# Shigley's Mechanical Engineering Design
# Tutorial 3-16:  Press and Shrink Fits

**APPLICATION OF THICK-WALL CYLINDRICAL PRESSURE VESSEL THEORY RELATING TO STRESSES DEVELOPED FROM INTERFERENCE FITS:**

1. Design application which uses the cylindrical pressure vessel Thick-Wall Theory.
2. Stresses develop between cylinders due to the contact pressure generated by an interference fit. The interference fit is achieved by pressing a larger inside member into the smaller opening of an outside member. In the specific case of a shaft press fit into the hub of a gear, the outside diameter (OD) of the shaft is slightly larger than the inside hole diameter (ID) of the hub. The diametral difference between the shaft OD and the ID of the hub hole is referred to as the interference fit.

- The radial deformation required by the interference fit causes an interfacial pressure, $p$, to develop at the nominal radius, at $r = R$. Consequently, radial and tangential stresses, $\sigma_r$ and $\sigma_t$, are produced.
- Assuming uncapped ends $(\sigma_l = 0)$, a biaxial state of stress exists for which two non-zero principal stresses must be considered.
- From the cylindrical pressure vessel theory, the radial and tangential stresses represent principal stresses.
- The length of the outer member is assumed to be equal to the length of the inner member.
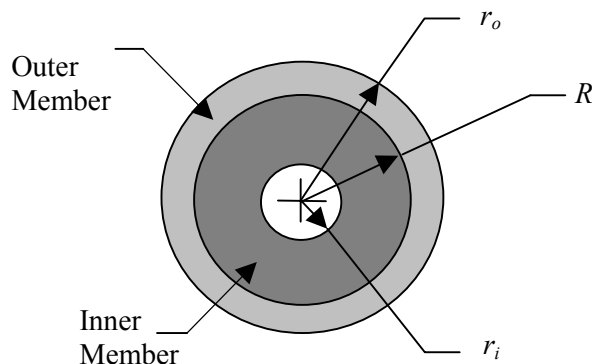


(a)  End view of inner and outer members, press fit together.
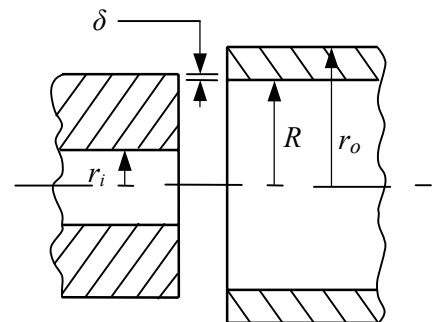
(b)  Cross-section of cylinders showing internal outside radius larger than external inside radius by a small amount of δ.

**FIGURE T3-16-1**  Interference fit of two cylinders of finite length and equal lengths.

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3. Referring to Fig. T3-16-1, the geometric features of the cylindrical parts are defined as:

$r_i$ = the inside radius of the inner cylinder

$R$ = nominal radius of internal outside radius and external inside radius after assembly

$r_o$ = outside radius of the outer cylinder

$\delta$ = radial interference

## INSIDE CYLINDER

- Inner member experiences an external pressure, $p_o = p$, resulting in compressive tangential and radial stresses.
- Thick-Wall Theory may be applied with $r_o = R$:                                      **(T-1)**

$$(\sigma_t)_i\big|_{r=R} = -p_o\left(\frac{R^2+r_i^2}{R^2-r_i^2}\right) = -pC_{it}$$

$$(\sigma_r)_i\big|_{r=R} = -p_o = -p$$

## OUTSIDE CYLINDER

- Outer member only experiences internal pressure, $p_i = p$, resulting in tensile tangential stress and compressive radial stress.
- Thick-Wall Theory is, as always, applicable with $r_i = R$:                           **(T-2)**

$$(\sigma_t)_o\big|_{r=R} = p_i\left(\frac{r_o^2+R^2}{r_o^2-R^2}\right) = pC_{ot}$$

$$(\sigma_r)_i\big|_{r=R} = -p_i = -p$$

## DEFINITION OF INTERFACIAL PRESSURE

We presently have two equations and three unknowns for both the inside and outside cylinder analyses. A third equation which relates the contact pressure and the interference can be derived by examining the deformation of the members.

### Deflection Equation

The total *radial* interference may be defined as:

$$\delta_{\text{total}} = |\delta_i| + |\delta_o|$$

where,

$$\delta_i = \text{decrease in radius of inner cylinder}$$

$$\delta_o = \text{increase in radius of hole}$$

The deformation may also be expressed as:

$$\delta_{\text{total}} = pRK_i + pRK_o \qquad \text{(Modified Text Eq. 3-56)}$$

where the outside member constant, $K_o$, is defined as,

$$K_o = \frac{1}{E_o}\left[\left(\frac{r_o^2 + R^2}{r_o^2 - R^2}\right) + \nu_o\right] = \frac{1}{E_o}[C_o + \nu_o]$$

Using the radius ratio form defined for the cylindrical pressure vessel formulation, $\zeta_o = r_o / R$, we can define

$$C_o = \frac{\zeta_o^2 + 1}{\zeta_o^2 - 1}$$

Note that the $C_o$ term is a function of geometry only, while the member constant term $K_o$ is a function of both geometry and material parameters. Similarly for the inside member constant $K_i$,

$$K_i = \frac{1}{E_i}\left[\left(\frac{R^2 + r_i^2}{R^2 - r_i^2}\right) - \nu_i\right] = \frac{1}{E_i}[C_i - \nu_i]$$

with $\zeta_i = R / r_i$, $C_i$ is defined as:

$$C_i = \frac{\zeta_i^2 + 1}{\zeta_i^2 - 1}$$

For the case of a solid shaft, $r_i = 0$, $\zeta_i = R / r_i = \infty$ and $C_i = 1$.

We can now solve for the deformation for a given class of interference fits,

$$\delta_{\text{total}} = [K_o + K_i]pR$$

Or, rearranging, the contact pressure, $p$, may be expressed as a function of the interference without assumptions regarding material property values:

$$p = \left[\frac{1}{K_o + K_i}\right]\frac{\delta_{\text{total}}}{R} \qquad \text{(Modified Text Eq. 3-56)}$$

*Example T3.16.1:  Shaft & Hub Shrink Fit*

**Problem Statement:**  A carbon-steel gear hub having a nominal hole diameter of 1 inch is to be shrink-fitted to a carbon-steel shaft using a class FN4 fit. The hub has a nominal thickness of ½ inch.

**Find:**
1. the maximum tangential and radial stresses in the hub and shaft when the loosest fit is obtained;
2. the same as (a), except using the tightest fit as a condition.

**Solution Methodology:**
1. Using Table A-1-2 of this document, identify the diametral size ranges for the shaft and the hole based on an ANSI US Customary Standard class FN4 fit which is discussed below.
2. Calculate the interferences for the loosest and tightest fits.
3. Compute the interfacial pressure for the loosest and tightest fits.
4. For each fit, calculate the radial and tangential stresses for both the hub and the shaft.

**Schematic:**

Shaft

Hub
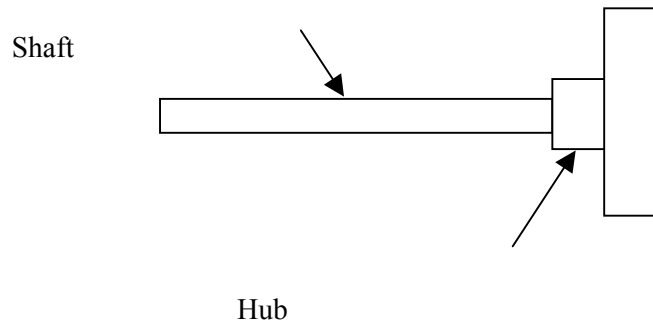
**Solution:**

1. Shaft and Hub Size Ranges:

This problem specifies a class FN4 fit. The class FN4 fit is a specification defined by the American National Standards Institute (ANSI), American Standard Limits for Cylindrical Parts ANSI B4.1-1978. The FN4 fit is a "*Force fit* suitable for parts which can be highly stressed or for shrink fits where the heavy pressing forces required are impractical."  Excerpts from the ANSI B4.1-1978 standard are provided in Table A-1 of this tutorial.

From Table A-1-2, for a nominal shaft/hole diameter of 1 in., the appropriate size range is 0.95–1.19 in. The allowable tolerances, in thousandths of an inch, are:

|              | Largest Tolerance $(10^{-3}$ in.$)$ | Smallest Tolerance $(10^{-3}$ in.$)$ |
|--------------|-----------------|------------------|
| Hub hole     | +0.8            | –0.0             |
| Shaft        | +2.3            | +1.8             |

The shaft and hub size ranges for a nominal 1 in. diameter are:

|              | Largest Diameter (in.) | Smallest Diameter (in.) |
|--------------|------------------------|-------------------------|
| Hub hole     | 1.0008                 | 1.0000                  |
| Shaft        | 1.0023                 | 1.0018                  |

2. Diametral and Radial Interference Calculations:

|          | Loosest Fit | Tightest Fit |
|----------|-------------|--------------|
| Hub hole | 1.0008      | 1.0000       |
| Shaft    | 1.0018      | 1.0023       |
|          | –0.0010     | –0.0023      |

The radial interferences are therefore $\delta = -0.0005$ in. (loosest fit) and $\delta = -0.001\ 15$ in. (tightest fit). The interference is taken as a positive number by convention. Consequently, the radial interferences for the two cases are:

$$\delta = 0.0005 \text{ in. (loosest fit)}$$
$$\delta = 0.001\ 15 \text{ in. (tightest fit)}$$

3. Interfacial Pressure

The interface pressure can be computed from Modified Eq. (3-56):

$$p = \left[ \frac{1}{K_o + K_i} \right] \frac{\delta_{\text{total}}}{R}$$

For this problem, the geometric features have been defined as:

$$r_o = \frac{d}{2} + t = \frac{1 \text{ in.}}{2} + 0.5 \text{ in.} = 1.0 \text{ in.} \qquad r_i = 0.0 \qquad R = \frac{d}{2} = 0.5 \text{ in.}$$

Thus, for the hub (outside member),

$$\zeta_o = \frac{r_o}{R} = \frac{(1 \text{ in.})}{(0.5 \text{ in.})} = 2$$

$$C_o = \frac{\zeta_o^2 + 1}{\zeta_o^2 - 1} = \frac{(2)^2 + 1}{(2)^2 - 1} = \frac{5}{3} = 1.6667$$

$$K_o = \frac{1}{E_o}[C_o + \nu_o] = \frac{1}{(30 \times 10^6 \text{ psi})}[1.667 + 0.292] = 6.5289 \times 10^{-8} \text{ (1/psi)}$$

Similarly for the shaft (inside member)

$$\zeta_i = \frac{R}{r_i} = \infty$$

$$C_i = \frac{\zeta_i^2 + 1}{\zeta_i^2 - 1} = 1.0$$

$$K_i = \frac{1}{E_i}[C_i - \nu_i] = \frac{1}{(30 \times 10^6 \text{ psi})}[1.0 - 0.292] = 2.360 \times 10^{-8} \text{ (1/psi)}$$

For the loosest fit case:

$$p_{\text{loosest fit}} = \left[\frac{1}{K_o + K_i}\right]\frac{\delta_{\text{loosest fit}}}{R} = \left[\frac{1}{6.5289 \times 10^{-8} + 2.360 \times 10^{-8}}\right]\left(\frac{0.0005}{0.5}\right)$$
$$= \mathbf{11\,250\,psi\ (loosest\ fit)}$$

For the tightest fit case:

$$p_{\text{tightest fit}} = \left[\frac{1}{K_o + K_i}\right]\frac{\delta_{\text{tightest fit}}}{R} = \left[\frac{1}{6.5289 \times 10^{-8} + 2.360 \times 10^{-8}}\right]\left(\frac{0.00115}{0.5}\right)$$
$$= \mathbf{25\,875\,psi\ (tightest\ fit)}$$

4. Radial & Tangential Stress Calculations for Shaft and Hub:

***Loosest Fit*** *(p* = 11 250 psi*)*

    *Hub:*   $\sigma_r(r = R) = -p = \mathbf{-11\,250\,psi}$

$$\sigma_t(r = R) = p\frac{r_o^2 + R^2}{r_o^2 - R^2} = pC_o = (11\,250\,\text{psi})(1.6667) = \mathbf{18\,750\,psi}$$

    *Shaft:*  $\sigma_r(r = R) = -p = \mathbf{-11\,250\,psi}$

$$\sigma_t(r = R) = -p\frac{R^2 + r_i^2}{R^2 - r_i^2} = -pC_i = (-11\,250\,\text{psi})(1) = \mathbf{-11\,250\,psi}$$

***Tightest Fit*** *(p* = 25 875 psi*)*

*Hub:*   $\sigma_r(r = R) = -p = -25\,875\ \text{psi}$

$$\sigma_t(r = R) = p\frac{r_o^2 + R^2}{r_o^2 - R^2} = pC_o = (25\,875\,\text{psi})(1.6667) = 43\,125\ \text{psi}$$

*Shaft:*   $\sigma_r(r = R) = -p = -25\,875\ \text{psi}$

$$\sigma_t(r = R) = -p\frac{R^2 + r_i^2}{R^2 - r_i^2} = -pC_i = (-25\,875\,\text{psi})(1) = -25\,875\ \text{psi}$$

Thus the shaft has equal radial and tangential stress for each tightness condition, whereas, the hub's tangential stress is consistently higher than its radial stress for both the loosest and the tightest condition.

*Note:*  Since the shaft length is greater than the hub length, which is typical in practice, this design case violates one of the assumptions of the interfacial pressure development. In this case, there would be an increase in the interfacial pressure at each end of the hub. This condition of increased interfacial pressure would typically be accounted for by applying a stress concentration factor, $K_t$, for stresses calculated at points at the end of the hub such as,

$$\sigma_{t\ \text{actual}} = K_{t,\ \text{tangential}}\sigma_t$$
$$\sigma_{r\ \text{actual}} = K_{t,\ \text{radial}}\sigma_r$$

# Table A-1 LIMITS AND FITS FOR CYLINDRICAL PARTS[†]

The limits shown in the accompanying tabulations are in thousandths of an inch. The size ranges include all sizes *over* the smallest size in the range, up to and *including* the largest size in the range. The letter symbols are defined as follows:

RC    *Running and sliding fits* are intended to provide a similar running performance, with suitable lubrication allowance, throughout the range of sizes. The clearance for the first two classes, used chiefly as slide fits, increases more slowly with diameter than the other classes, so that accurate location is maintained even at the expense of free relative motion.

RC1   *Close sliding fits* are intended for the accurate location of parts which must assemble without perceptible play.

RC2   *Sliding fits* are intended for accurate location but with greater maximum clearance than class RC1. Parts made to this fit move and turn easily, but are not intended to run freely, and in the larger sizes may seize with small temperature changes.

RC3   *Precision running fits* are about the closest fits which can be expected to run freely and are intended for precision work at slow speeds and light journal pressures, but are not suitable where appreciable temperature differences are likely to be encountered.

RC4   *Close running fits* are intended chiefly for running fits on accurate machinery with moderate surface speeds and journal pressures, where accurate location and minimum play is desired.

RC5–RC6   *Medium running fits* are intended for higher running speeds, heavy journal pressures, or both.

RC7   *Free running fits* are intended for use where accuracy is not essential or where large temperature variations are likely to be encountered, or under both of these conditions.

RC8–RC9   *Loose running fits* are intended for use where wide commercial tolerances may be necessary, together with an allowance, on the external member.

L    *Locational fits* are fits intended to determine only the location of the mating parts; they may provide rigid or accurate location, as with interference fits, or provide some freedom of location, as with clearance fits. Accordingly, they are divided into three groups: clearance fits, transition fits, and interference fits.

LC   *Locational clearance fits* are intended for parts which are normally stationary but which can be freely assembled or disassembled. They run from snug fits for parts requiring accuracy of location, through the medium clearance fits for parts such as ball, race, and housing, to the looser fastener fits where freedom of assembly is of prime importance.

LT   *Locational transition fits* are a compromise between clearance and interference fits, for application where accuracy of location is important, but either a small amount of clearance or interference is permissible.

LN   *Locational interference fits* are used where accuracy of location is of prime importance and for parts requiring rigidity and alignment with no special requirements for bore pressure. Such fits are not intended for parts designed to transmit frictional loads form one part to another by virtue of the tightness of fit, since these conditions are covered by force fits.

FN   *Force and shrink fits* constitute a special type of interference fit, normally characterized by maintenance of constant bore pressure throughout the range of sizes. The interference therefore varies almost directly with diameter, and the difference between its minimum and maximum value is small so as to maintain the resulting pressures within reasonable limits.

FN1   *Light drive fits* are those requiring light assembly pressures and producing more or less permanent assemblies. They are suitable for thin sections or long fits or in cast-iron external members.

FN2   *Medium drive fits* are suitable for ordinary steel parts or for shrink fits on light sections. They are about the tightest fits that can be used with high-grade cast-iron external members.

FN3   *Heavy drive fits* are suitable for heavier steel parts or for shrink fits in medium sections.

FN4–FN5   *Force fits* are suitable for parts which can be highly stressed or for shrink fits where the heavy pressing forces required are impractical.

[†]Extracted from American Standard Limits for Cylindrical Parts ANSI B4.1-1978, with the permission of the publishers, The American Society of Mechanical Engineers, United Engineering Center, 345 East 47th Street, New York 10017. Limit dimensions are tabulated in this standard for nominal sizes up to and including 200 in. An SI version is also available.

**Table A-1-1** RUNNING AND SLIDING FITS

| Class | | Diameter Size Range (in.) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 0.00 - 0.12 | | 0.12 - 0.24 | | 0.24 - 0.40 | | 0.40 - 0.71 | |
| RC1 | Hole | +0.20 | -0.00 | +0.20 | -0.00 | +0.25 | -0.00 | +0.30 | -0.00 |
| | Shaft | +0.10 | -0.25 | -0.15 | -0.30 | -0.20 | -0.35 | -0.25 | -0.45 |
| RC2 | Hole | +0.25 | -0.00 | +0.30 | -0.00 | +0.40 | -0.00 | +0.40 | -0.00 |
| | Shaft | -0.10 | -0.30 | -0.15 | -0.35 | -0.20 | -0.45 | -0.25 | -0.55 |
| RC3 | Hole | +0.40 | -0.00 | +0.50 | -0.00 | +0.60 | -0.00 | +0.70 | -0.00 |
| | Shaft | -0.30 | -0.55 | -0.40 | -0.70 | -0.50 | -0.90 | -0.60 | -1.00 |
| RC4 | Hole | +0.60 | -0.00 | +0.70 | -0.00 | +0.90 | -0.00 | +1.00 | -0.00 |
| | Shaft | -0.30 | -0.70 | -0.40 | -0.90 | -0.50 | -1.10 | -0.60 | -1.30 |
| RC5 | Hole | +0.60 | -0.00 | +0.70 | -0.00 | +0.90 | -0.00 | +1.00 | -0.00 |
| | Shaft | -0.60 | -1.00 | -0.80 | -1.30 | -1.00 | -1.60 | -1.20 | -1.90 |
| RC6 | Hole | +1.00 | -0.00 | +1.20 | -0.00 | +1.40 | -0.00 | +1.60 | -0.00 |
| | Shaft | -0.60 | -1.20 | -0.80 | -1.50 | -1.00 | -1.90 | -1.20 | -2.20 |
| RC7 | Hole | +1.00 | -0.00 | +1.20 | -0.00 | +1.40 | -0.00 | +1.60 | -0.00 |
| | Shaft | -1.00 | -1.60 | -1.20 | -1.90 | -1.60 | -2.50 | -2.00 | -3.00 |
| RC8 | Hole | +1.60 | -0.00 | +1.80 | -0.00 | +2.20 | -0.00 | +2.80 | -0.00 |
| | Shaft | -2.50 | -3.50 | -2.80 | -4.00 | -3.00 | -4.40 | -3.50 | -5.10 |
| RC9 | Hole | +2.50 | -0.00 | +3.00 | -0.00 | +3.50 | -0.00 | +4.00 | -0.00 |
| | Shaft | -4.00 | -5.60 | -4.50 | -6.00 | -5.00 | -7.20 | -6.00 | -8.80 |

| Class | | Diameter Size Range (in.) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 0.71 - 1.19 | | 1.19 - 1.97 | | 1.97 - 3 .15 | | 3.15 - 4.73 | |
| RC1 | Hole | +0.40 | -0.00 | +0.40 | -0.00 | +0.50 | -0.00 | +0.60 | -0.00 |
| | Shaft | -0.30 | -0.55 | -0.40 | -0.70 | -0.40 | -0.70 | -0.50 | -0.90 |
| RC2 | Hole | +0.50 | -0.00 | +0.60 | -0.00 | +0.70 | -0.00 | +0.90 | -0.00 |
| | Shaft | -0.30 | -0.70 | -0.40 | -0.80 | -0.40 | -0.90 | -0.50 | -1.10 |
| RC3 | Hole | +0.80 | -0.00 | +1.00 | -0.00 | +1.20 | -0.00 | +1.40 | -0.00 |
| | Shaft | -0.80 | -1.30 | -1.00 | -1.60 | -1.20 | -1.90 | -1.40 | -2.30 |
| RC4 | Hole | +1.20 | -0.00 | +1.60 | -0.00 | +1.80 | -0.00 | +2.20 | -0.00 |
| | Shaft | -0.80 | -1.60 | -1.00 | -2.00 | -1.20 | -2.40 | -1.40 | -2.80 |
| RC5 | Hole | +1.20 | -0.00 | +1.60 | -0.00 | +1.80 | -0.00 | +2.20 | -0.00 |
| | Shaft | -1.60 | -2.40 | -2.00 | -3.00 | -2.50 | -3.70 | -3.00 | -4.40 |
| RC6 | Hole | +2.00 | -0.00 | +2.50 | -0.00 | +3.00 | -0.00 | +3.50 | -0.00 |
| | Shaft | -1.60 | -2.80 | -2.00 | -3.60 | -2.50 | -4.30 | -3.00 | -5.20 |
| RC7 | Hole | +2.00 | -0.00 | +2.50 | -0.00 | +3.00 | -0.00 | +3.50 | -0.00 |
| | Shaft | -2.50 | -3.70 | -3.00 | -4.60 | -4.00 | -5.80 | -5.00 | -7.20 |
| RC8 | Hole | +3.50 | -0.00 | +4.00 | -0.00 | +4.50 | -0.00 | +5.00 | -0.00 |
| | Shaft | -4.50 | -6.50 | -5.00 | -7.50 | -6.00 | -9.00 | -7.00 | -10.50 |
| RC9 | Hole | +5.00 | -0.00 | +6.00 | -0.00 | +7.00 | -0.00 | +9.00 | -0.00 |
| | Shaft | -7.00 | -10.50 | -8.00 | -12.00 | -9.00 | -13.50 | -10.00 | -15.00 |

**Table A-1-2** FORCE AND SHRINK FITS

| Class | | 0.00 - 0.12 | | 0.12 - 0.24 | | 0.24 - 0.40 | | 0.40 - 0.56 | |
|---|---|---|---|---|---|---|---|---|---|
| | | **Diameter Size Range (in.)** | | | | | | | |
| FN1 | Hole | +0.25 | -0.00 | +0.30 | -0.00 | +0.40 | -0.00 | +0.40 | -0.00 |
| | Shaft | +0.50 | +0.30 | +0.60 | +0.40 | +0.75 | +0.50 | +0.80 | +0.50 |
| FN2 | Hole | +0.40 | -0.00 | +0.50 | -0.00 | +0.60 | -0.00 | +0.70 | -0.00 |
| | Shaft | +0.85 | +0.60 | +1.00 | +0.70 | +1.40 | +1.00 | +1.60 | +1.20 |
| FN3 | Hole | | | | | | | | |
| | Shaft | | | | | | | | |
| FN4 | Hole | +0.40 | -0.00 | +0.50 | -0.00 | +0.60 | -0.00 | +0.70 | -0.00 |
| | Shaft | +0.95 | +0.70 | +1.20 | +0.90 | +1.60 | +1.20 | +1.80 | +1.40 |
| FN5 | Hole | +0.60 | -0.00 | +0.70 | -0.00 | +0.90 | -0.00 | +1.00 | -0.00 |
| | Shaft | +1.30 | +0.90 | +1.70 | +1.20 | +2.00 | +1.40 | +2.30 | +1.60 |

| Class | | 0.56 - 0.71 | | 0.71 - 0.95 | | 0.95 - 1.19 | | 1.19 - 1.58 | |
|---|---|---|---|---|---|---|---|---|---|
| | | **Diameter Size Range (in.)** | | | | | | | |
| FN1 | Hole | +0.40 | -0.00 | +0.50 | -0.00 | +0.50 | -0.00 | +0.60 | -0.00 |
| | Shaft | +0.90 | +0.60 | +1.10 | +0.70 | +1.20 | +0.80 | +1.30 | +0.90 |
| FN2 | Hole | +0.70 | -0.00 | +0.80 | -0.00 | +0.80 | -0.00 | +1.00 | -0.00 |
| | Shaft | +1.60 | +1.20 | +1.90 | +1.40 | +1.90 | +1.40 | +2.40 | +1.80 |
| FN3 | Hole | | | | | +0.80 | -0.00 | +1.00 | -0.00 |
| | Shaft | | | | | +2.10 | +1.60 | +2.60 | +2.00 |
| FN4 | Hole | +0.70 | -0.00 | +0.80 | -0.00 | +0.80 | -0.00 | +1.00 | -0.00 |
| | Shaft | +1.80 | +1.40 | +2.10 | +1.60 | +2.30 | +1.80 | +3.10 | +2.50 |
| FN5 | Hole | +1.00 | -0.00 | +1.20 | -0.00 | +1.20 | -0.00 | +1.60 | -0.00 |
| | Shaft | +2.50 | +1.80 | +3.00 | +2.20 | +3.30 | +2.50 | +4.00 | +3.00 |

| Class | | 1.58 - 1.97 | | 1.97 - 2.56 | | 2.56 - 3 .15 | | 3.15 - 3.94 | |
|---|---|---|---|---|---|---|---|---|---|
| | | **Diameter Size Range (in.)** | | | | | | | |
| FN1 | Hole | +0.60 | -0.00 | +0.70 | -0.00 | +0.70 | -0.00 | +0.90 | -0.00 |
| | Shaft | +1.40 | +1.00 | +1.80 | +1.30 | +1.90 | +1.40 | +2.40 | +1.80 |
| FN2 | Hole | +1.00 | -0.00 | +1.20 | -0.00 | +1.20 | -0.00 | +1.40 | -0.00 |
| | Shaft | +2.40 | +1.80 | +2.70 | +2.00 | +2.90 | +2.20 | +3.70 | +2.80 |
| FN3 | Hole | +1.00 | -0.00 | +1.20 | -0.00 | +1.20 | -0.00 | +1.40 | -0.00 |
| | Shaft | +2.80 | +2.20 | +3.20 | +2.50 | +3.70 | +3.00 | +4.40 | +3.50 |
| FN4 | Hole | +1.00 | -0.00 | +1.20 | -0.00 | +1.20 | -0.00 | +1.40 | -0.00 |
| | Shaft | +3.40 | +2.80 | +4.20 | +3.50 | +4.70 | +4.00 | +5.90 | +5.00 |
| FN5 | Hole | +1.60 | -0.00 | +1.80 | -0.00 | +1.80 | -0.00 | +2.20 | -0.00 |
| | Shaft | +5.00 | +4.00 | +6.20 | +5.00 | +7.20 | +6.00 | +8.40 | +7.00 |

**Table A-1-2**  FORCE AND SHRINK FITS (CONTINUED)

| Class | | 3.94 - 4.73 | | 4.73 - 5.52 | | 5.52 - 6.30 | | 6.30 - 7.09 | |
|---|---|---|---|---|---|---|---|---|---|
| | | Diameter Size Range (in.) | | | | | | | |
| FN1 | Hole | +0.90 | -0.00 | +1.00 | -0.00 | +1.00 | -0.00 | +1.00 | -0.00 |
| | Shaft | +2.60 | +2.00 | +2.90 | +2.20 | +3.20 | +2.50 | +3.50 | +2.80 |
| FN2 | Hole | +1.40 | -0.00 | +1.60 | -0.00 | +1.60 | -0.00 | +1.60 | -0.00 |
| | Shaft | +3.90 | +3.00 | +4.50 | +3.50 | +5.00 | +4.00 | +5.50 | +4.50 |
| FN3 | Hole | +1.40 | -0.00 | +1.60 | -0.00 | +1.60 | -0.00 | +1.60 | -0.00 |
| | Shaft | +4.90 | +4.00 | +6.00 | +5.00 | +6.00 | +5.00 | +7.00 | +6.00 |
| FN4 | Hole | +1.40 | -0.00 | +1.60 | -0.00 | +1.60 | -0.00 | +1.60 | -0.00 |
| | Shaft | +6.90 | +6.00 | +8.00 | +7.00 | +8.00 | +7.00 | +9.00 | +8.00 |
| FN5 | Hole | +2.20 | -0.00 | +2.50 | -0.00 | +2.50 | -0.00 | +2.50 | -0.00 |
| | Shaft | +9.40 | +8.00 | +11.60 | +10.00 | +13.60 | +12.00 | +13.60 | +12.00 |