIR – Total (or full) Indicator Reading (See Section 17.2).

l. Typical (Type) – When associated with a dimension or feature that appear to be identical in size and configuration.

7 CORNERS

7.1 SHARP EDGES

When a sharp edge is shown but not specified, burrs and sharp edges shall be removed to leave a radius, a chamfer, or a combination of these. The corner may be dulled by any process, which produces a radius or equivalent between .005 and .020. Gages are not required. Conformance may be determined by visual or feel inspection. When drawings specify “sharp corner” radii or chamfers, up to .003 will be permitted.

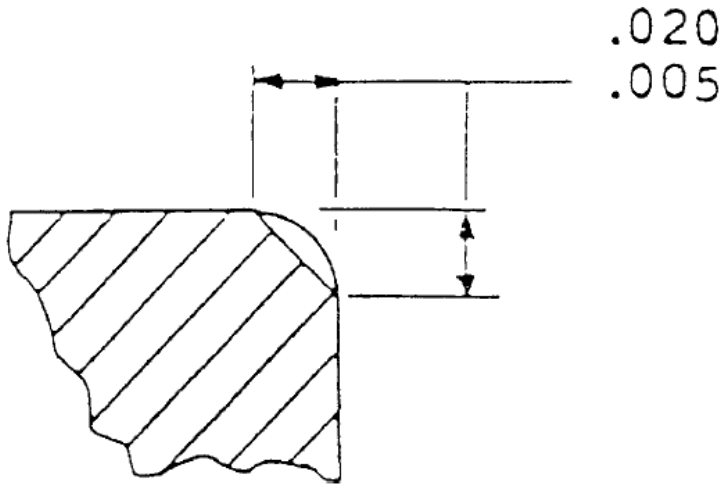


FIGURE 7-1 CONFIGURATION OPTIONAL WITHIN LIMITS OF RADIUS AND CHAMFER

7.2 INSIDE CORNERS (RE-ENTRANT ANGLES)

When an inside corner is shown without either a fillet radius or an undercut specified, the fillet may be .00 - .03R. When either of these surfaces adjacent to such corners is to be ground, a tool relief undercut as shown by dimensions AA or AB is permitted. When the limits of the fillet radius are specified, no undercut is permitted.

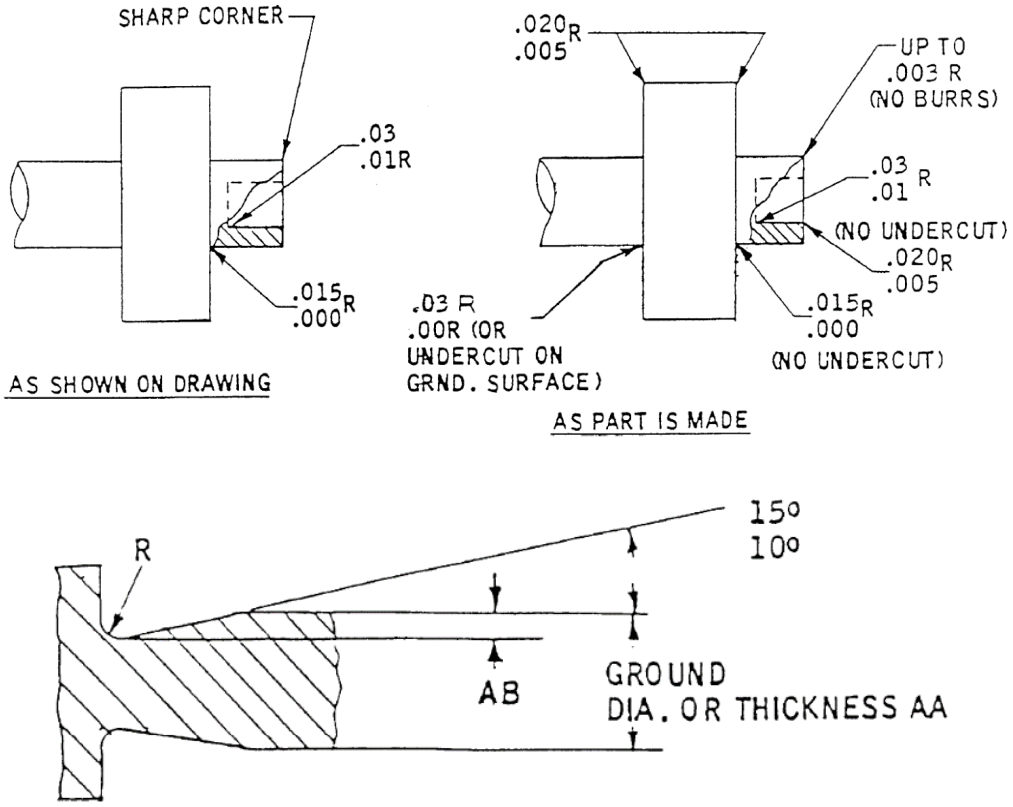


FIGURE 7-2 INSIDE CORNERS

TABLE 7-1 TOOL RELIEF FOR GRINDING

AA		AB	R
OVER	INCL		
.12	.25	.003 - .005	.005 - .010
.25	.50	.003 - .008	.005 - .010
.50	-	.006 - .011	.005 - .015

7.3 TANGENT RADII

When a dimensioned radius is shown as a tangent, the radius shall be tangent to the adjacent surface(s) within ±.005 except that any resultant step or undercut shall not exceed the specified max-min limits of the adjacent surface(s) and shall be blended.

8 CHAMFERS

Chamfers on external threaded ends – All threaded ends shall be chamfered 25° to 50° (measured from the cutoff plane). The width of chamfer on the cut off end shall be from 1 (min.) to 1½ (max.) times the depth of the thread.

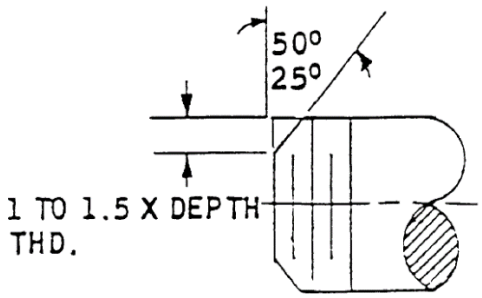


FIGURE 8-1 CHAMFERS

9 HOLES

9.1 DISPLACED MATERIAL

Displaced material, either solid or loose, (e.g., drill or broach chips, curls, burrs, etc.) shall be removed from all holes and recesses.

9.2 DEPTH OF HOLE

The depth “A” of hole shall be measured from the surface drilled to the depth of the full diameter.

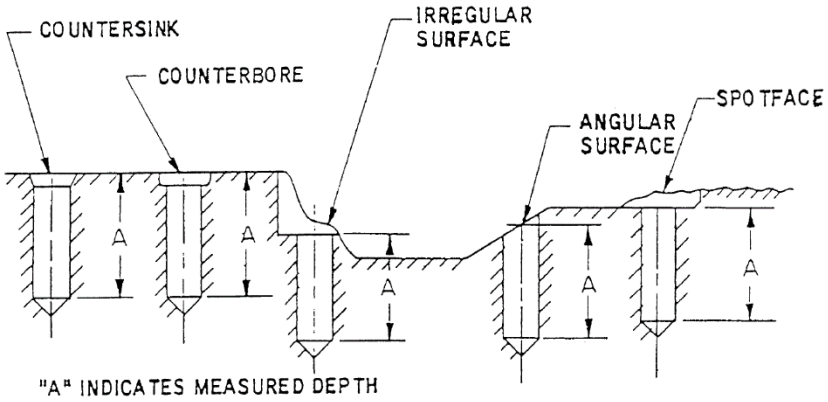


FIGURE 9-1 DEPTH OF HOLE

9.2.1 HOLES, DEPTH, TAP DRILL

The tap drill depth beyond the specified perfect thread length shall not exceed the values tabulated here.

TABLE 9-1 HOLES, DEPTH, TAP DRILL

TAP DRILL DIAMETER	TAP DRILL DEPTH BEYOND FULL THREAD	
.04 - .50 INCL	MINIMUM	MAXIMUM
	5P	5P + .06
OVER .50	5P	5P + .10

(P = Pitch of thread)

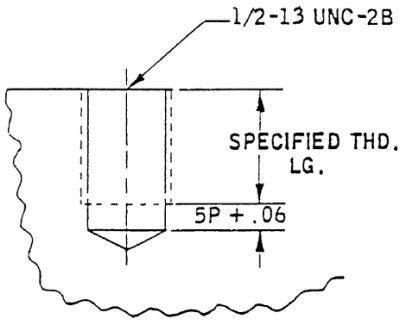


FIGURE 9-2 HOLES, DEPTH, TAP DRILL

9.3 SQUARENESS OF PLAIN HOLES DELINEATED AT RIGHT ANGLES TO SURFACES

a. For holes up to and including .125 diameter, the axis of the hole shall be square with the face withi 1° 30’ (.026/inch of R max).

b. For holes over .125 diameter, the axis shall be square with the face of 1° (.017/inch of R max).

c. In no case shall the angularity of the hole allow any part of the centerline of the hole to exceed the locational tolerance designated.

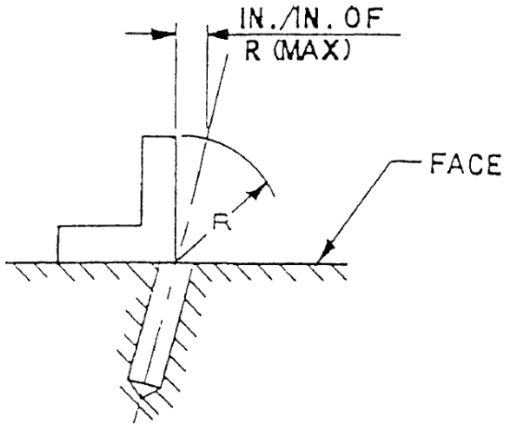


FIGURE 9-3 SQUARENESS OF PLAIN HOLES

9.4 SIZE-DIAMETRAL DIMENSIONS FOR HOLES

Size-diametral dimensions for holes are the max-min limits; drill size callouts are for reference only.

9.5 SHAPE OF HOLES

A hole may be out-of-round, tapered, or wavy provided that the diameter at any point in the hole is within the diametral limits, and that a minimum diameter cylindrical plug gage can be inserted the full length of the hole.

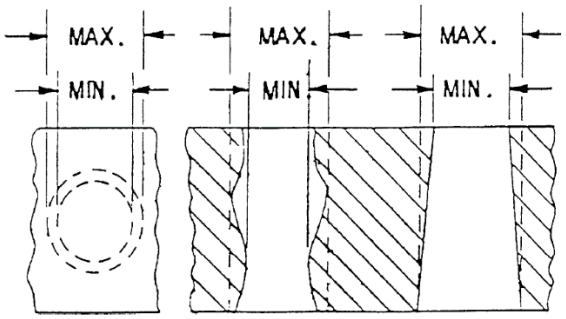


FIGURE 9-4 SHAPE OF HOLES

9.6 COUNTERSINK FOR THREADED HOLES

a. All holes for threading shall be countersunk 80° - 120° before threading to prevent burrs.

b. Through holes shall be countersunk at both ends where practical.

c. Through or blind holes having four or fewer threads shall be countersunk to the major diameter of thread (C) ±.01.

d. Holes having more than four threads shall be countersunk to the diameter “D” shown in table 9-2.

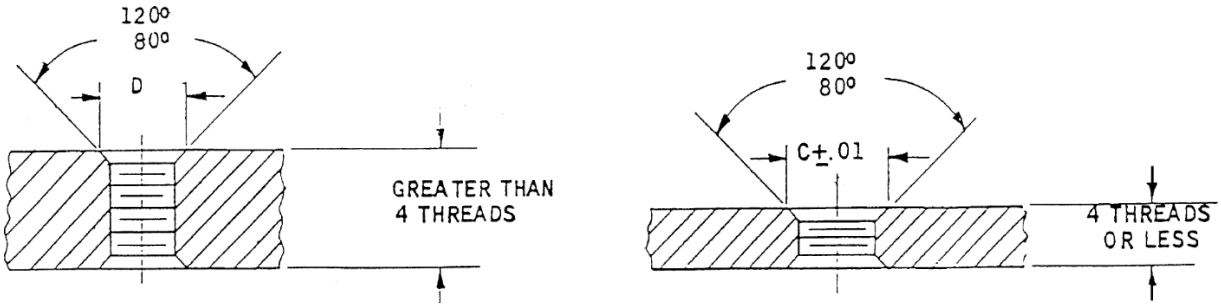


FIGURE 9-5 COUNTERSINK FOR THREADED HOLES MEASUREMENTS

TABLE 9-2 COUNTERSINK FOR THREADED HOLES TOLERANCES

THREAD SIZE C	COUNTERSINK DIAMETER "D"
No. 2 (.086)	.09 - .12
No. 4 (.112)	.12 - .15
No. 6 (.138)	.15 - .19
No. 8 (.164)	.19 - .22
No. 10 (.190)	.22 - .25
.250	.28 - .31
OVER .250	(C + .03) – (C + .06)

9.7 PRECISION HOLES

A precision hole is one whose diametral tolerance does not exceed .002.

9.7.1 ALIGNMENT AND ROUNDNESS

a. The alignment of precision holes delineated in line with other precision holes shall be measured in terms of total indicator reading (TIR).
b. Parallelism of in-line holes with a machined base shall be within the tolerances on the hole location.
c. Holes shall be round within a TIR equal to one-half the diametral tolerance.

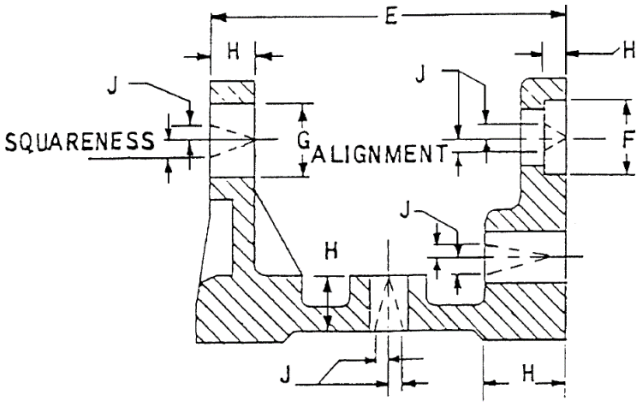


FIGURE 9-6 ALIGNMENT AND ROUNDNESS MEASUREMENTS

TABLE 9-3 ALIGNMENT AND ROUNDNESS TOLERANCES

DISTANCE "E"		TIR BETWEEN BORES F & G
OVER	INCL	
0	12	.001
12	18	.002
18	-	.003

9.7.2 SQUARENESS

A precision hole delineated at a right angle to an adjacent machined surface shall be square with that surface within "J" max = .0005 in./inch of "H" for "H" less than one inch. For "H" greater than or equal to one inch, "J" max = .0005".

9.8 HOLE SPACING ON A BOLT CIRCLE

a. When holes in a bolt circle are specified on a drawing as equally spaced, the specified tolerance shall be non-cumulative.

b. When there are other cylindrical surfaces on the same part with a bolt circle, the bolt circle shall be concentric with the axis of the adjacent cylindrical surface having the smallest diametrical tolerance within a TIR equal to the tolerance specified on the bolt circle diameter.

10 ALIGNMENT

10.1 FEATURE DELINEATED ON A CENTERLINE

a. Where a feature such as a hole or slot (except per 12.2) is delineated on the centerline of a part, the feature center shall be on the centerline of a part.

b. The feature center shall be on the centerline of the finished part within .01 D either side of the centerline.

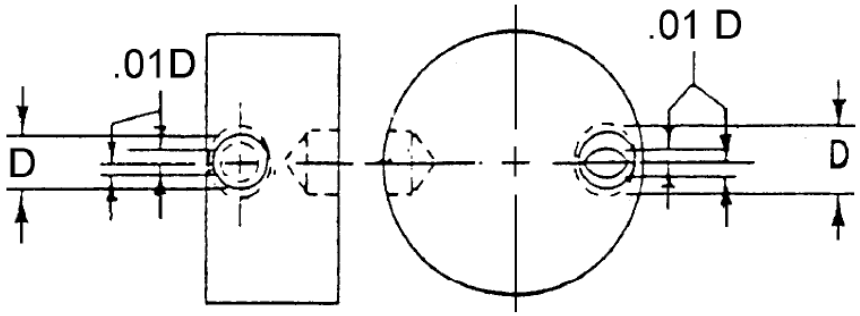


FIGURE 10-1 FEATURE DELINEATED ON A CENTERLINE MEASUREMENT

10.2 FEATURES AT RIGHT ANGLES

Center lines of features, delineated at right angles to each other, shall be square within 1° (.017 inch/inch) but not to exceed .030 at distance “R” up to including 3”, .045 above 3” to including 6” .060 above 6”.

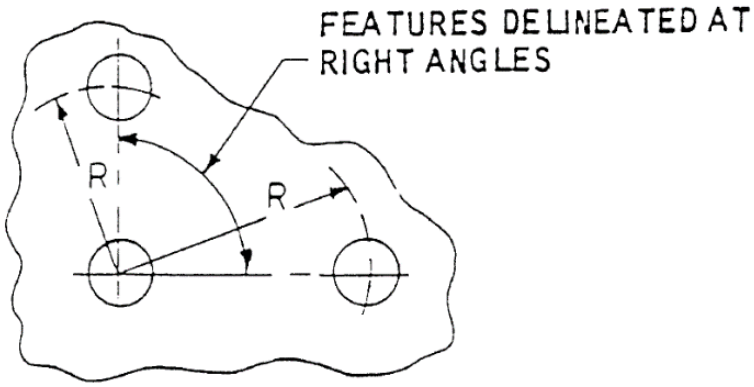


FIGURE 10-2 FEATURES AT RIGHT ANGLES MEASUREMENT

10.3 INTERRUPTED SURFACES

Interrupted surfaces delineated in the same plane shall be on a common plane with each other within the values given in the Table 10-1 as depicted in Figure 10.3.

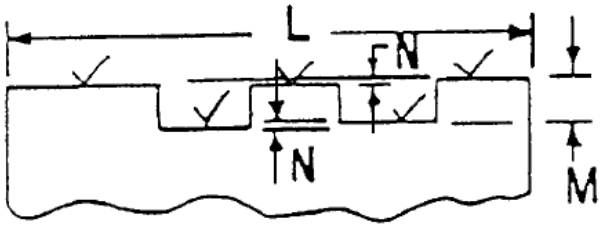


FIGURE 10-3 INTERRUPTED SURFACES TOLERANCE MEASUREMENTS

TABLE 10-1 TOLERANCES FOR INTERRUPTED SURFACES

TOTAL TOLERANCE ON DIMENSION "M"		TOLERANCE "N"
OVER	INCL	
0	.020	.002/IN. OF "L" TO A MAX. OF .006 BUT NOT TO EXCEED LIMITS OF DIM "M"
.020	-	.006

10.4 PARALLELISM OF SURFACES

Surfaces delineated parallel to each other shall be parallel within "P".

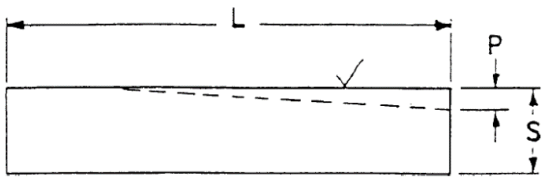


FIGURE 10-4 SURFACES PARALLELISM MEASUREMENTS

TABLE 10-2 SURFACES PARALLELISM TOLERANCES

TOTAL TOLERANCE ON DIMENSION "S"		TOLERANCE "P"
OVER	INCL	
0	.020	.001/IN. OF "L" TO A MAX. OF .010 BUT NOT TO EXCEED LIMITS OF DIM "S"
.020	-	.010

10.5 SQUARENESS OF MACHINED SURFACES

Any machined surface delineated at 90° to another surface or to a centerline shall be square with that surface or centerline within .002 per inch of surface up to .020 maximum.

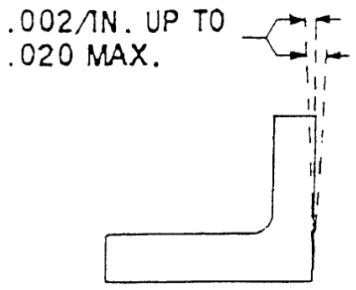


FIGURE 10-5 MACHINED SURFACES SQUARENESS MEASUREMENTS

10.6 FLATNESS OF MACHINED SURFACES

The flatness of a machined surface shall be within "T" except that in no case shall "T" fall outside the locational limits of the surface.

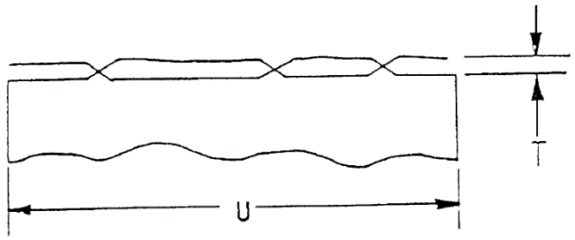


FIGURE 10-6 MACHINED SURFACES FLATNESS MEASUREMENTS

TABLE 10-3 MACHINED SURFACES FLATNESS TOLERANCES

SURFACE ROUGHNESS	LENGTH "U"		TOTAL "T"
UP TO 32√ INCL.	0	6	.001
	6	12	.002
	12	---	.004
63√ 125√ 250√	0	6	.004
	6	12	.008
	12	---	.012

10.7 WARPAGE OF MACHINED PARTS

a. Warpage of machined parts (circular, square, rectangular, or irregular in shape) which are machined on the flat surface or surfaces shall not exceed "W".

b. Warpage tolerances shall be separate from the part thickness tolerance.

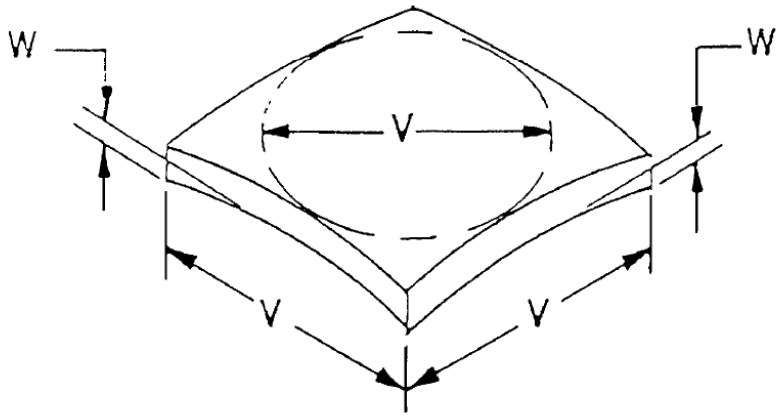


FIGURE 10-7 MACHINED PARTS WARPAGE MEASUREMENTS

TABLE 10-4 MACHINED PART WARPAGE TOLERANCES

MATERIAL THICK		DIA. OR LENGTH "V"		TOTAL "W" MAX.
OVER	INCL.	OVER	INCL.	
.06	.12	0	2	.01
		2	6	.02
		6	12	.04
		12	---	.07
.12	.20	0	2	.007
		2	6	.010
		6	---	.015
.20	.50	0	2	.007
		2	6	.010
		6	---	.015
.50	1.00	0	2	.005
		2	6	.007
		6	12	.010
		12	---	.015
1.00	1.50	0	2	.0025
		2	6	.005
		6	12	.007
		12	---	.010

11 STAKING OF FLAT HEAD SCREWS

a. When staking of flat head screws is specified on the drawing, the screws shall be firmly secured by staking at each end of slot.

b. The staking tool shall be of proper shape and size to produce a flow of adjacent metal into screw head slot.

12 KEYWAYS

12.1 KEYWAYS, CORNER RADII

Internal corner radii of key seats and keyways shall be as tabulated.

TABLE 12-1 KEYSEAT AND KEYWAY CORNER RADII TOLERANCES

KEYSEAT AND KEYWAY		
DEPTH		RADIUS MAX
OVER	TO	
.031	.094	.005
.094	.156	.010
.156	.312	.015

12.2 KEYWAYS, RADIAL LOCATION

When delineated on a drawing as being in-line but not otherwise specified, the radial position of keyways, splines, and gear teeth may be at random with respect to each other or to the other features, when random location is not permissible, the drawing will specify the relationship.

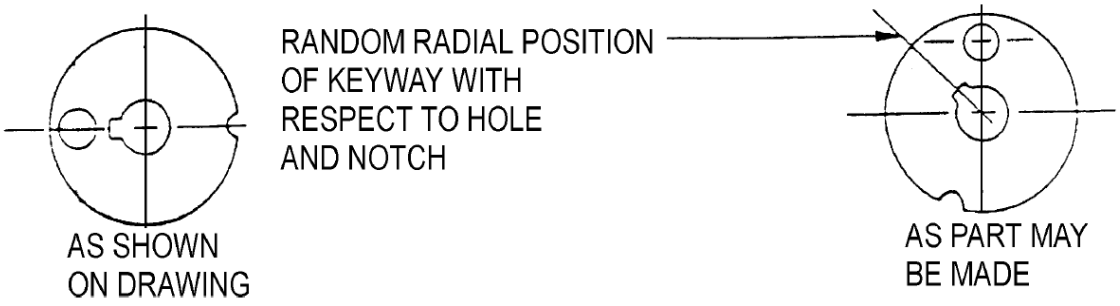


FIGURE 12-1 KEYWAYS, RADIAL LOCATION

12.3 KEYWAY LOCATION RELATIVE TO CENTERLINES

a. The centerline of a keyway in a shaft or bore shall be centered within the tolerance “Y” (12.3.c)

b. When a drawing shows two or more keyways in line in a shaft or bore and specifies “keyways must be in line”, each such keyway shall be on a common centerline and on the centerline of the shaft or bore each within tolerance “Y” (12.3.c).

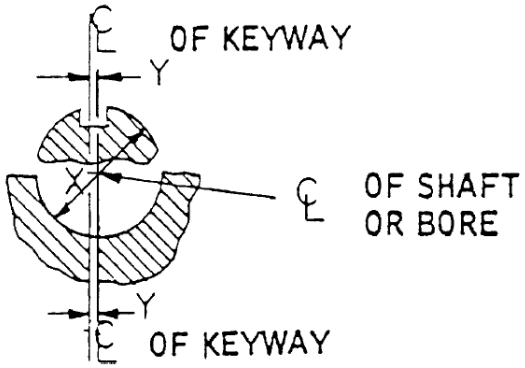


FIGURE 12-2 KEYWAYS, RADIAL LOCATION MEASUREMENT

c. When two keyways are delineated at 90° (or dimensioned at other angular locations), the centerline of one keyway shall be on the centerline of the shaft or bore within tolerance “Y” and the centerline of the second keyway shall be 90° (or another specified angle) from the first keyway within “Y” measured at radius “R”.

TABLE 12-2 TWO KEYWAYS DELINEATED AT 90° TOLERANCES

DIAMETER "X"		TOL "Y"
OVER	INCL	MAX.
.00	.50	.001
.50	4.00	.002
4.00	---	.003

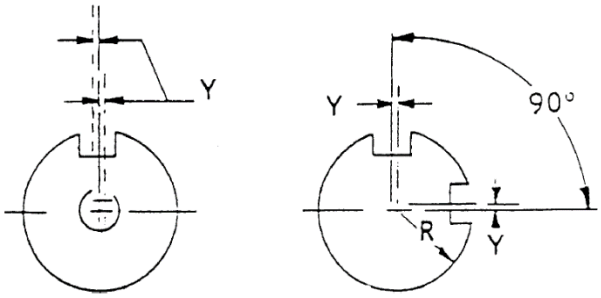


FIGURE 12-3 TWO KEYWAYS DELINEATED AT 90° MEASUREMENTS

13 AXES AND SURFACES OR REVOLUTION

13.1 COINCIDENT AXES (CONCENTRICITY)

(For threads, see section 15.4) where a common axis * is shown for more than one surface of revolution of the same part, the axis for each such surface shall be coincident with the common axis within a TIR equal to one half the tolerance on the diameter involved. This TIR includes run out due to out of roundness. (For non-rigid parts, see paragraph 4.e).

*This includes axes on the same part which, if extended, would be common.

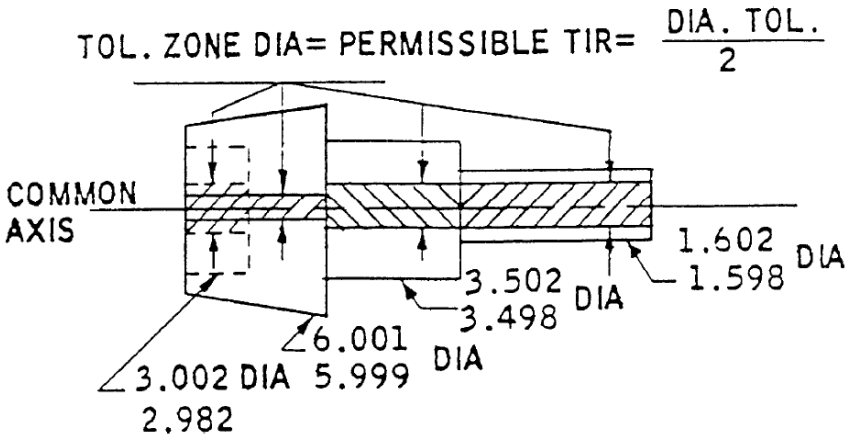


FIGURE 13-1 COINCIDENT AXES (CONCENTRICITY)

13.2 ROUNDNESS

A surface of revolution shall be round within a TIR equal to one half the diametral tolerance (For non-rigid parts see paragraph 4.e).

14 CENTERS FOR MACHINING

a. Centers for machining are optional in the completed part. When centers are used, the diameter (AD) shall be determined by the minimum diameter (AC) of groove, thread, etc., in the area of the centers.

b. Centers shall be in accordance with Table 14-1.

c. When centers are required in the completed part, they will be specified on the model/drawing.

d. When centers are not allowed in the completed part, it should be stated on the model/drawing.

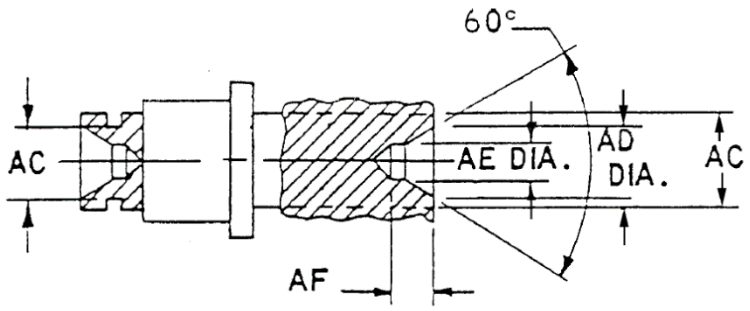


FIGURE 14-1 CENTERS FOR MACHINING MEASUREMENTS

TABLE 14-1 CENTERS FOR MACHINING TOLERANCES

DIAMETER AC	AD MAX.	AE	AF	CENTER DRILL NO.
.12 TO .15 INCL.	.08	.05	.08	1
OVER .15 TO .19 INCL.	.12	.08	.11	2
OVER .19 TO .25 INCL.	.13	.08	.12	2
OVER .25 TO .38 INCL.	.16	.08	.14	2
OVER .38 TO .62 INCL.	.22	.12	.20	4
OVER .62 TO 1.00 INCL.	.26	.12	.23	4
OVER 1.00 TO 1.50 INCL.	.35	.19	.31	5
OVER 1.50 TO 2.00 INCL.	.38	.19	.34	5

15 THREADS

15.1 GENERAL

All elements of designated screw threads shall be in accordance with FED-STD-H28 Federal Standard Screw-Thread Standards for Federal Services.

15.2 THREAD LENGTHS

a. When a part is shown to be threaded to a shoulder, all thread-elements shall be within specified limits to within three threads from the shoulder; no undercut permitted.

b. When a part has a defined length of threads (L), either internal or external, all thread elements shall be within specified limits up to the full-defined length.

c. When such threads do not end at the shoulder, undercut or hole bottom, there may be additional perfect or imperfect threads and up to three and one half for external threads and up to five for internal threads.

d. When undercuts are shown on a drawing but not dimensioned, the following dimensions and tolerances shall apply:

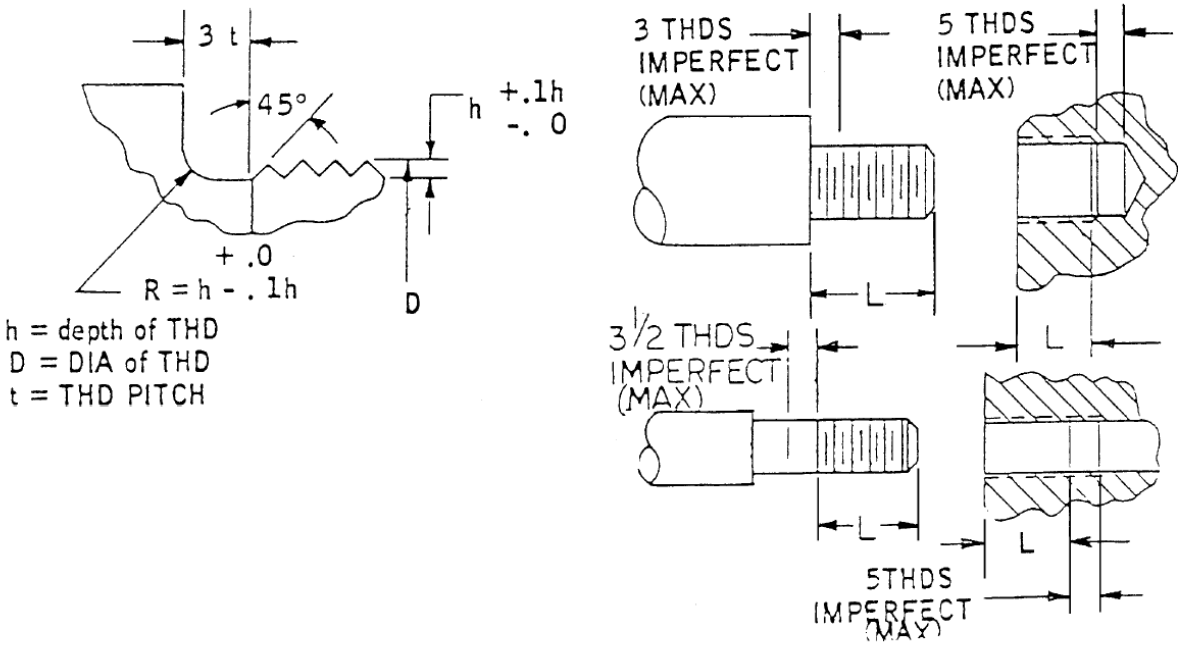


FIGURE 15-1 THREAD LENGTHS

15.3 SQUARENESS OF THREADS

(External & Internal) The actual axis of threads delineated as square with adjacent face or shoulder shall be square within .005/inch of radius.

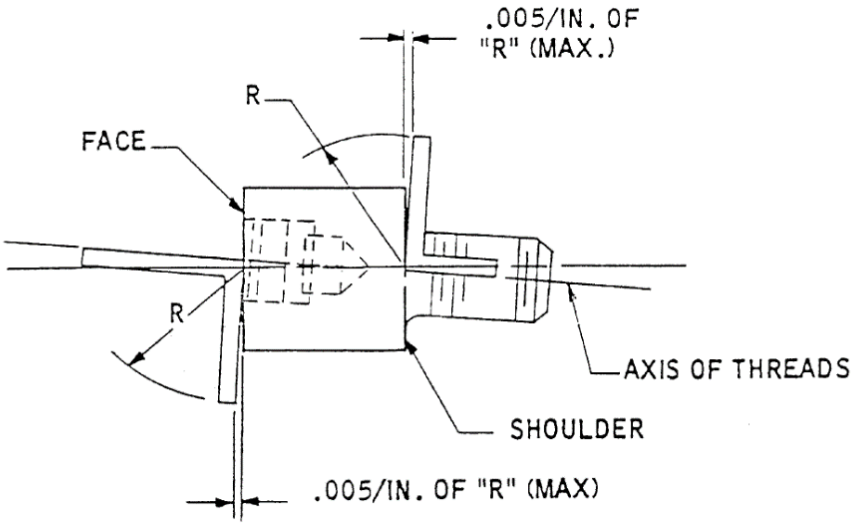


FIGURE 15-2 SQUARENESS OF THREADS

15.4 CONCENTRICITY OF THREADS

Threads (external & internal) shown as having a common centerline with each other or with adjacent cylindrical surfaces (disregarding tool relief of other similar undercuts) shall be concentric with each other and with adjacent cylindrical surfaces within .01 TIR.

16 FACES

16.1 SQUARENESS OF FACES

a. Faces and shoulders delineated at right angle to an axis of revolution shall be square within .002 up to 1” radius.

b. Above 1” radius the squareness shall be within .002/IN. of radius “R” except that no portion of face or shoulder shall be outside the limits.

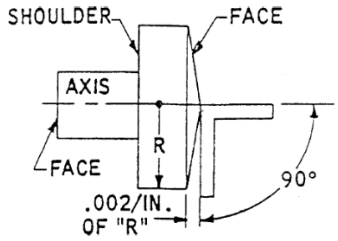


FIGURE 16-1 SQUARENESS OF THREADS

16.2 RUNOUT, FACE

a. The runout for faces and shoulders shall be .002 TIR up to 1” radius.
b. Above 1” radius, the lateral runout shall be within a TIR of .002/Inch of radius “R”.
c. No portion of face or shoulder shall be outside the limits of length, nor shall the runout exceed .005 TIR at any radius.

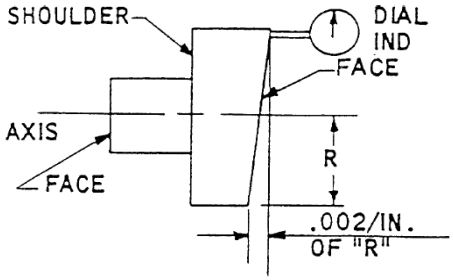


FIGURE 16-2 RUNOUT, FACE

17 PRACTICE

17.1 STOCK

When the word stock or (stk) follows a normal dimension, the commercial mil tolerance and surface texture for the specified material and raw stock size shall apply.

17.2 TOTAL INDICATOR READING (TIR)

Where TIR is specified, other means of measurement may be used which will provide equivalent values.

18 WELDING

This section of the document contains the minimum requirements for visual inspection and acceptance of welds.

18.1 GENERAL REQUIREMENTS

a. The quality of weld shall be verified by visual examination at 1X magnification.
    1. Inspection shall be performed in the “as-welded” condition.
b. The following shall be causes for rejection when visually observed on any weld:
    1. Cracks in base metal or weld. NOTE: No cracks, regardless of size or location, shall be permitted.
    2. Porosity or gas pockets – surface holes or areas void of solid material.
    3. Craters – Depressions at the termination of welds.
    4. Undercutting – Erosion or notching of the base metal at the fusion line. NOTE: Undercuts shall not be sharp “V” shaped or exceed 1/32 inches in depth nor 2 inches in length; or 10% of the base material thickness, nor 2 inches in length whichever is least.
    5. Non-metallic inclusion – Oxides or other solids encountered as inclusions in the weld.
    6. Weld spatter – All weld spatter shall be removed.
    7. Bead appearance – Weld Beads shall present a neat workmanlike appearance.
    8. Burn through – Caused by excessive penetration of the weld bead.

18.2 ANGULAR TOLERANCE – WELDED STUDS

The angle of welded studs shall not exceed 1° per inch of “A” in any direction.

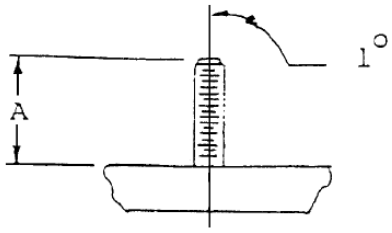


FIGURE 18-1 WELDED STUDS

18.3 FILLET WELDS, OUTSIDE CORNERS

Unless otherwise specified, the following practices shall be applied to outside corner fillet welds for aluminum and steel.

a. A lap corner construction shall be used for material thickness of .062 and over (See Figure 18-2).

b. Welds shall be reinforced with a melt-through. The size (L) (Leg and throat) of the melt-through shall be as specified in Figure 18-2.

c. The minimum outside fillet weld size (Leg and Throat) shall be as follows:

    1. The size specified on the drawing shall be considered the minimum.

    2. When the size is not specified on the drawing, the minimum size shall be equal to the thickness of the thinner member welded. (Figure 18-2).

d. The maximum outside fillet weld size (Leg and Throat) shall be equal to the minimum size plus (+) “H” as shown in Figure 18-2.

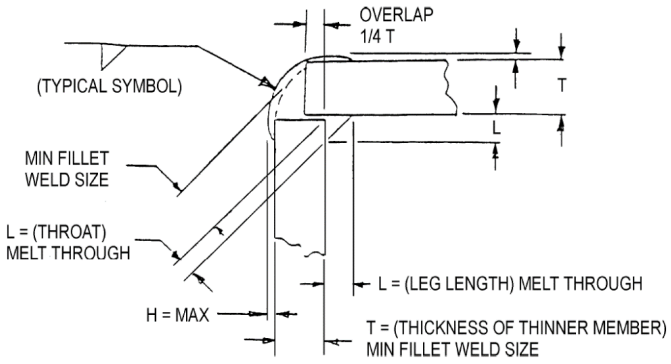


FIGURE 18-2 FILLET WELDS, OUTSIDE CORNERS MEASUREMENT

TABLE 18-1 FILLET WELDS, OUTSIDE CORNERS TOLERANCES

T THICKNESS	H	L (ALUM)		L (STEEL)	
	MAX	MIN	MAX	MIN	MAX
.030	.020	.02	.07	.02	.07
.040	.030	.03	.08	.03	.08
.050	.040	.04	.09	.04	.09
.062	.045	.04	.09	.04	.09
.094	.045	.06	.12	.06	.12
.125	.045	.06	.12	.06	.12
.188	.062	.09	.16	.06	.12
.250	.062	.09	.16	.06	.12

18.4 FILLET WELDS, INSIDE CORNERS

Unless otherwise specified, the following practices shall be applied to inside corner fillet welds for aluminum and steel.

a. The minimum inside fillet weld size (Leg and Throat) shall be as follows:
   1. The size specified on the drawing shall be considered minimum.
   2. When the size is not specified on the drawing, the minimum size shall be equal to the thickness of the thinner member welded (Figure 18-2).

b. The maximum inside fillet weld size (Leg and Throat) shall be as follows:
   1. Equal to the size specified on the drawing plus (+) .062.
   2. When the size is not specified on the drawing, the maximum size shall be as shown in Figure 18-3.

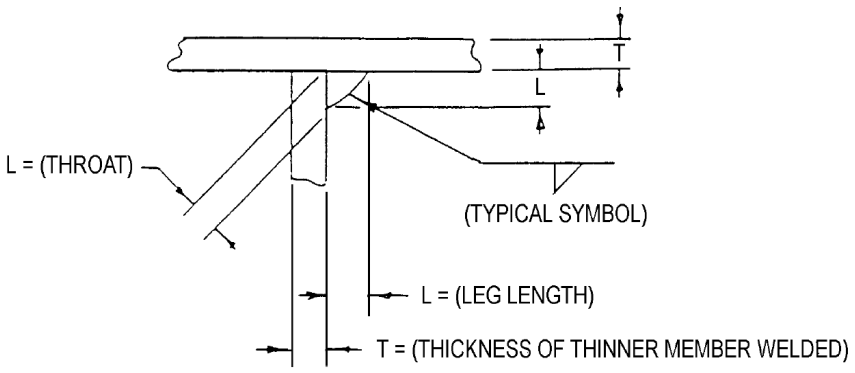


FIGURE 18-1 FILLET WELDS, INSIDE CORNERS MEASUREMENTS

TABLE 18-2 FILLET WELDS, INSIDE CORNERS TOLERANCES

T THICKNESS	L	
	MIN	MAX
.03	.03	.10
.04	.04	.11
.05	.05	.12
.062	.06	.12
.094	.09	.16
.125	.12	.18
.188	.18	.25
.250	.25	.32

18.5 SQUARE – GROOVE WELDS

a. Unless otherwise specified, the following practices shall be applied to square-groove welds for aluminum and steel.

   1. The nearside (symbol side) of the weld shall exhibit an approximately flat-faced condition(s) as shown in Figure 18-4 without recourse to any method of finishing.
   2. The far side (opposite symbol side) of the weld shall exhibit a reinforcement melt-through (H) as shown in Figure 18-4.

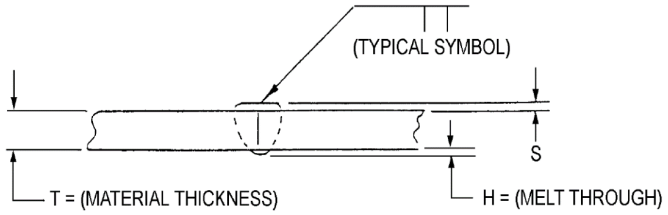


FIGURE 18-1 SQUARE-GROOVE WELDS MEASUREMENTS

TABLE 18-3 SQUARE-GROOVE WELDS TOLERANCES

T	S	H
.062	.03 - .06	.02 - .06
.094	.03 - .06	.02 - .08
.125	.03 - .09	.02 - .08

NOTE: Materials in excess of .125 thickness that need to be butt-welded should have a bevel groove weld.

19 TYPICAL HEADS

Relief Slot For Out Gassing in Vacuum Application --

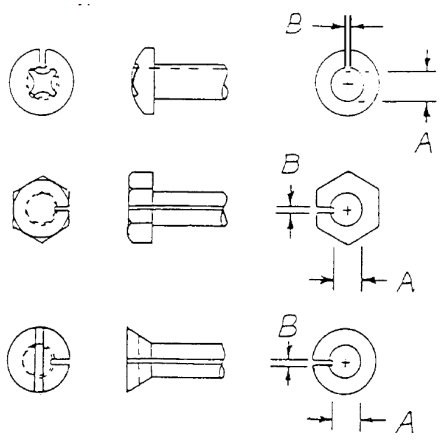


FIGURE 19-1 TYPICAL HEADS

TABLE 19-1 TYPICAL HEADS

THREAD SIZE	A ± .002	B + .004/-.002	THREAD SIZE	A ± .002	B + .004/-.002
4-48 UNF	.0994	.020	1/2-20 UNF	.463	.032
4-40 UNC	.0992	.020	1/2-13 UNC	.445	.032
5-44 UNF	.107	.020	9/16-18 UNF	.522	.032
5-40 UNC	.106	.020	9/16-12 UNC	.504	.032
6-40 UNF	.117	.020	5/8-18 UNF	.585	.063
6-32 UNC	.113	.020	5/8-11 UNC	.560	.063
8-36 UNF	.141	.020	3/4-16 UNF	.704	.063
8-32 UNC	.139	.020	3/4-10 UNC	.679	.063
10-32 UNF	.161	.020			
10-24 UNC	.159	.020			
1/4-28 UNF	.223	.032			
1/4-20 UNC	.212	.032			
5/16-24 UNF	.281	.032			
5/16-18 UNC	.272	.032			
3/8-24 UNF	.343	.032			
3/8-16 UNC	.331	.032			
7/16-14 UNC	.386	.032			
7/16-20 UNF	.400	.032			

20 SHEET METAL PRACTICES

20.1 GENERAL PRACTICES

a. Scribed layout lines are not permissible on aluminum.

b. Sheared edges shall be smoothed by draw filling, machining, or sanding to remove rough edges.

c. Edges of aluminum, at break lines, shall be full radiused and sanded smooth with strips of 220 grit emery cloth prior to breaking.

d. Radii for bend relief when pictorially shown on the drawing, but not dimensioned, shall be ½ of the bend allowance.

   1. The cutouts shall be uniform in size and location for each bend.

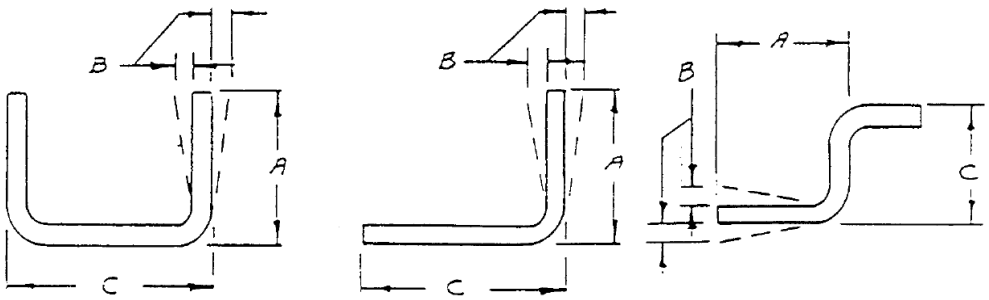
e. Break dies shall be clean and free of nicks or protrusions.

f. Proper dies for breaking shall be used to provide radius required by drawing without thinning or die marking parent metal.

g. Direction or grain, when not specified on drawing, shall be perpendicular to break lines. When two or more angles are to be broken, breaking with the grain shall be on the longest break line.

20.2 ANGULARITY, FORMED PARTS

Unless otherwise specified, angularity tolerance shall be as indicated below:



"B" Shall not be such as to exceed linear tolerance of "C" or "A"

FIGURE 20-1 ANGULARITY, FORMED PARTS

20.3 FLATNESS, SHEET METAL PARTS

Flatness shall be as indicated below:

TABLE 20-1 FLATNESS, SHEET METAL PARTS

MATERIAL THICKNESS		ALL TOLERANCES PLUS OR MINUS		
FROM	TO & INCL	TOLERANCE PER INCH	MAXIMUM TOLERANCE	
			TO 16” INCL	16” TO 48” INCL
---	.062	.006	.090	.125
.062	.093	.007	.100	.140
.093	.125	.009	.125	.175
---	.062	.003	.040	.055
.062	.093	.004	.050	.070
.093	.125	.005	.065	.090
---	.062	.004	.050	.070
.062	.093	.005	.065	.090
.093	.125	.007	.100	.140
---	.062	.003	.040	.055
.062	.093	.005	.065	.090
.093	.125	.007	.100	.140

NOTE: Flatness deviation to be measured perpendicular at the point of maximum departure of the curved edge from a straight line joining the extremities of the edge.

20.4 HOLES, BELL MOUTH

When a punched hole has a bell mouth flare extending into the hole, the bell mouth shall not exceed 1/3 the material thickness. This may cause the hole to be out of tolerance for 1/3 the material thickness.

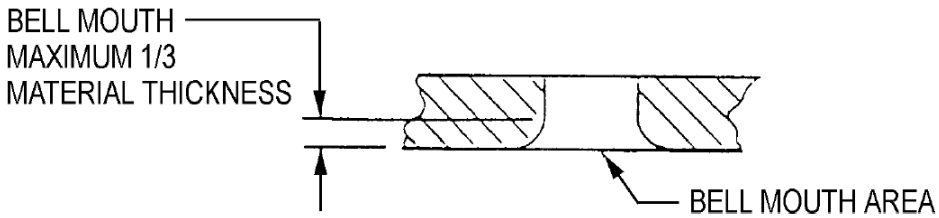


FIGURE 20-2 HOLES, BELL MOUTH MEASUREMENT

20.5 TWIST, FORMED PARTS

Tolerance on the twist will not exceed the value given in Table 20-2.

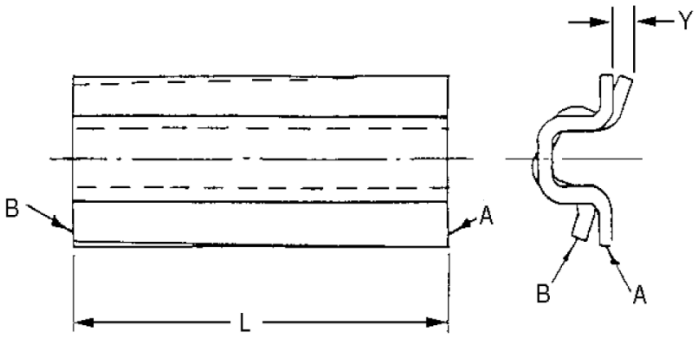


FIGURE 20-3 TWIST, FORMED PARTS

TABLE 20-2 TWIST, FORMED PARTS TWIST TOLERANCE

THICKNESS OF MATERIAL	LENGTH "L"		TOLERANCE FOR TWIST "Y"
UP TO AND INCLUDING .125"	FROM	TO & INCL	
	----	1.00	± .015
	1.00	12.00	± .030
	12.00	24.00	± .046