Chapter

22

Floating and Fixed Fasteners

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22.1 Introduction

Systems, subsystems, subassemblies, and/or parts that require disassembly (for maintenance, upgrades, or replacement of defective parts) are typically designed using snap fits, threaded fasteners, or rivets. This chapter discusses the design and manufacturing considerations for threaded fasteners and rivets.

22.2 Floating and Fixed Fasteners

The intent of a design is to meet all functional requirements, one of these being interchangeability. With that in mind, the Geometric Dimensioning and Tolerancing (GD&T) standard ASME Y14.5M-1994 documents the rules for fixed and floating fasteners. The GD&T standard covers both the fixed and floating fastener rules in Appendix B, "Formulas for Positional Tolerancing." To understand and use the rules, we must first identify the *type* of condition (or case) where the fastener is being used. There are three different

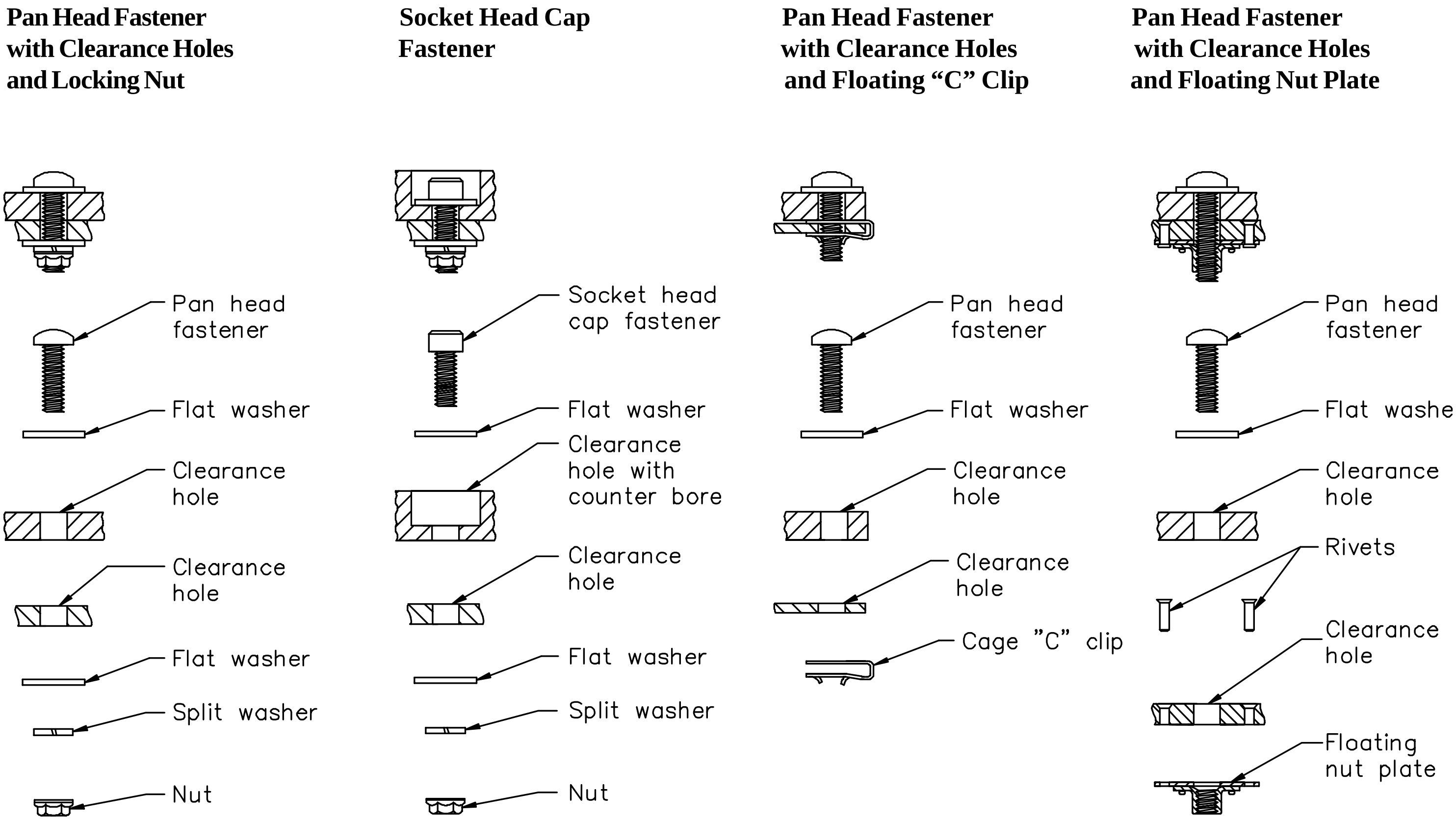

Figure 22-1 Examples of floating fasteners

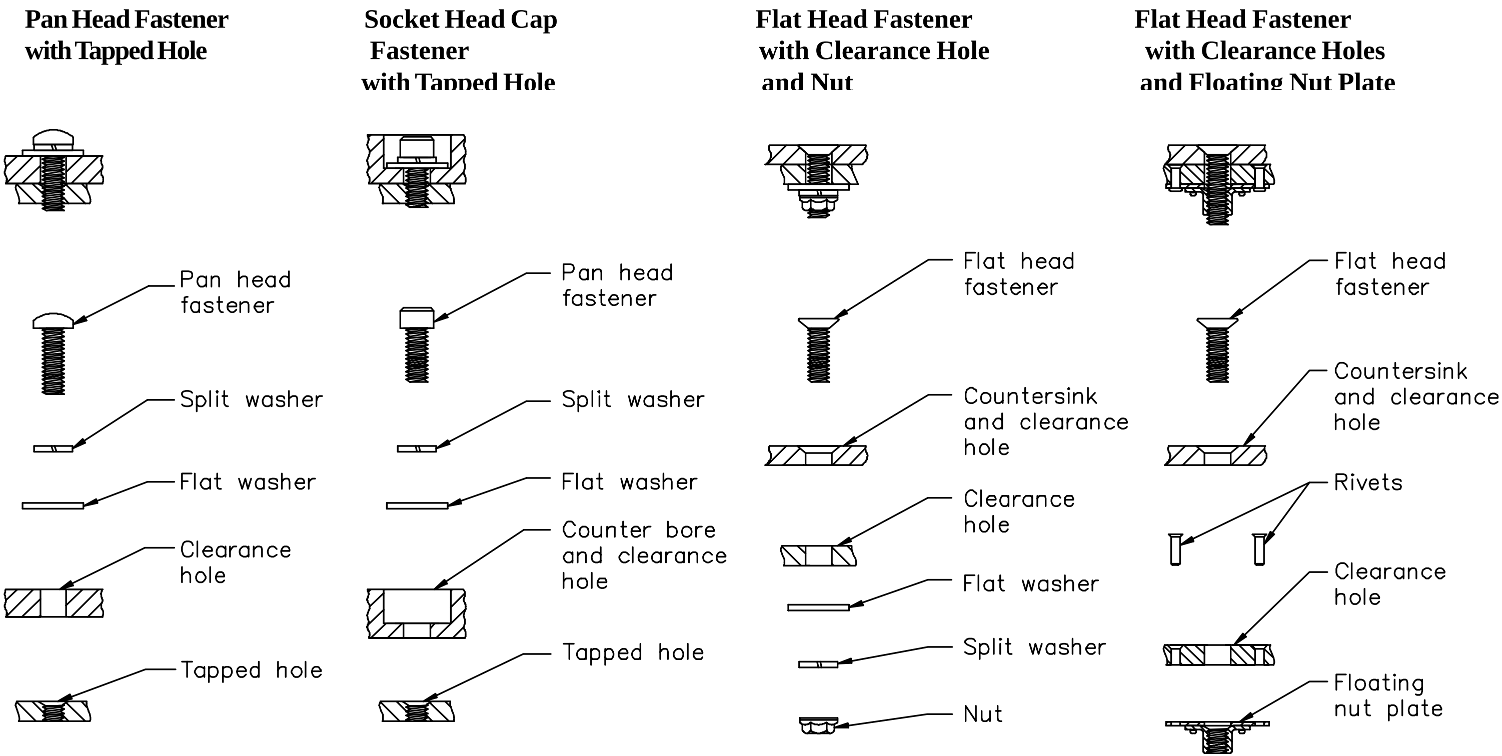

Figure 22-2 Examples of fixed fasteners

conditions: floating fasteners, fixed fasteners, and double-fixed fasteners. Y14.5 only discusses the floating fastener case and the fixed fastener case.

22.2.1 What Is a Floating Fastener?

A floating fastener is a bolt, pan head fastener, socket head fastener, and nut, C'Clip, or floating nut plate used to fasten two or more parts together. All parts have clearance holes and the nut plates must be free floating (see Fig. 22-1).

22.2.2 What Is a Fixed Fastener?

A fixed fastener uses a bolt, pan head fastener, socket head fastener, flat head fastener or alignment pin. One end of the fastener (or pin) is restrained in a tapped hole or is pressed into a hole. The other end of the fastener (or pin) is free to float in a clearance hole (see Fig. 22-2). In the case of a flat head fastener, the countersink diameter/clearance hole and the angle of the flat head fastener by design will constrain the fastener, making it a fixed fastener application.

22.2.3 What Is a Double-Fixed Fastener?

Y14.5 does not discuss what is known as a double-fixed fastener. A double-fixed fastener uses a flat head threaded fastener with a countersink, which restrains the head, and a tapped hole that effectively restrains both ends of the fastener (see Fig. 22-3).

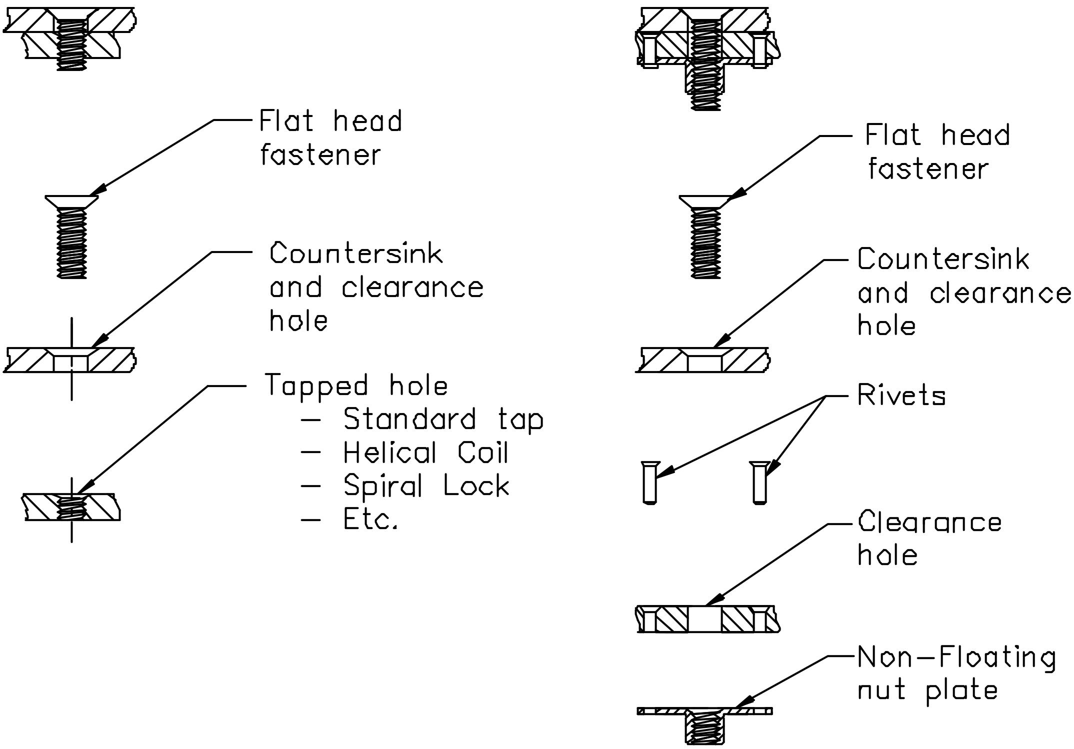

Figure 22-3 Examples of double-fixed fasteners

22.3 Geometric Dimensioning and Tolerancing (Cylindrical Tolerance Zone Versus +/- Tolerancing)

Tolerancing fixed and floating fasteners is frequently done so that the mating parts are 100% interchangeable. The methods of allocating tolerances discussed in Y14.5 ensure 100% interchangeability. In these applications, three things determine the size of the clearance holes:

1) The location tolerance that is applied to the clearance hole
2) The location tolerance that is applied to the mating tapped hole (for a fixed fastener) or the mating clearance hole (for a floating fastener)
3) The size tolerances applied to the holes

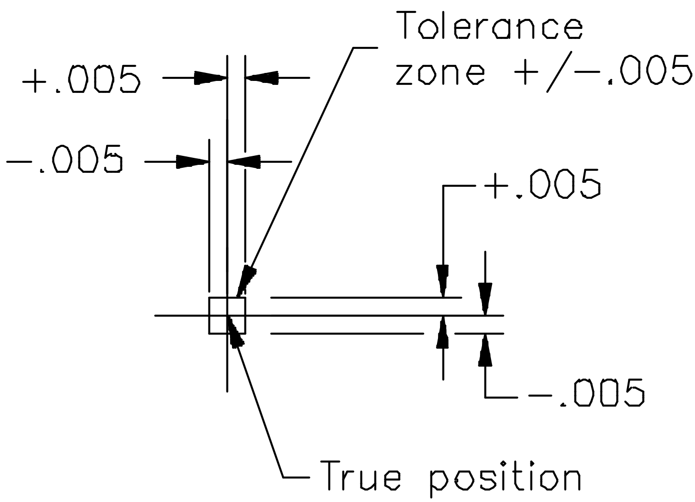

Figure 22-4 Rectangular tolerance zone (plus/minus tolerancing)

Historically, there have been two types of tolerancing methods used: plus or minus tolerancing (a rectangular tolerance zone usually shown as, e.g., ±.005) and positional tolerancing (a cylindrical tolerance zone). An example of a rectangular, or ± tolerance zone, is shown in Fig. 22-4.

Fig. 22-5 shows an example of a cylindrical tolerance zone: (∅) .014. The rules in Y14.5 use a cylindrical tolerance zone to locate the features. In general, if a system is designed using threaded fasteners, bolts, rivets, or alignment pins, cylindrical fasteners are installed into a cylindrical hole. The functional tolerance zone that can accept all conditions and sizes of mating features is a cylindrical tolerance zone.

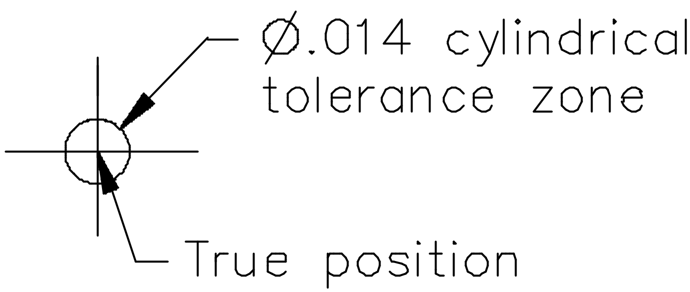

Figure 22-5 Cylindrical tolerance zone

When calculating the size of the clearance hole, the engineer should take into account the amount of allowable variation for both the clearance hole and the tapped hole. Fig. 22-6 shows a fixed fastener example with a .250-28 UNF-2B threaded fastener. Suppose the tapped hole was perfectly located (.000, .000), and the clearance hole deviates from its position in the X direction by .005, and is at nominal in the Y direction (+.005, .000) (see Fig. 22-6). If we were to calculate the hole size that is required to permit the fastener to pass through, the size of the clearance hole for this example is .260 diameter (∅.260). The same size clearance hole is necessary if the hole deviates from its position in the opposite direction by .005 (-.005,.000).

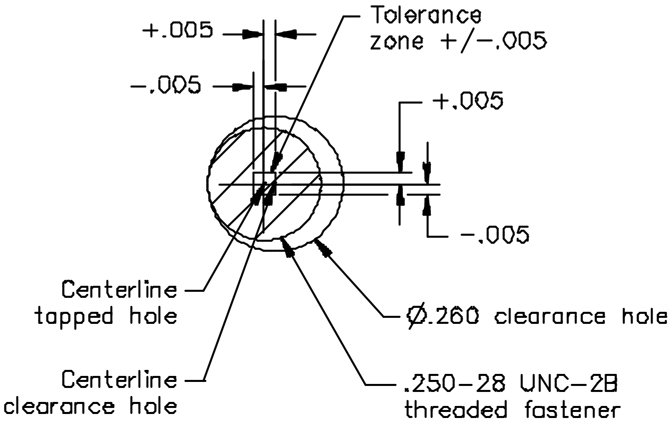

Figure 22-6 Tapped hole located (.000, .000) and clearance hole off location by (+.005, .000)

Let's assume the design engineer takes into account the allowable variation for both the clearance hole and the tapped hole. If the .250-28 UNF-2B tapped hole was located (-.005, .000) and the clearance hole was located (+.005, .000), the size of the clearance hole for this example would be .270 diameter (∅.270). This would account for the possibility of a +.005 / -.005 shift of both the tapped hole and the clearance hole (see Fig. 22-7).

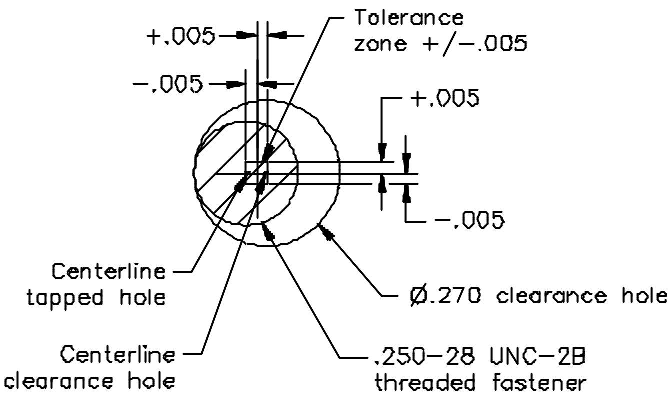

Figure 22-7 Tapped hole is located (-.005, .000) and clearance hole is located (+.005,.000)

Let's look at a worst case location tolerance. The hole size must be calculated when both the tapped hole and the clearance hole are at their worst case location. Assume the tapped hole was located at its worst case location, (X direction was at -.005, and the Y direction was at -.005 (-.005, -.005)), and the clearance hole was also located at its worst case location, (X direction at +.005, and the Y direction at +.005

(+.005, +.005)). Refer to Fig. 22-8. This results in the worst case possible location of both the threaded hole and the tapped hole). The size of the clearance hole for this example is ∅.278 to account for the possibility of a +.005,-.005 shift of both the tapped hole and the clearance hole (see Fig. 22-8). By manufacturing a part at the worst case location tolerance of +/-.005, the feature is located a radial distance of .007 from the nominal dimension.

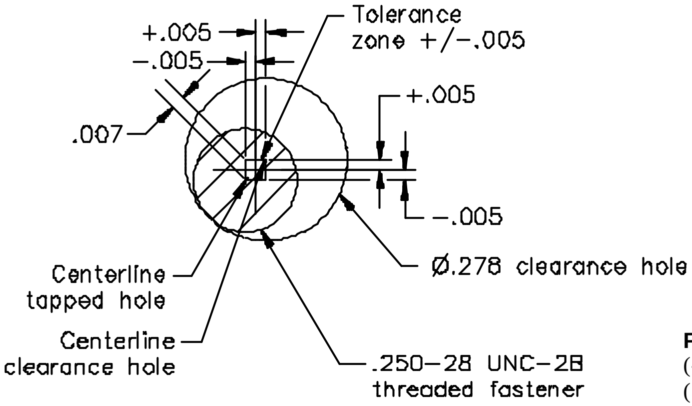

Figure 22-8 Tapped hole is located (-.005, -.005) and clearance hole is located (+.005, +.005)

If the tapped holes and the clearance holes that are located by (+.005, -.005) are functional parts that have a .007 radial location, then a tapped hole manufactured at (-.007, .000) and the clearance hole manufactured at (+.007, .000) is also functional. Its tolerance zone also results in a .007 radial location (see Fig. 22-9). The resulting tolerance zone is a diameter .014.

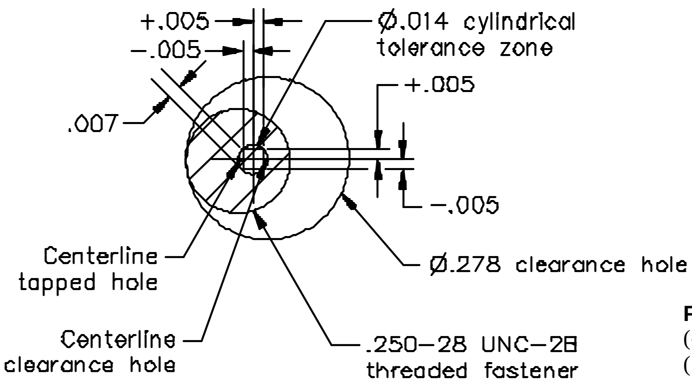

Figure 22-9 Tapped hole is located (-.007, .000) and clearance hole is located (+.007, .000)

Allowing a tolerance of (+.007, .000) for the clearance hole and (-.007, .000) for the tapped hole, the tolerance zone is effectively a diametrical (cylindrical) tolerance zone of ∅.014. The use of a cylindrical tolerance zone is the preferred method because it allows all functional parts to be used. If a ±.005 tolerance zone had been used, this part would have been rejected (see Fig. 22-10).

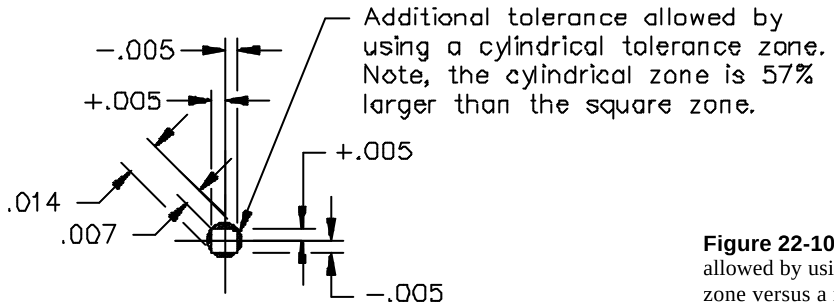

Figure 22-10 Additional tolerance allowed by using a cylindrical tolerance zone versus a rectangular tolerance zone

22.4 Calculations for Fixed, Floating and Double-fixed Fasteners

The purpose of this section is to demonstrate the formulas for calculating the fixed, floating, and double-fixed fasteners. The purpose in calculating the applicable tolerances and hole sizes are two-fold. The first objective is to assure the interchangeability of mating parts and subassemblies. The second is to allocate tolerances with process capabilities in mind, ensuring that the parts can be manufactured cost effectively. The rules or formulas for calculating the fixed and floating fasteners are straightforward.

First we should establish the symbols to be used in the formulas:

FD = Fastener maximum material condition (MMC) size (diameter)
CH = Clearance hole nominal size (diameter)
STCH = Lower limit size tolerance for the clearance hole (diameter)
CBD = Counterbore (C'Bore) nominal size (diameter)
STCBH = Lower limit size tolerance for the C'Bore hole (diameter)
WD = Flat washer MMC size of the outer diameter
PTCH = Positional tolerance of the clearance hole (diameter)
PTTH = Positional tolerance of the tapped hole (diameter)
PTCBH = Positional tolerance of the C'Bore hole (diameter)

22.5 Geometric Dimensioning and Tolerancing Rules/Formulas for Floating Fastener

Assembled parts that have clearance holes in all parts are referred to as floating fastener applications (see Fig. 22-1).

22.5.1 How to Calculate Clearance Hole Diameter for a Floating Fastener Application

The formula for calculating a clearance hole diameter for a floating fastener application follows:

CH = FD + PTCH + STCH

An example of the calculation follows. If we were designing a fastened assembly with a .250-28 UNF-2B fastener being used, then FD would be equal to ∅.250.

CH = ∅.250 + PTCH + STCH

Next, we assign a Six Sigma tolerance for the location tolerance of the clearance holes. (Refer to Chapter 11 for detailed discussion on Six Sigma tolerancing.) Let us assume that for a Numerical Controlled (N/C) machining process, the Six Sigma tolerance value is ∅.014 for the location of a clearance hole. Therefore we set PTCH equal to ∅.014.

CH = ∅.250 + ∅.014 + STCH

Then we assign a Six Sigma tolerance for the size tolerance of the hole. When drilling a hole, the drill will normally produce a hole that is larger than the drill diameter. As the drill wears, it will produce holes that are undersized. Knowing that the drilling operations process is a skewed distribution, we must take this into account. Knowing that the process capability for a drill hole results in a skewed distribution, let us assume the Six Sigma tolerance range for the drilling process is +.005/-.002. Since we are trying to calculate the nominal diameter for the clearance hole drill size, we must add the negative size tolerance (or the STCH). We then set the STCH equal to .002 to get to the nominal diameter of the clearance hole.

$$CH = \varnothing.250 + \varnothing.014 + \varnothing.002$$

$$CH = \varnothing.266$$

Once the clearance hole has been calculated, go to the drill chart and pick the nearest drill size from a drill chart. We select the nearest drill size so that we do not need to manufacture a special form cutter. In this case, the nearest drill size is ∅.2656 (17/64). The clearance hole diameter is ∅.266 +.005/-.002

22.5.2 How to Calculate Counterbore Diameter for a Floating Fastener Application

To calculate the diameter of the counterbore to be used for a .250-28 UNF-2B fastener, the diameter of the flat washer must be used in the floating fastener formula. The formula for calculating a counterbore diameter is as follows:

$$CBD = WD + PTCBH + STCBH$$

We must use the MMC size of the flat washer diameter (WD) to calculate the counterbore diameter. If the outside diameter and the size tolerance of the washer are ∅.734 +.015/-.007, the MMC of the washer is ∅.749. Therefore, we set the WD equal to ∅.749.

$$CBD = \varnothing.749 + PTCBH + STCBH$$

Note: This formula does not take into account any allowable shifting between the inner diameter of the washer and the outer diameter of the fastener.

The next step is to assign a Six Sigma tolerance for the location of the clearance holes. If we assume the Six Sigma tolerance for the location of a clearance hole using an N/C machining process is ∅.014, we set PTCBH equal to ∅.014.

$$CBD = \varnothing.749 + \varnothing.014 + STCBH$$

Next, we assign a Six Sigma size tolerance for the counterbore diameter. When machining a counterbore, there are three methods of manufacturing the counterbore holes. One method is to use a mill cutter and plunge the cutter to depth. The second method is to use a form cutter that creates both the clearance hole and the counterbore holes in the same operation. The third method is to profile mill the diameter using an undersized cutter. Both the plunging and form cutter drill operation are comparable to a drilling operation. Both will produce a hole that is larger than the diameter of the cutter. As the drill wears, it will produce holes that are undersized. With this in mind, the process capability of the plunged hole or the form cutter hole results in a skewed distribution, and the Six Sigma tolerance for the drilling process is +.005/-.002. If the counterbore were profile milled, the process capability results in a tolerance of +/-.010 for the diameter of the clearance hole. In this example, we will use the profile milling method. Therefore, we set the STCBH equal to .010 to get to the nominal diameter of the counterbore hole.

Note: Process capabilities for tolerances shown in these examples reflect industry standards. Process capability studies should be conducted to establish shop specific process capabilities. (Reference Chapters 8, 10, and 17 for information on Cp, Cpk, and process capabilities.)

$$CBD = \varnothing.749 + \varnothing.014 + \varnothing.010$$

$$CBD = \varnothing.773$$

Once the counterbore hole size has been calculated, go to the drill chart and pick the nearest drill size from the drill chart. In this case, the nearest drill size is ∅.781 (25/32). The counterbore hole diameter is ∅.781 +/-.010.

22.5.3 Why Floating Fasteners Are Not Recommended

The use of floating fasteners is not a recommended practice. When assembling parts and/or subassemblies, it requires work on both sides of the parts to tighten the fasteners and to hold the nuts. When designing large systems such as automobiles, it could require two people working together to tighten the hardware. If floating fasteners are necessary, the design engineer should consider using captive hardware such as a C'Clip or nut plate that alleviates the problem of requiring two assemblers. However, the use of C'Clips and/or nut plates adds additional hardware, complexity, and additional process steps. This additional hardware results in additional cost and assembly time.

22.6 Geometric Dimensioning and Tolerancing Rules/Formulas for Fixed Fasteners

As shown in Fig. 22-2, assemblies having a clearance hole in one part and a tapped hole in the other are fixed fastener applications.

22.6.1 How to Calculate Fixed Fastener Applications

The formula for calculating a clearance hole diameter for a fixed fastener application is:

CH = FD + PTCH + PTTH + STCH

An example of the calculation follows. If we were designing a fastened assembly where a .250-28 UNF-2B fastener is being used, then set FD equal to .250.

CH = ∅.250 + PTCH + PTTH + STCH

Next we assign Six Sigma tolerances to the location of both the clearance hole and the tapped holes. Since the drilling and tapping is also done on an N/C machining process, the Six Sigma tolerance is ∅.014 for a drilled and tapped hole. Set both PTCH and the PTTH equal to ∅.014.

CH = ∅.250 + ∅.014 + ∅.014 + STCH

Again, assign a Six Sigma tolerance for the size tolerance of the hole, and set STCH equal to ∅.002.

CH = ∅.250 + ∅.014 + ∅.014 + ∅.002

CH = ∅.280

The nearest or next largest drill size is ∅.2812 (9/32). The clearance hole diameter is:

CH = ∅.281 +.005/-.002

Note: In the fixed fastener cases, variations in the perpendicularity of the tapped hole or pressed-in pins will cause a projected error that could cause interference in mating parts. To avoid this, the hole in the mating part needs to be enlarged to account for the error, or a projected tolerance zone must be applied to the threaded holes.

22.6.2 How to Calculate Counterbore Diameter for a Fixed Fastener Application

To calculate the diameter of the counterbore to be used for a .250-28 UNF-2B fastener, the diameter of the flat washer must be used in the fixed fastener formula. The fixed fastener formula for calculating a counterbore diameter follows:

CBD = WD + PTCBH + PTTH + STCBH

CBD = ∅.749 + ∅.014 + ∅.014 + ∅.010

CBD = ∅.787

Note: This formula does not take into account any allowable shifting between the inner diameter of the washer and the outer diameter of the fastener.

Once the counterbore size is calculated, go to the drill chart and pick the nearest or next largest drill size from the drill chart. In this case, the nearest or next largest drill size is ∅.797 (51/64). The counterbore hole diameter is ∅.797 +/-.010

Note: In the fixed fastener cases, variations in the perpendicularity of the tapped hole will cause a projected error that could cause interference in mating parts. To avoid this, the hole in the mating part needs to be enlarged to account for the error, or a projected tolerance zone must be applied to the threaded holes.

22.6.3 Why Fixed Fasteners Are Recommended

Fixed fasteners are recommended when assembling parts or subassemblies. Fixed fasteners allow Z axis or top down assembly. There is no additional hardware to assemble the fastener, no C'Clips, no floating nut plates, no rivets to hold the floating nut plates, and no nuts. It also takes less time to assemble. As long as the parts are not repeatedly assembled and disassembled, the use of self-tapping fasteners is highly recommended because they do not require an additional tapping operation.

22.7 Geometric Dimensioning and Tolerancing Rules/Formulas for Double-fixed Fastener

When assembling parts using a flat head fastener, the threads on the fastener in the tapped hole and the flat head fastener are restrained by the countersink. This effectively restrains both ends of the fastener (see Fig. 22-3). Since both ends of the flat head fastener are restrained, theoretically both parts must be perfectly located in order to assemble the mating parts. Since locational tolerances for both the tapped hole and clearance hole are required to make the parts manufacturable, the locational tolerance is calculated using the fixed fastener rule. Assigning locational tolerances to both the tapped hole and the countersink causes the flat head fastener head height to be above or below the surface.

22.7.1 How to Calculate a Clearance Hole

The formula for calculating the clearance hole for a double-fixed fastener is the same as the fixed fastener application:

CH = FD + PTCH + PTTH + STCH

Here is an example. Let's say we were designing a double-fixed fastened assembly where a .250-28 UNF-2B fastener is being used. It has a positional tolerance of ∅.014, and the fastener diameter (FD) is equal to ∅.250,

CH= ∅.250 + ∅.014 + ∅.014 + ∅.002

CH = ∅.280

Again, the nearest drill size is ∅.2812 (9/32). The clearance hole is:

CH = ∅.281 +.005/-.002

22.7.2 How to Calculate the Countersink Diameter, Head Height Above and Head Height Below the Surface

When calculating the countersink diameter for a flat head fastener, we must control the head height above and below the surface. The worst case head height above the surface occurs when the countersink/clearance hole and the tapped holes are off location by the maximum allowable - when the flat head diameter is at its MMC and the countersink diameter is at its MMC (see Fig. 22-11). The worst case head

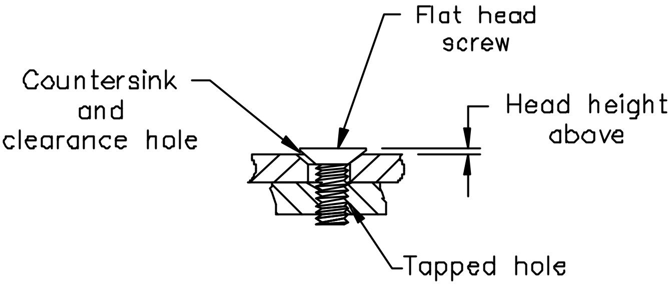

Figure 22-11 Worst case head height above the surface

height below the surface occurs when the countersink/clearance hole and the tapped holes are on perfect location, when the flat head diameter is at its least material condition, and the countersink diameter is at its least material condition (see Fig. 22-12).

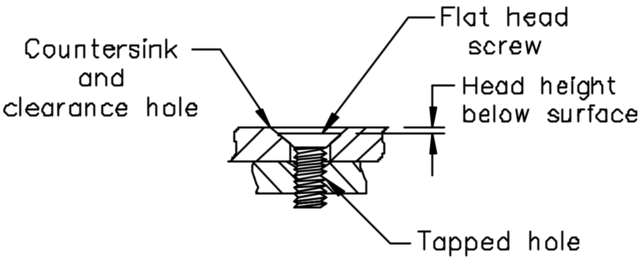

Figure 22-12 Worst case head height below the surface

First we should establish the symbols to be used in the formulas:

CSHM = Countersink MMC diameter (nominal countersink diameter - STCSH)
CSHL = Countersink LMC diameter (nominal countersink diameter + STCSH)
STCSH = Equal bilateral size tolerance for the countersink hole
FHDM = Flat head fastener MMC diameter
FHDL = Flat head fastener LMC diameter
PTCH = Positional tolerance of the clearance hole and countersink diameter
PTTH = Positional tolerance of the tapped hole
CSA = Countersink included angle (82° or $100^\circ \pm 1^\circ$)
CSAMin = Minimum countersink included angle (CSA - 1°)
HHA = Head height above
HHB = Head height below

The formulas for calculating the head heights for a double-fixed fastener application are:

HHA = ((.5*FHDM)-(.5*CSHM)+(.5*PTTH)+(.5*PTCH))/TAN(.5*CSAMin)

and

HHB = ((.5*FHDL)-(.5*CSHL))/TAN(.5*CSAMax)

Note: These formulas do not take into account the perpendicularity of the tapped hole. When calculating the head height above and the head height below, the objective is to determine a countersink diameter that allows an equal bilateral tolerance on the amount the head of the fastener is above and below the surface. In the double-fixed fastener cases, variations in the perpendicularity of the tapped hole will cause a projected error that could cause interference in mating parts. It could increase the amount the head of the flat head fastener will protrude above the surface.

For this example, the objective is to determine a countersink diameter that allows an equal bilateral tolerance on the amount the head of the fastener is above and below the surface. Therefore, we should solve the equations simultaneously to obtain an equal head height above and below the surface.

Fig. 22-13 shows a .250-28 UNF-2B flat head fastener with a 100° flat head (100° included angle).

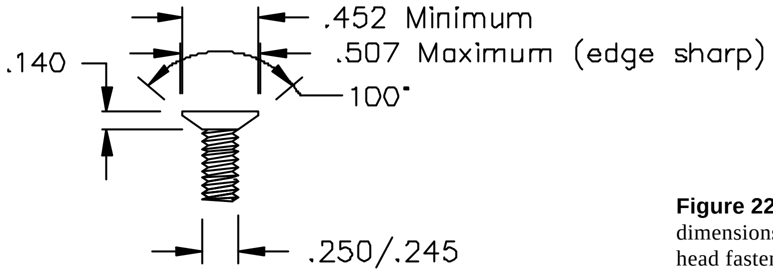

Figure 22-13 Flat head fastener dimensions for a .250-28-UNC 2B flat head fastener

When solving for head height above, we set the flat head fastener diameter at MMC (∅.507). Next we set the minimum included countersink angle (CSAMin) to 99° (100° - 1°). The positional tolerances for the clearance/countersink hole and the tapped hole are position ∅.014.

If we assume the countersink diameter to be the same as the flat head screw and set the countersink diameter to ∅.510±.010, then the MMC diameter of the countersink is ∅.500. Therefore we set CSHM = ∅.500, and:

HHA = ((.5*FHDM)-(.5*CSHM)+(.5*PTTH)+(.5*PTCH))/TAN(.5* CSAMin)

HHA = ((.5*.507)-(.5*.500)+(.5*.014)+(.5*.014))/TAN(.5*99 °)

HHA = (.2535 - .250 + .007 + .007)/TAN(49.5 °)

HHA = .0175 / 1.170849566113 =. 0.01622753302381

HHA = .0149

When solving for head height below the surface, we use the LMC of the fastener head diameter. We set FHDL = ∅.452. Since we set the countersink diameter equal to ∅.510 ±.010, then the LMC diameter of the countersink is ∅.520 and we set CSHL = ∅.520. The angle of the flat head fastener that is used is 100°. Therefore we set CSAMin = 100° - 1° = 99°. Again, the positional tolerance of the clearance hole/countersink hole and the tapped hole are a ∅.014.

Therefore:

HHB = ((.5*FHDL)-(.5*CSHL)) / TAN(.5* CSAMin)

HHB = ((.5*.452)-(.5*.520)) / TAN(.5*99 °)

HHB = (.226-.260) / TAN(49.5 °)

HHB = -.034 / 1.170849566113 = -0.02476833987843

HHB = -.029

Note: To determine the amo unt a flat head screw is above or below the surface, reference Table 22-5, “Flat Head Screw Height Above and Below the Surface.”

22.7.3 What Are the Problems Associated with Double-fixed Fasteners?

As stated in section 22.7.2, when using a double-fixed fastener, we must control the head height above and below the surface. The worst case head height above the surface occurs when both the countersink/clearance hole and the tapped holes are off location by the maximum amount, when the flat head diameter is at its MMC, and the countersink diameter is at its MMC (see Fig. 22-11). Statistically, the probability that the countersink and tapped hole will deviate from their theoretical perfect locations is much greater than it is for the countersink, clearance hole, and tapped hole being perfectly located. Therefore, there is a greater chance for the head of the flat head fastener to be above the surface than below. This can be resolved by making the countersink diameter larger if the material thickness allows.

Another problem associated with the use of double-fixed fasteners is the countersink diameter. Normally, the countersink diameter is toleranced +/-.010, while the clearance hole diameter is toleranced +.005 / -.002. Since the countersink diameter controls the head height, the additional tolerance allocated to a countersink increases the head height above the surface.

22.8 Nut Plates: Floating and Nonfloating (see Fig. 22-14)

When designing a fastener assembly that uses a floating nut plate, the engineer should account for several factors:

- The type of nut plate being used (floating or nonfloating) and the amount of float that the nut plate has designed into it
- The type of fastener assembly (floating, fixed, or double-fixed fastener assembly)
- The tolerancing scheme used for the rivet holes used to mount the nut plate
- The amount of tolerance that is applied to the rivet holes

The formulas used for calculating the clearance hole sizes are discussed in sections 22.5, 22.6, and 22.7.

In the following example, we will look at a floating fastener assembly that uses a floating nut plate. To standardize hole sizes when designing a fastener assembly using a floating nut plate, the following method could be used to calculate the clearance hole tolerance and the rivet hole tolerance.

PTCH = (CH - STCH - FD)/2

If we use the clearance hole diameter that was calculated for a fixed fastener using a .250-28 UNF-2B fastener, then CH is equal to ∅.2812.

PTCH = (.2812 - .002 - .250)/2

PTCH = ∅.0146

For the part that only has the clearance hole, it is straightforward. The PTCH can be applied directly to the part that only has a clearance hole. Therefore the positional tolerance of the clearance hole would be set to ∅.014.

For the mating part (the part that has both the nut plate and a clearance hole), the ∅.014 tolerance must be distributed to both the clearance hole and the floating nut plate rivet holes that are used to mount the floating nut plate. The required positional tolerance for the rivet holes and the diameter of the rivet must be taken into account. If the rivet holes are a ∅.098 +.005/-.001, and the rivet diameter is ∅3/32 (∅.093), we would then need to calculate the required tolerance to the rivet holes. The following calculations show that the tolerance required for the rivet hole results in PTRH = ∅.002.

PTRH = (CHDR - RD) / 2

PTRH = (.097 - .093) / 2

PTRH = ∅.002

where,

PTRH = Positional tolerance of the rivet hole (diameter)

CHDR = Rivet hole MMC size (diameter)

RD = Rivet MMC size (diameter)

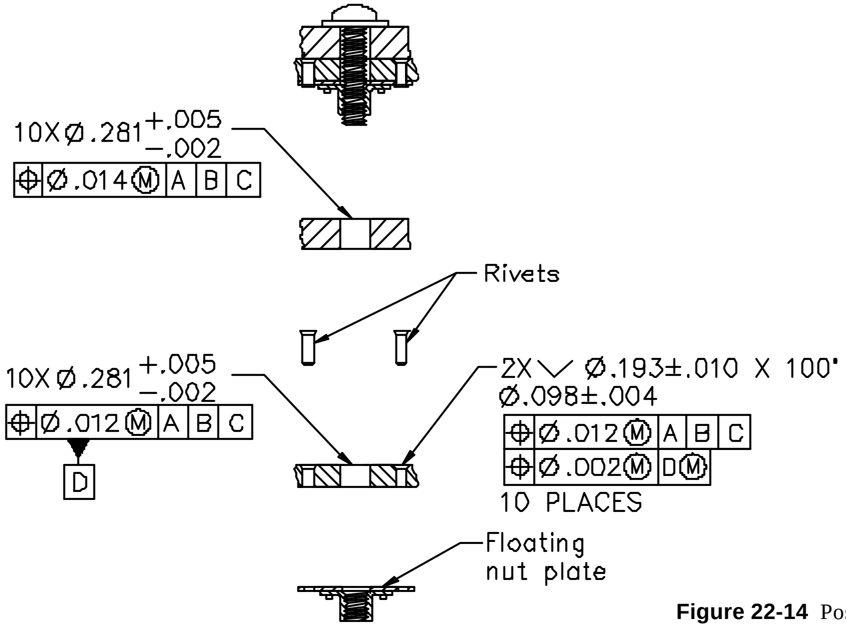

Figure 22-14 Positional tolerance for clearance holes and nut plate rivet holes

22.9 Projected Tolerance Zone

When using fixed or double-fixed fasteners, a projected tolerance zone should be used regardless of whether the design is using threaded fasteners or alignment pins. Variation in the perpendicularity of the screw or pin could cause assembly problems. If a threaded fastener was out of perpendicular by the total amount of the positional tolerance of (∅.014), an interference problem could occur (see Figs. 22-15 and 22-16).

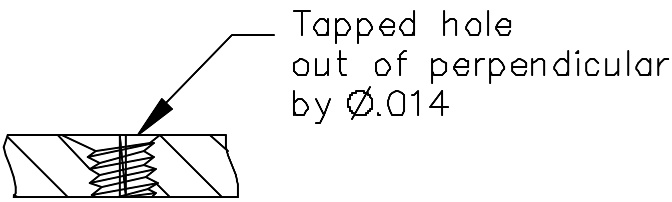

Figure 22-15 Tapped hole out of perpendicular by ∅.014

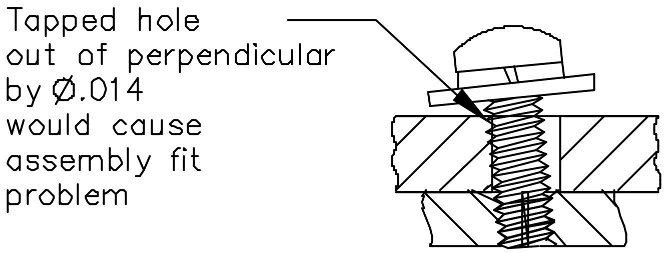

Figure 22-16 Variation in perpendicularity could cause assembly problems

Fig. 22-17 shows how a projected tolerance zone corrects the interference problem shown in Fig. 22-16. The projected tolerance zone is applied to the threaded fastener or the pressed pin. The tolerance zone for the tapped hole extends through the mating parts clearance hole, thereby assuring the mating parts will fit.

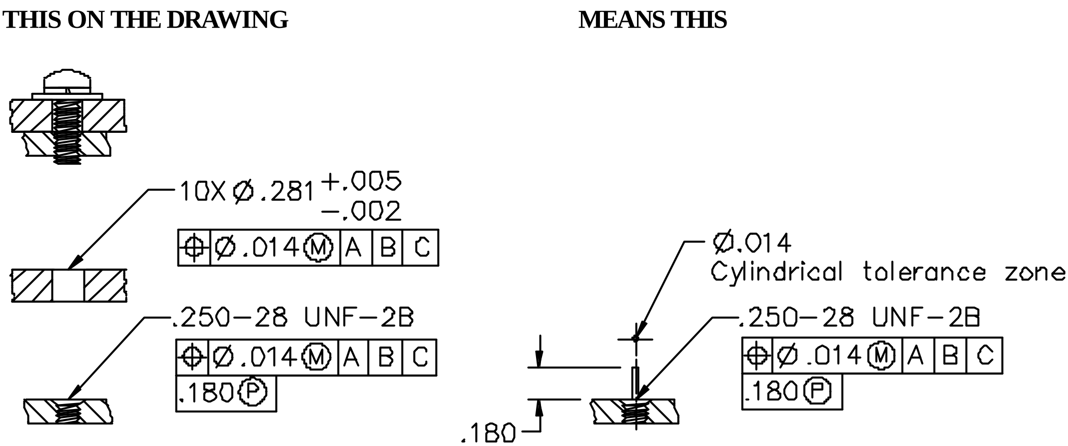

Figure 22-17 Projected tolerance zone example

22.9.1 Comparison of Positional Tolerancing With and Without a Projected Tolerance Zone

This section compares two position tolerancing methods to locate size features for fixed fasteners. In the first method, we use a projected tolerance zone and calculate the functional tolerance zone using the fixed fastener formulas, as shown previously. We consider this a *functional* method for the case of a fixed fastener. In the second method, we convert the projected tolerance zone to a zone that is *not* projected, and consider this a *nonfunctional* method. As a comparison, we then calculate how much tolerance is lost when dimensioning nonfunctionally.

Assuming a maximum orientation (perpendicularity) error, Fig. 22-18 shows the relationships between the functional (projected) tolerance zone, T_f, and the nonfunctional tolerance zone, T_{nf} (not projected).

$$\frac{T_f/2}{(D/2)+P} = \frac{T_{nf}/2}{(D/2)} \tag{22.1}$$

Where D is the depth of the nonfunctional tolerance zone, and P is the projected height of the functional tolerance zone (see Fig. 22-18).

Eq. (22.1) reduces to:

$$T_{nf} = \frac{T_f}{\left(\dfrac{2P}{D}+1\right)} \tag{22.2}$$

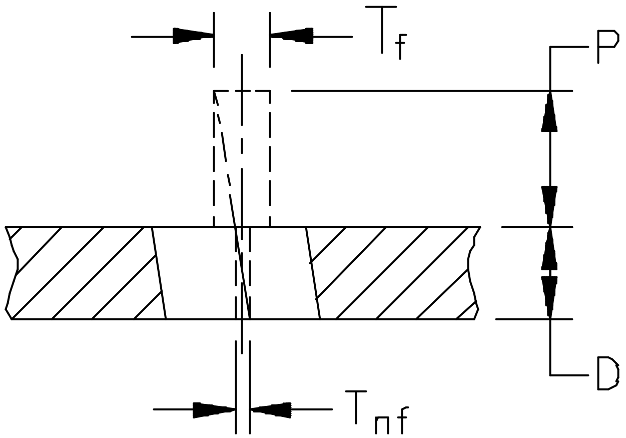

Figure 22-18 Projected tolerance zone — location and orientation components

If we measure the orientation of a feature on a workpiece, we can verify the following relationship:

$$T_{nf,orientation,actual} = \frac{T_{f,orientation,actual}}{\left(\frac{2P}{D}+1\right)} \quad (22.3)$$

where $T_{nf,\,orientation,actual}$ is the measured nonfunctional orientation error and $T_{f,\,orientation,actual}$ is the measured functional orientation error.

If we tolerance functionally, the maximum *allowable* location tolerance, $T_{f,\,location,maximum}$ for a given (actual) orientation error in the functional tolerance zone is:

$$T_{f,\,location,\max imum} = T_f - T_{f,\,orientation,actual} \quad (22.4)$$

If we tolerance nonfunctionally, the maximum allowable location tolerance, $T_{nf,\,location,maximum}$, for given (actual) orientation is:

$$T_{nf,\,location,\,\max imum} = T_{nf} - T_{nf,\,orientation,\,actual} \quad (22.5)$$

The difference between Eq. (22.4) and Eq. (22.5) represents the amount of allowable location tolerance that is lost by dimensioning nonfunctionally.

$$D = T_{f,location,\max imum} - T_{nf,\,location,\max imum} = T_f - T_{f,\,orientation,actual} - T_{nf} + T_{nf,\,orietation,\,actual} \quad (22.6)$$

Substituting Eq. (22.2) and Eq. (22.3) into Eq. (22.6) gives:

$$D = T_f - T_{f,orientation,actual} - \left[\frac{T_f}{\left(\frac{2P}{D}+1\right)}\right] + \left[\frac{T_{f,orientation,actual}}{\left(\frac{2P}{D}+1\right)}\right]$$

$$D = \left(T_f - T_{f,orientation,actual}\right)\left[\frac{2P}{(2P+D)}\right] \quad (22.7)$$

22.9.2 Percent of Actual Orientation Versus Lost Functional Tolerance

Fig. 22-19 demonstrates how much functional tolerance is lost as a function of actual orientation tolerance. The Y-axis is the percent that the actual orientation tolerance contributes to the total tolerance. The X-axis is the Δ value.

22.10 Hardware Pages

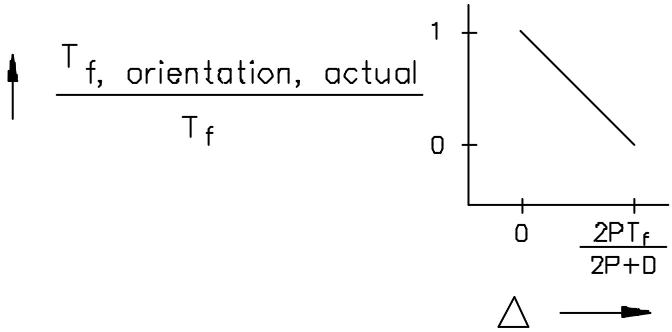

Figure 22-19 Lost functional tolerance versus actual orientation tolerance

The following pages show recommended tolerances for clearance holes C'Bores, C'Sinks, C'Bore Depths, and fasteners. See Tables 22-1, 22-2, and 22-3.) The following general notes apply as noted in Figs. 22-20, 22-21, and 22-22.

GENERAL NOTES:

1. The hole charts reflect recommended tolerance for locating the hole pattern back to the datum surface (hole to surface).
2. The hole charts reflect recommended tolerance for hole-to-hole, and/or hole to a datum feature of size (datum holes). Using a positional tolerance of ∅.014 on both an N/C drilled and sheet metal punched holes enables us to standardize the clearance hole diameters. Hole diameters, counterbore diameters and depths, and countersink diameters were calculated using the positional tolerance and the tolerances assigned to the hole diameters, counterbore diameters and depths, and countersink diameters.

   Note: It is not recommended that you use hole-to-hole tolerance greater than ∅.014, because as the hole-to-hole tolerance gets larger, the clearance hole must get larger to accommodate the additional tolerance.
3. Counterbore diameters and depths are calculated using a flat washer with a worst case (MMC) outside diameter, and a worst case thickness. C'Bore diameters are calculated, and the nearest fractional drill diameter is used.
4. Worst case flat head screw height above and below the surface is shown in Table 22-5, and is calculated for a positional tolerance of ∅.014.
5. Flat head screws are not recommended because of head height issues, and alignment issues.
6. Floating fasteners are not recommended because of the additional hardware required, and because of the difficulty of assembly.
7. For C'Bore depths, (see Table 22-4). For .060-56 threaded holes, the C'Bore depth is calculated using only a flat washer. For .086-56 through .500-20, the C'Bore depth is calculated using both a flat washer and a split washer.

8. Floating and nonfloating nut plate rivet hole diameters, and C'Sink diameters are dependent on the nut plate design and size. (See section 22.8 for information on how to calculate rivet diameter and location tolerance.)
9. Hole-to-hole tolerance for clearance holes and for nut plate rivet holes must be calculated per section 22.7.
10. Projected tolerance zone (PTOL) is determined by the maximum thickness of the mating part.
11. When using floating and nonfloating nut plates, projected tolerance issues could cause interchangeability issues. See section 22.9.

Table 22-1 Floating fastener clearance hole and C'Bore hole sizes and tolerances

Fastener Size	Clearance Hole Diameter .AAA	Clearance Hole Size Tolerance	C'Bore Hole Diameter .BBB	C'Bore Hole Size Tolerance
.060-56 UNF	.076 (#48)	+.005/-.002	.213 (#3)	+/-.010
.086-56 UNC .086-64 UNF	.104 (#37)	+.005/-.002	.272 (I)	+/-.010
.112-40 UNC .112-48 UNF	.1285 (#30)	+.005/-.002	.406 (13/32)	+/-.010
.125-40 UNC .125-44 UNF	.1406 (9/64)	+.005/-.002	.438 (7/16)	+/-.010
.138-32 UNC .138-40 UNF	.154 (#23)	+.005/-.002	.469 (15/32)	+/-.010
.164-32 UNC .164-36 UNF	.180 (#15)	+.005/-.002	.531 (17/32)	+/-.010
.190-32 UNC .190-36 UNF	.2055 (#5)	+.005/-.002	.594 (19/32)	+/-.010
.250-20 UNC .250-28 UNF	.266 (H)	+.005/-.002	.781 (25/32)	+/-.010
.312 -18 UNC .312-24 UNF	.328 (21/64)	+.005/-.002	.922 (59/64)	+/-.010
.375-16 UNC .375-24 UNF	.3906 (25/64)	+.005/-.002	1.047 (1 3/64)	+/-.010
.438-14 UNC .438-20 UNF	.4531 (29/64)	+.005/-.002	1.172 (1 11/64)	+/-.010
.500-13 UNC .500-20 UNF	.5156 (33/64)	+.005/-.002	1.312 (1 5/16)	+/-.010

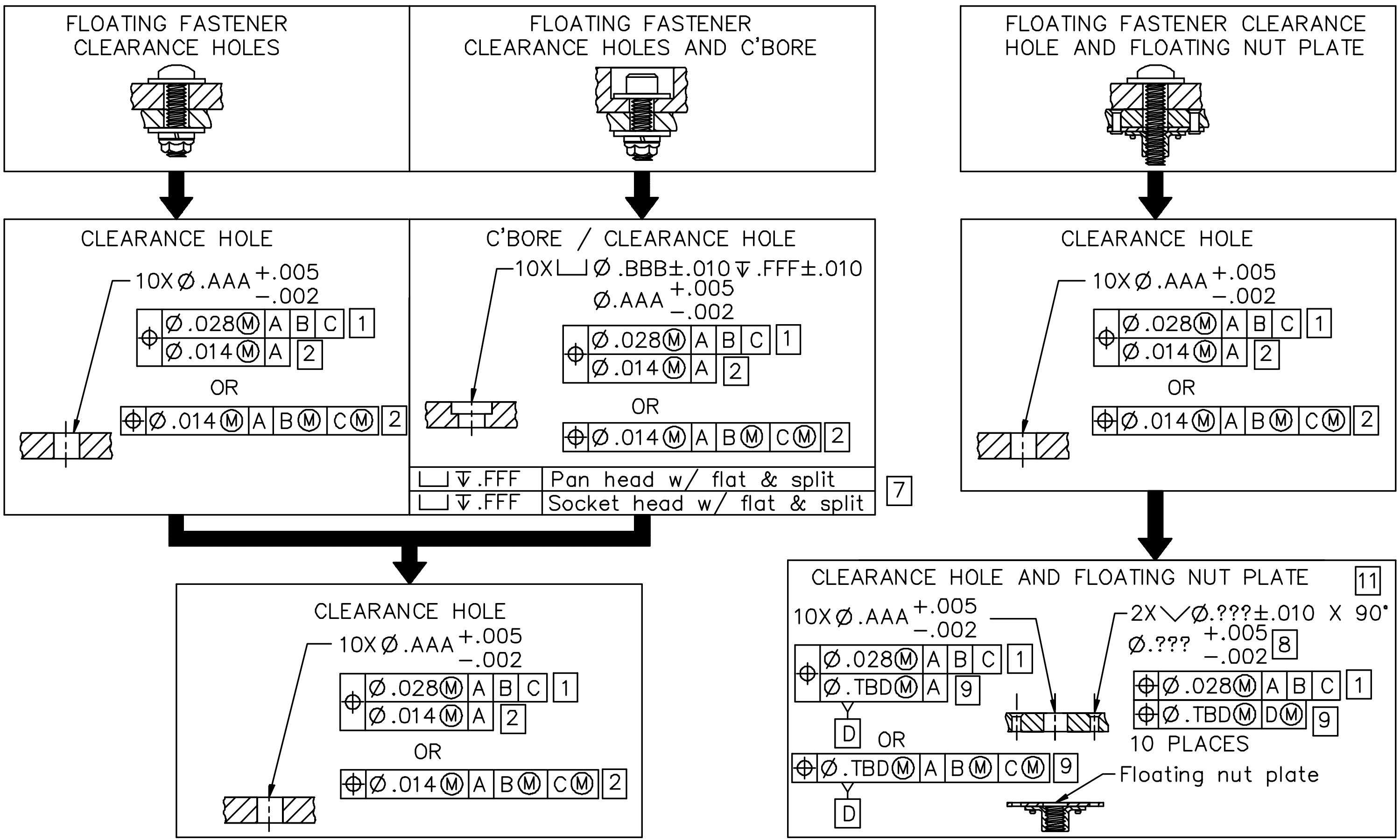

Figure 22-20 Floating fastener tolerance and callouts

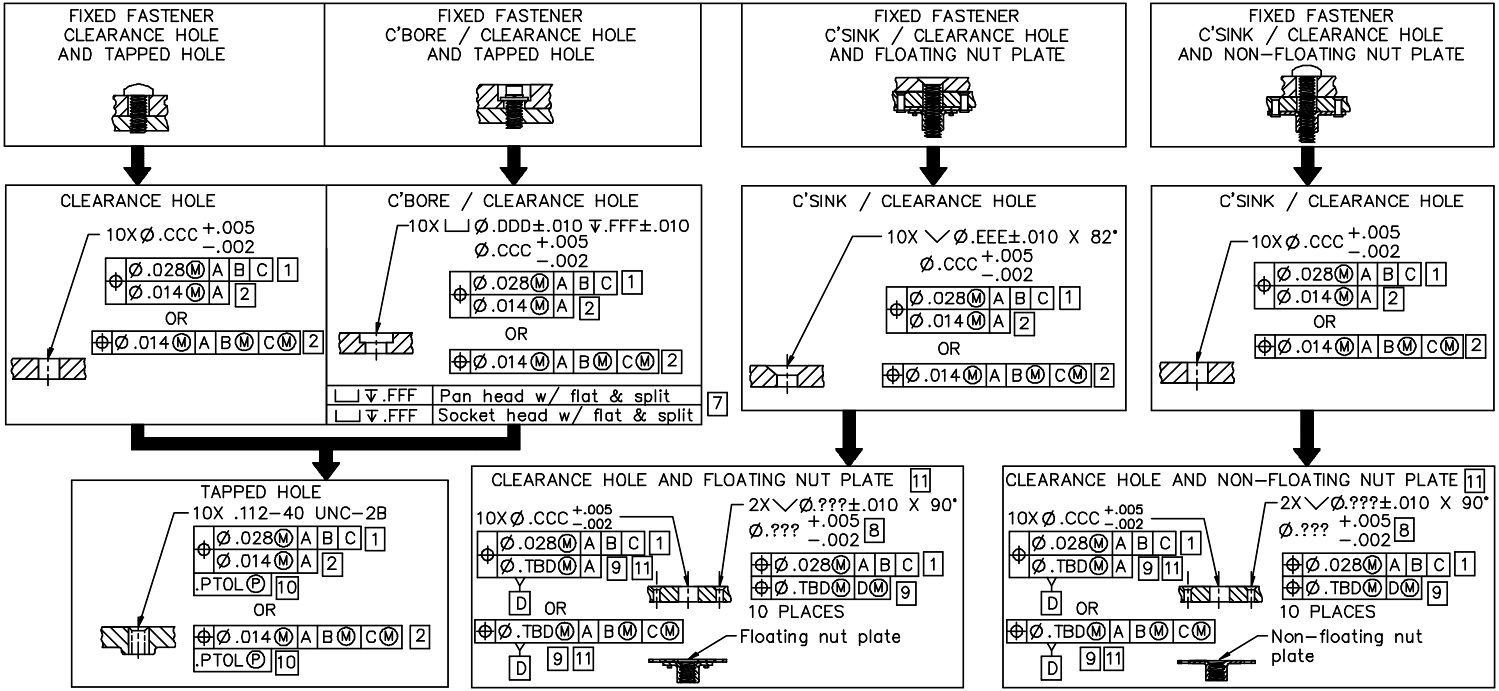

Figure 22-21 Fixed fastener tolerance and callouts

Table 22-2 Fixed fastener clearance hole, C'Bore, and C'Sink sizes and tolerances

Fastener Size	Clearance Hole Diameter .CCC	Clearance Hole Size Tolerance	C'Bore Hole Diameter .DDD	C'Bore Hole Size Tolerance	C'Sink Diameter .EEE	C'Sink Size Tolerance
.060-56 UNF	.0935 (#42)	+.005/-.002	.228 (#1)	+/-.010	.125	+/-.010
.086-56 UNC	.120 (#31)	+.005/-.002	.290 (L)	+/-.010	.180	+/-.010
.086-64 UNF						
.112-40 UNC	.144 (#27)	+.005/-.002	.421 (27/64)	+/-.010	.230	+/-.010
.112-48 UNF						
.125-40 UNC	.1562 (5/32)	+.005/-.002	.453 (29/64)	+/-.010	.255	+/-.010
.125-44 UNF						
.138-32 UNC	.1695 (#18)	+.005/-.002	.484 (31/64)	+/-.010	.285	+/-.010
.138-40 UNF						
.164-32 UNC	.1935 (#10)	+.005/-.002	.547 (35/64)	+/-.010	.335	+/-.010
.164-36 UNF						
.190-32 UNC	.221 (#2)	+.005/-.002	.609 (39/64)	+/-.010	.390	+/-.010
.190-36 UNF						
.250-20 UNC	.2812 (9/32)	+.005/-.002	.797 (51/64)	+/-.010	.510	+/-.010
.250-28 UNF						
.312 -18 UNC	.3438 (11/32)	+.005/-.002	.938 (15/16)	+/-.010	.640	+/-.010
.312-24 UNF						
.375-16 UNC	.4062 (13/21)	+.005/-.002	1.063 (1 1/16)	+/-.010	.765	+/-.010
.375-24 UNF						
.438-14 UNC	.4688 (15/32)	+.005/-.002	1.188 (1 3/16)	+/-.010	.815	+/-.010
.438-20 UNF						
.500-13 UNC	.5312 (17/32)	+.005/-.002	1.328 (1 21/64)	+/-.010	.880	+/-.010
.500-20 UNF						

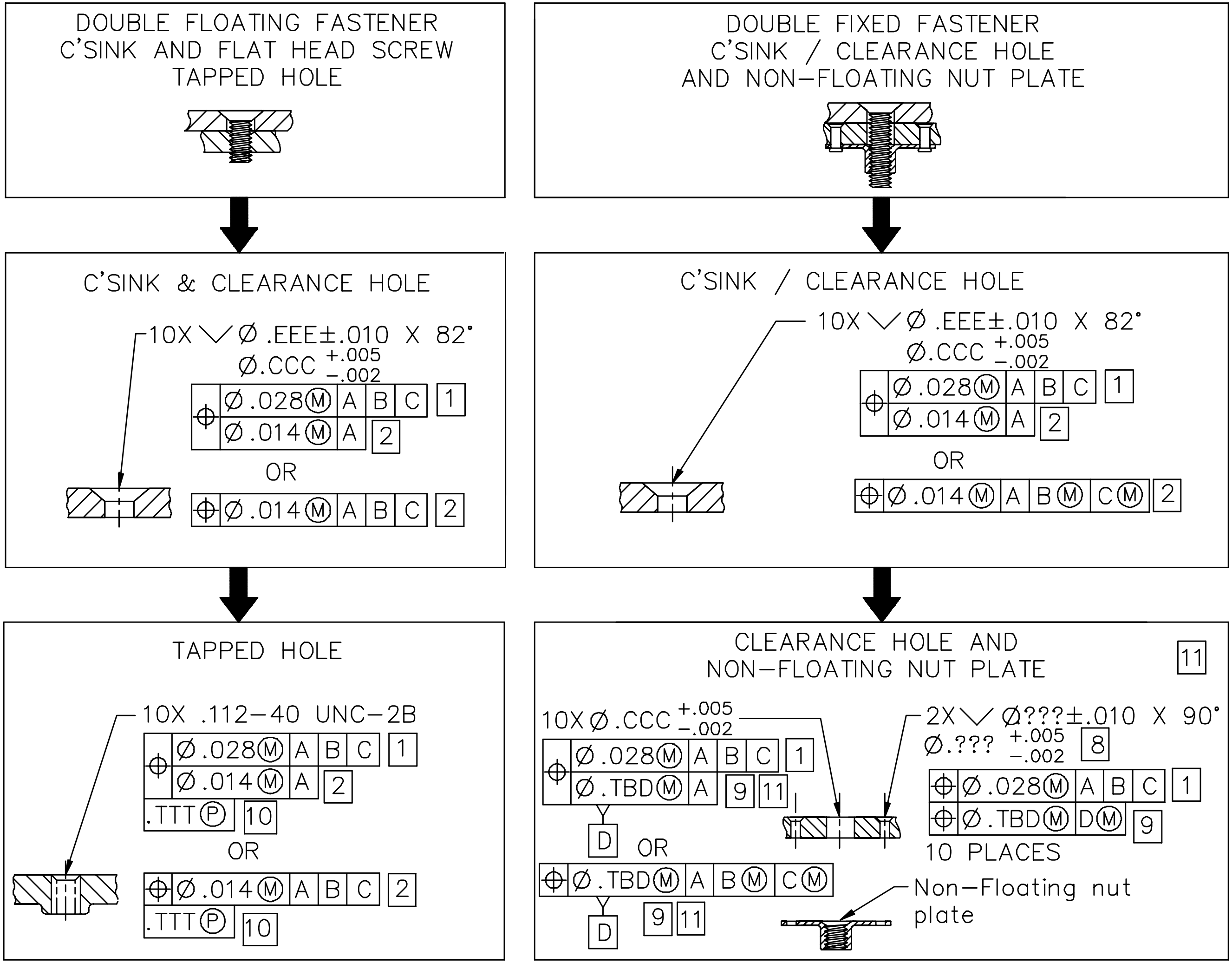

Figure 22-22 Double-fixed fastener tolerance and callouts

Table 22-3 Double-fixed fastener clearance hole and C'Bore sizes and tolerances

Fastener Size	Clearance Hole Diameter .CCC	Clearance Hole Size Tolerance	C'Sink Diameter .EEE	C'Sink Size Tolerance
.060-56 UNF	.0935 (#42)	+.005/-.002	.125	+/-.010
.086-56 UNC .086-64 UNF	.120 (#31)	+.005/-.002	.180	+/-.010
.112-40 UNC .112-48 UNF	.144 (#27)	+.005/-.002	.230	+/-.010
.125-40 UNC .125-44 UNF	.1562 (5/32)	+.005/-.002	.255	+/-.010
.138-32 UNC .138-40 UNF	.1695 (#18)	+.005/-.002	.285	+/-.010
.164-32 UNC .164-36 UNF	.1935 (#10)	+.005/-.002	.335	+/-.010
.190-32 UNC .190-36 UNF	.221 (#2)	+.005/-.002	.390	+/-.010
.250-20 UNC .250-28 UNF	.2812 (9/32)	+.005/-.002	.510	+/-.010
.312 -18 UNC .312-24 UNF	.3438 (11/32)	+.005/-.002	.640	+/-.010
.375-16 UNC .375-24 UNF	.4062 (13/21)	+.005/-.002	.765	+/-.010
.438-14 UNC .438-20 UNF	.4688 (15/32)	+.005/-.002	.815	+/-.010
.500-13 UNC .500-20 UNF	.5312 (17/32)	+.005/-.002	.880	+/-.010

22.10.4 Counterbore Depths - Pan Head and Socket Head Cap Screws

Table 22-4 C'Bore depths (pan head and socket head)

Fastener Size	Type of Fastener	C'Bore Depths .DDD	C'Bore Depths Tolerance
.060-56 UNF	Pan Head	.080	+/-.010
	Socket head	.100	+/-.010
.086-56 UNC	Pan Head	.120	+/-.010
.086-64 UNF	Socket head	.155	+/-.010
.112-40 UNC	Pan Head	.150	+/-.010
.112-48 UNF	Socket head	.195	+/-.010
.125-40 UNC	Pan Head	.160	+/-.010
.125-44 UNF	Socket head	.210	+/-.010
.138-32 UNC	Pan Head	.170	+/-.010
.138-40 UNF	Socket head	.225	+/-.010
.164-32 UNC	Pan Head	.190	+/-.010
.164-36 UNF	Socket head	.260	+/-.010
.190-32 UNC	Pan Head	.215	+/-.010
.190-36 UNF	Socket head	.295	+/-.010
.250-20 UNC	Pan Head	.290	+/-.010
.250-28 UNF	Socket head	.395	+/-.010
.312 -18 UNC	Pan Head	.340	+/-.010
.312-24 UNF	Socket head	.475	+/-.010
.375-16 UNC	Pan Head	.390	+/-.010
.375-24 UNF	Socket head	.550	+/-.010
.438-14 UNC	Pan Head	.440	+/-.010
.438-20 UNF	Socket head	.630	+/-.010
.500-13 UNC	Pan Head	.530	+/-.010
.500-20 UNF	Socket head	.750	+/-.010

22.10.5 Flat Head Screw Head Height - Above and Below the Surface

Table 22-5 Flat head screw head height above and below the surface

Flat Head Screw Head Height Above and Below Surface for 100 Degree Flat Head		
.060-56 UNF	Above Surface	.019
	Below Surface	-.021
.086-56 UNC	Above Surface	.018
.086-64 UNF	Below Surface	-.025
.112-40 UNC	Above Surface	.022
.112-48 UNF	Below Surface	-.023
.125-40 UNC	Above Surface	.020
.125-44 UNF	Below Surface	-.026
.138-32 UNC	Above Surface	.022
.138-40 UNF	Below Surface	-.027
.164-32 UNC	Above Surface	.020
.164-36 UNF	Below Surface	-.031
.190-32 UNC	Above Surface	.022
.190-36 UNF	Below Surface	-.032
.250-20 UNC	Above Surface	.020
.250-28 UNF	Below Surface	-.040
.312 -18 UNC	Above Surface	.022
.312-24 UNF	Below Surface	-.040
.375-16 UNC	Above Surface	.020
.375-24 UNF	Below Surface	-.053
.438-14 UNC	Above Surface	.020
.438-20 UNF	Below Surface	-.060
.500-13 UNC	Above Surface	.022
.500-20 UNF	Below Surface	-.064

22.11 References

1. Orberg, Erik, Franklin D. Jones, and Holbrook L. Horton. 1979. *Machinery's Handbook*. 21st ed. New York, NY: Industrial Press, Inc.
2. The American Society of Mechanical Engineers. 1995. *ASME Y14.5M-1994, Dimensioning and Tolerancing*. New York, New York: The American Society of Mechanical Engineers.