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A PRESS-FIT INTERFERENCE-LIMIT
STUDY FOR MINIATURE ASSEMBLIES

October 1975

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Topical Report

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A PRESS-FIT INTERFERENCE-LIMIT STUDY FOR MINIATURE ASSEMBLIES

BDX-613-1319, October 1975

Prepared by C. W. Elder, Jr., D/822, under PDO 6984735

A study was made to determine the effect of press-fit variables on the axial movement of 0.020- and 0.060-inch-diameter (0.508 and 1.52 mm) pins installed in mating collars. Interference limits, the use of lubrication, press-rate, outer diameter of collar, and length of engagement were evaluated. Statistical analysis indicated that the smaller pins were affected more by hole size and surface finish than the larger pins. Lubrication and press-rate had no significant effect upon press-in force or holding-power. A need for improvement in hole-measuring techniques is indicated. Other pin-retention methods are recommended when pin diameters are less than 0.060 inch.

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SUMMARY

Variables affecting the axial holding-ability of 0.020- and 0.060-inch-diameter (0.508 and 1.52 mm) miniature pins after installation in mating collars were studied. Interference limits, the use of lubrication, press-rate, outer diameter of collar, and length of engagement between pin and collar were studied.

An equation was derived to define the holding-power of a press-fit joint; however, poor sample quality due to limitations of available hole-measuring techniques caused considerable variation of the data from predicted results. Rough surface finish and nonuniformity of inside collar diameter revealed a need for processing refinements.

The 0.020-inch (0.508 mm) pins were affected more by the surface finish and collar-size problems than were the 0.060-inch (1.52 mm) pins. This possibly was because diametral interference was the only significant variable which affected the press-in force and holding-power of the joint. The 0.060-inch pins were affected by the depth to which the pin was pushed (length of engagement) and the outer diameter of the collar. The conclusion therefore was reached that the smaller the pin diameter, the more subject the joint is to hole-finish and size-uniformity conditions.

Neither the use of alcohol as a lubricant nor a variation of the press-rate had a significant effect on the press-in force or the holding-power of the sample joints.

Additional testing was performed with 0.031-inch-diameter (0.78 mm) samples in which the holes had been ball-broached to determine whether better surface finish and a more uniform hole size would improve the holding-power. The results obtained were inconsistent and indicated that the hole size could not be measured accurately enough with available measuring equipment to maintain proper interference fit. Further work on the endeavor therefore was suspended. The consensus was that a more accurate method of measuring small holes must be developed before any additional productive study of interference fit is possible.

When press-fit parts having diameters less than 0.060 inch (1.5 mm) are to be fabricated, the recommendation is made that such other pin-retention methods as staking, bonding, or welding be considered.

DISCUSSION

SCOPE AND PURPOSE

This study was conducted to determine whether interference-fit conditions produced by available manufacturing techniques would keep miniature pins from moving axially after their installation in mating collars. Interference limit, lubrication, press-rate, outer diameter of collar, length of engagement between pin and collar, and different material combinations were evaluated.

If the general rule of maintaining an interference of 0.001 inch (25.4 μm) per inch (25.4 mm) of diameter were followed for small pins, a 0.020-inch-diameter (0.508 mm) pin would have only a 0.000020-inch (0.508 μm) interference with its corresponding hole. This approaches the practical size-tolerance limit for making the pins and leaves no hole-size tolerance to maintain the correct interference conditions. Samples having interference-measurement intervals of several ten-thousandths inch therefore were tested to determine the effect of interference on the holding-power between the mated parts and on the force required to press them together.

ACTIVITY

The press-fit interference-limit study was begun with a literature search. Most of the researched information related to larger-diameter parts than are to be found in miniature electromechanical assemblies. Most sources supported a rule-of-thumb allowance of 0.001 to 0.0015-inch (25.4 to 38.1 μm) interference per inch (25.4 mm) of shaft diameter. On a 0.020-inch-diameter (0.508 mm) pin, this would amount to an interference of 0.000020 inch (0.508 μm), which would be far too costly to maintain in the production of parts. Test samples having interference measurement-intervals of several ten-thousandths inch therefore were made to determine the following facts:

- Whether the parts would maintain sufficient holding-power over a wide variation of interference fits;
- Whether a correlation existed between the press-in force and the holding-power; and
- Whether the required press-in force could be predicted mathematically.

Holding-Power Equations

An equation to define the holding-power of a press-fit joint was derived from information obtained from reference sources. If stress end-effects are neglected, the relationship may be expressed by the following equation.

$$F_H = \pi L f d \left[\frac{e}{\frac{1}{E_h} \left(\frac{D^2 + d^2}{D^2 - d^2} \right) + \mu_h \left(\frac{1}{E_s} \right) - \mu_s} \right], \quad (1)$$

where

F_H = holding-force,

L = length of joint,

f = coefficient of friction between the materials,

d = pin (or shaft) diameter,

e = press-fit per inch of shaft diameter (interference),

E_h = modulus of elasticity of collar material,

D = outside diameter of collar,

μ_h = Poisson's ratio for the collar material,

E_s = modulus of elasticity of shaft material, and

μ_s = Poisson's ratio for the shaft material.

In this equation, F_H is in pounds, and L , d , e , and D are in inches. If the shaft and the collar are of the same material, the relationship may be expressed by Equation 2.

$$F_H = \pi L f d \left(\frac{E e}{2} \right) \left(\frac{D^2 - d^2}{D^2} \right). \quad (2)$$

Description of Samples and Tests

The initial group of samples was fabricated and tested to determine the effect of the following variables on holding-power and press-in force.

- Length of Engagement: The collar thickness was 0.040 inch (1.016 mm) for the 0.020-inch-pin-diameter (0.508 mm) samples, and 0.020 and 0.100 inch (0.508 and 2.54 mm) for the 0.060-inch-pin-diameter (1.524 mm) samples.
- Lubrication: The pins were pressed dry or with alcohol used as a lubricant.
- Press-Rate: Ram speeds of 0.5 inch (12.7 mm) and 20 inches (508 mm) per minute were used to simulate a slow, even press and an impact, respectively.
- Interference Limits: Line-to-line and 0.0002-inch (5.1 μ m) limits were used for the 0.020-inch-pin-diameter (0.508 mm) samples, and 0.0002 and 0.0007-inch (5.1 and 17.8 μ m) limits were used for the 0.060-inch-pin-diameter (1.52 mm) samples.
- Test-Collar Outside Diameter: Outside diameters of 0.040 and 0.080 inch (1.016 and 2.032 mm) were used for the 0.020-inch-inside-diameter (0.508 mm) samples, and outside diameters of 0.080 and 0.125 inch (2.032 and 3.175 mm) were used for the 0.060-inch-inside-diameter (1.52 mm) samples.

These values were applied to the following three different material combinations selected to represent extremes in material-strength combinations:

- 420 annealed stainless steel pin in Hyperco 50 heat-treated collar (materials of equal yield-strength),
- 303Se annealed stainless steel pin in 7075-T6 aluminum collar (pin-to-collar strength approximately 1:2), and
- 17-4PH stainless steel pin (Condition H-900) in 6061-T6 aluminum collar (pin-to-collar strength approximately 4.5:1).

The pin and collar samples were made in the Precision Machining Department by standard production methods. This approach was chosen to provide results similar to those that could be expected from normal production parts. The collar samples were made first and were assigned individual numbers. Their hole diameters then were measured optically and corresponding pins were ground to the proper interference fit.

Testing was performed on the Instron Tensile Tester (Figures 1 and 2). The pins were installed by the use of modified drill bushings which were sized at intervals throughout the size-range of the pin samples. The collars were held in a supporting block which was set directly on the load cell. Force readings were recorded on a strip chart. The recorded press-in force value for each test was the maximum reading obtained from the chart during the installation of the pin.

The push-out (holding) force was determined by setting the crossarm to a speed of 0.2 inch (5.08 mm) per minute, applying pressure to the pin in the opposite direction from that of pin-installation, and reading the force value from the chart at the point where the plot first dropped or changed slope from the initial rise--the point at which the pin started to move in the collar.

Several tests had to be repeated using extra parts because of bent pins or defective holes. Some samples required force to push the parts together, but the parts were loose after the pin had been pressed into the collar. This condition was probably caused by a burr or a rough spot which gave an improper hole-size reading during inspection.

Two groups of tests were conducted. In Group 1, three experiments (1A, 2A, and 3A) used a 0.020-inch-diameter (0.508 mm) pin to investigate the effect of four factors on the maximum press-in force (Table 1). In Test Group 2, three experiments (1B, 2B, and 3B) used a 0.060-inch-diameter (1.52 mm) pin to investigate the effect of five factors on the maximum press-in force (Table 2). The three different pin and collar materials used are listed in Table 3.

Data Analysis

For each set of data obtained, the analysis-of-variance technique was used to determine and estimate the significant effects (Appendix). There was no independent estimate of the experimental error; half-normal plots were used, where appropriate, to provide an estimate of the experimental error. The use of the half-normal plot was not applicable for Test 1A data; an estimate of the error was obtained from the two smaller contrasts.

The data also was fitted to the model

$$F = CX, \quad (3)$$

where

F = maximum press-in force,

C = value to be estimated,

Text continued on page 15.

Figure 1. Diagram of Instron Testing Apparatus

Figure 2. Details of Instron Testing Setup

Table 1. Test Group 1 Variables

Factor	Level 1 (-)	Level 2 (+)
Lubrication	None	Alcohol
Press Rate	Fast	Slow
Interference	0.0002 inch (5.1 μ m)	None
Collar Outside Diameter	Low	High

Table 2. Test Group 2 Variables

Factor	Level 1 (-)	Level 2 (+)
Collar thickness	Low	High
Lubrication	None	Alcohol
Press Rate	Fast	Slow
Interference	0.0002 inch (5.08 μ m)	0.0007 inch (17.8 μ m)
Collar Outside Diameter	0.080 inch (2.03 mm)	0.125 inch (3.175 mm)

Table 3. Test Materials

Test	Collar Material	Pin Material
1A, 1B	Hyperco 50 (Heat-Treated)	420 Stainless Steel (Annealed)
2A, 2B	6061 Aluminum (T-6 Condition)	17-4PH Stainless Steel (H-900 Condition)
3A, 3B	7075 Aluminum (T-6 Condition)	303Se Stainless Steel (Annealed)

$$X = \frac{LI d}{\frac{1}{E_h} \left[\left(\frac{D^2 + d^2}{D^2 - d^2} \right) + \mu_h \right] + \frac{1 - \mu_s}{E_s}}, \quad (4)$$

L = length of pin engagement in hole,

I = interference fit between pin and collar (shaft diameter minus collar inside diameter),

d = pin (or shaft) diameter,

E_h = modulus of elasticity of collar material,

D = collar outside diameter,

μ_h = Poisson's ratio for the collar material,

μ_s = Poisson's ratio for the pin material, and

E_s = modulus of elasticity of shaft material.

Test Results

The results for Test 1A were inconclusive because of a poor estimate of the experimental error. Three effects in Test 1B were significant.

- Collar Outside Diameter: A change in this factor from 0.080 to 0.125 inch (2.03 to 3.18 mm) resulted in an average increase in the press-in force of about 25.2 lb (112.1 N).
- Collar Thickness: A change in collar thickness from 0.020 to 0.10 inch (0.508 to 2.54 mm) caused an average increase in press-in force of approximately 21.2 lb (94.3 N).
- Interference: An increase in the interference level from 0.0002 to 0.0007 inch (5.1 to 17.8 μ m) resulted in an average press-in force increase of approximately 12.2 lb (54.3 N).

The interaction between the outside diameter and the thickness of the collar was significant. Small collar diameters and low thickness values required less press-in force than did high values for both factors (Table 4).

In Test 2A, the change from zero interference to a 0.0002-inch (51 μ m) interference increased the press-in force an average of 6.675 lb (29.7 N). In Test 2B, the effects, in order of significance, were as follows.

Table 4. Average Press-In Force Resulting From Interaction
(Test 1B)

Collar Thickness	Press-In Force (Pounds)(N)	
	0.080-Inch-Outside-Diameter (2.032 mm) Collar	0.125-Inch-Outside-Diameter (3.175 mm) Collar
0.020 Inch (0.508 mm)	7.22 (32.1)	21.25 (94.5)
0.100 Inch (2.54 mm)	17.25 (76.7)	53.62 (238.5)

- Collar Thickness: A change in this factor from the low level to the high level increased the press-in force an average of 31 lb (137.9 N).
- Interference: A change from 0.0002 to 0.0007 inch (5.1 to 17.8 μ m) resulted in an average press-in force increase of approximately 22.4 lb (99.6 N).
- Collar Outside Diameter: An increase in this factor resulted in an average increase in press-in force of approximately 20.2 lb (89.9 N).

In Test 3A, the effect of interference caused an average press-in force increase of approximately 7.9 lb (35.1 N). In Test 3B, changing the collar thickness from the high to the low level resulted in an increase in force of approximately 30.3 lb (134.8 N).

Approximately 60 percent of the 0.060-inch-diameter (1.52 mm) pins installed in aluminum collars shaved a ring of collar material out of the hole. Consequently, the actual interference of the joint was impossible to ascertain. Table 5 shows the material properties of the press-fit samples.

The primary quality deficiency was the poor surface finish and nonuniformity of hole-size encountered in the collar specimens, particularly in the 0.020-inch-diameter size. Several samples that had to be pressed together produced a slip-fit. The probable cause was a burr or high spot in the hole, thus resulting in an incorrect measurement of hole-size and a consequent use of the wrong size pin. It was apparent that further processing refinements or better methods of hole-measurement had to be established

Table 5. Material Properties of Press-Fit Samples

Material	Yield Strength (psi)(kPa)	Modulus of Elasticity (psi x 10 ⁶) (kPA x 10 ⁶)	Poisson's Ratio
6061-T6 Aluminum	40,000 (275,760)	10.6 (73.0)	0.330
7075-T6 Aluminum	73,000 (503,262)	10.4 (71.7)	0.332
303Se Stainless Steel (Annealed)	35,000 (241,290)	28.0 (193.0)	0.305
17-4PH Stainless Steel (H-900 Condition)	178,000 (1,227,132)	28.5 (196.5)	0.305
Hyperco 50 (Heat-Treated)	48,000 (330,912)	30.0 (206.8)	0.280
420 Stainless Steel (Annealed)	50,000 (344,700)	29.0 (199.9)	0.305

to improve hole quality and produce consistent results. The effects of poor surface finish and hole-size nonuniformity appeared to be greater on the 0.020-inch-diameter pins, possibly because the diametral interference was the only significant variable which affected the press-in force and holding-power of the joint.

On the 0.060-inch-diameter samples, the depth to which the pin was pushed (length of engagement) and the outer diameter of the collar had a greater effect on press-in force and holding-power than did the interference (Table 6). The length of engagement was not varied on the 0.020-inch-diameter samples. The conclusion therefore was reached that the smaller the pin diameter, the more sensitive the process is to hole finish and uniformity of size.

From all of the data on the 0.060-inch-diameter samples, the length of engagement had the most significant effect on press-in force and holding-power. The graphs indicated a greater effect on the holding-power than on the press-in force from increasing the length of engagement. This condition may have been caused by a galling condition which occurred during the press-in operation; no indication could be seen on the parts. The material combination

Table 6. Significant Effects on Press-In Force and Holding-Power (in Order of Significance for Each Test)

Test Number and Pin Diameter	Press-In Force	Holding Power
1A (0.020 inch) (0.508 mm)	No Significant Effects	No Significant Effects
1B (0.060 inch) (1.514 mm)	a) Collar Outside Diameter b) Length of Engagement c) Diametral Interference d) Length of Engagement/Collar Outside Diameter	a) Length of Engagement b) Collar Outside Diameter c) Length of Engagement/Collar Outside Diameter d) Press Rate/Collar Outside Diameter e) Diametral Interference
2A (0.020 inch) (0.508 mm)	a) Diametral Interference	a) Diametral Interference
2B (0.060 inch) (1.514 mm)	a) Length of Engagement b) Diametral Interference c) Collar Outside Diameter	a) Length of Engagement b) Collar Outside Diameter c) Length of Engagement/Collar Outside Diameter d) Lubrication e) Press Rate
3A (0.020 inch) (0.508 mm)	a) Diametral Interference	No Significant Effects
3B (0.060 inch) (1.514 mm)	a) Length of Engagement b) Diametral Interference	a) Length of Engagement

of a high-yield-strength pin to a low-yield-strength collar (17-4PH stainless steel pin to 6061-T6 aluminum collar) showed the least effect.

Second in significance only to the length of engagement was the outside diameter of the collar (for 0.060-inch-diameter pins only). The greatest effect occurred on the holding-power of the combination of sample materials having equal yield strengths (420 stainless steel pin to Hyperco 50 collar) and became less when the yield-strength ratio varied either direction from this value.

From the data results, the conclusion was reached that variation of the press-rate and the addition of alcohol for lubrication during pin installation had no significant effect on either the press-in force or the holding-power of the sample joints.

A study determined that a correlation exists between the press-in force and the holding-power for each set of data grouped according to pin size and material combination (Table 7). The correlation factor has a limit of -1 or +1; the sign merely indicates whether the relationship between the press-in force and the holding-power is a direct or inverse function. The equation tested in this case was

Holding-Power = Constant x Press-In Force.

If the correlation factor is greater than +0.5 or less than -0.5, a definite function relating the variables exists. The closer this value approaches +1 or -1, the better the equation defines the relationship. With improved quality control of parts, a prediction of the holding-power of a particular joint, based upon the force required to assemble the parts, should prove to be very accurate.

Tests of Ball-Broached Samples

A third group of parts in which the collar samples had been ball-broached was assembled and tested. It was anticipated that these holes (0.031 inch or 0.787 mm in diameter) would have smoother finishes and be more uniform in size throughout the depth of the hole, thus improving the consistency of the test results. All of the collars were dimensionally identical, but they were made of three different materials and were matched with pin materials according to the following plan:

- Subgroup 1--Hyperco 50 collars and 420 stainless steel pins (equal yield-strength materials);
- Subgroup 2--17-4PH (H-900) stainless steel collars and 420 stainless steel pins (collar-to-pin strength approximately 3.5:1), and

Table 7. Correlation Between
Maximum Press-In and
Maximum Push-Out Forces

Test Number	Correlation Factor
1A	0.6686
1B	0.8848
2A	0.9654
2B	0.7949
3A	0.7164
3B	0.9199

- Subgroup 3--304L stainless steel collars and 17-4PH (H-900) stainless steel pins (collar-to-pin strength approximately 1:6).

All samples were pressed together at the same speed using the Instron tensile-test setup that was used with the first group of samples. The only test variable was the diametral interference between the parts (0.0000 to 0.0008 inch or 0.0000 to 0.0203 mm).

The press-in force test results were inconsistent. Half of the test joints produced an off-scale reading or a slip-fit condition. The correlation between interference and press-in force was only 0.5321.

While the second group of samples was being prepared for testing, the hole sizes were measured on three different occasions, once optically and twice using Deltronic size-wires. Variations as much as 0.0004 inch (0.0102 mm) were observed among the different measurements. The optical measurements were consistently higher than the size-wire readings, possibly because the instrument can focus only on the top edge of the hole (bell-mouth condition), while size-wires will pick up only the smallest section of a hole (a burr, for example) and will not give the average size. Because pin and hole samples could not be accurately matched using the available methods of measurement, good test results could not be expected. Further work on the study therefore was suspended.

The conclusion was reached that the same problems would be encountered in matching press-fit pin and hole sizes for production parts when the diameters were less than 0.060 inch (1.5 mm).

Therefore, since satisfactory part yields could not be expected, consideration should be given to such other methods of pin-retention as staking, bonding, or welding.

ACCOMPLISHMENTS

The investigation of 0.020-, 0.031-, and 0.060-inch (0.508, 0.787, and 1.52 mm) press-fit pins and mating collars produced the following conclusions.

Use of the equation defining the holding-power of a press-fit joint was hampered by poor quality of the samples and inaccuracies caused by present hole-size measurement techniques.

The 0.020-inch (0.508 mm) pins appeared to be affected more by surface finish and collar size than did the larger pins. The 0.060-inch (1.52 mm) pins were affected more by the depth to which the pin was pushed (length of engagement) and the outer diameter of the collar. Apparently, the smaller the pin, the more subject the joint is to surface-finish and collar-outer-diameter conditions, from both a size and a measurement standpoint.

The use of alcohol as a lubricant and the variation of the press-in rate had no significant effect on either the press-in force or the holding-power of the joints.

When press-fit parts having diameters less than 0.060 inch (1.5 mm) are to be fabricated, the recommendation is made that consideration be given to such other methods of pin-retention as staking, bonding, or welding.

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Appendix

TEST DATA

Table A-1. Analysis of Variance for Test 1A,
Press-In Force (No effects were
significant.)

Source of Variation	Estimate of Effect	Degrees of Freedom	Mean Square
1*	-2.658750	1	28.275806
2**	4.271250	1	72.974306
12	0.591250	1	1.398306
3***	-7.878750	1	248.298806
13	0.308750	1	0.381306
23	-5.503750	1	121.165056
123	-2.633750	1	27.746556
4****	7.508750	1	225.525306
14	-4.071250	1	66.300306
24	4.333750	1	75.125556
124	-4.053750	1	65.731556
34	-6.641250	1	176.424806
134	3.328750	1	44.322306
234	-7.891250	1	249.087306
1234	-2.221250	1	19.735806

*Factor 1 is evaluation of lubrication effects.
 **Factor 2 is evaluation of press-rate effects.
 ***Factor 3 is evaluation of interference-fit effects.
 ****Factor 4 is evaluation of collar-outside-diameter effects.

Table A-2. Analysis of Variance for Test 1A, Push-Out Force

Source of Variation	Estimate of Effect	Degrees of Freedom	Mean Square	F-Ratio
1*	-1.512500	1	9.150625	0.66
2**	-2.887500	1	33.350625	2.42
12	2.400000	1	23.040000	1.67
3***	0.612500	1	1.500625	0.11
13	0.625000	1	1.562500	0.11
23	-2.050000	1	16.810000	1.22
123	-2.462500	1	24.255625	1.76
4****	3.825000	1	58.522500	4.25
14	0.887500	1	3.150625	0.23
24	-1.862500	1	13.875625	1.01
124	2.650000	1	28.090000	2.04
34	2.037500	1	16.605625	1.21
134	1.225000	1	6.002500	0.44
234	-1.050000	1	4.410000	0.32
1234	-1.237500	1	6.125625	0.44

Estimate of σ^2 used in F-Test was 13.777 lb (61.38 N) using 3rd- and 4th- order interactions. No effects were significant.

*Lubrication test
 **Press test
 ***Interference test
 ****Collar outside diameter

Table A-3. Analysis of Variance for Test 1B,
Press-In Force

Source of Variation	Estimate of Effect	Degrees of Freedom	Mean Square
1*	21.203125	1	3596.580078†
2**	1.015625	1	8.251953
12	-4.515625	1	163.126953
3***	-6.078125	1	295.548828
13	-2.921875	1	68.298828
23	3.390625	1	91.970703
123	4.984375	1	198.751953
4****	12.234375	1	1197.439453†
14	4.515625	1	163.126953
24	-2.171875	1	37.736328
124	5.546875	1	246.142578
34	4.359375	1	152.033203
134	-0.234375	1	0.439453
234	4.828125	1	186.486328
1234	-0.828125	1	5.486328
5*****	25.203125	1	5081.580078†
15	11.171875	1	998.486328†
25	-2.515625	1	50.626953
125	-5.984375	1	286.501953
35	-8.671875	1	601.611328
135	-2.578125	1	53.173828
235	0.484375	1	1.876953
1235	2.640625	1	55.783203
45	6.390625	1	326.720703
145	3.859375	1	119.158203
245	-4.828125	1	186.486328
1245	4.703125	1	176.955078
345	2.390625	1	45.720703
1345	-1.015625	1	8.251953
2345	3.296875	1	86.955078
12345	-2.546875	1	51.892578
*Collar-thickness test **Lubrication test ***Press test ****Interference test *****Collar-outside-diameter test †Significant effect

Figure A-1. Comparison of Variables for High and Low Collar Outside Diameter, Test 1B, Press-In Force

Table A-4. Analysis of Variance for Test 1B, Push-Out Force

Source of Variation	Estimate of Effect	Degrees of Freedom	Mean Square	F-Ratio
1*	21.581250	1	3726.002812	69.99†
2**	2.668750	1	56.977812	1.07
12	1.850000	1	27.380000	0.51
3***	-4.637500	1	172.051250	3.23
13	-1.993750	1	31.800312	0.60
23	-1.381250	1	15.262812	0.29
123	-2.000000	1	32.000000	0.60
4****	6.637500	1	352.451250	6.62†
14	4.443750	1	157.975312	2.97
24	-1.368750	1	14.987812	0.28
124	3.175000	1	80.645000	1.51
34	1.887500	1	28.501250	0.54
134	2.268750	1	41.177812	0.77
234	-1.343750	1	14.445313	0.27
1234	-2.325000	1	43.245000	0.81
5*****	24.281250	1	4716.632812	88.59†
15	18.850000	1	2842.580000	53.39†
25	1.387500	1	15.401250	0.29
125	-0.156250	1	0.195312	0.003
35	-7.681250	1	472.012812	8.8658†
135	-5.437500	1	236.531250	4.441
235	-1.425000	1	16.245000	0.3051
1235	-2.693750	1	58.050313	1.09
45	4.793750	1	183.840313	3.45
145	4.500000	1	162.000000	3.04
245	-0.062500	1	0.031250	0.0006
1245	3.131250	1	78.437812	1.47
345	2.181250	1	38.062812	0.71
1345	2.037500	1	33.211250	0.62
2345	0.025000	1	0.005000	0.00001
12345	-1.481250	1	17.552812	0.3297

Estimate of σ^2 used in F-Test was 50.24 lb (223.47 N) using 3rd-, 4th- 5th- order interactions.

*Collar-thickness test

**Lubrication test

***Press test

****Interference test

*****Collar-outside-diameter test

†Significant effect

Figure A-2. Comparison of Variables for High and Low Collar Outside Diameter, Test 1B, Push-Out Force

Table A-5. Test 1A Data, Using 0.020-Inch-Diameter (0.508 mm) Pins, Collar Material of Hyperco 50 (Heat-Treated), and Pin Material of 420 Stainless Steel (Annealed)

Test Number	Pin Sample Number	Collar Sample Number	Alcohol Lubed	Press Rate (In/Min)*	Interference (Inch)**	Collar Outside Diameter (Inch)	Max Press-In Force (Lb)***	Push-Out Force (Lb)
1	5E1	5E1	No	20	0.0002	0.040	5.4	4.8
2	5E2	5E2	Yes	20	0.0002	0.040	13.5	3.8
3	5E9	5E9	No	0.5	0.0002	0.040	6.0	3.8
4	5E4	5E4	Yes	0.5	0.0002	0.040	8.0	4.75
5	5A6	5A6	No	20	Line Fit	0.040	5.0	3.75
6	5A3	5A3	Yes	20	Line Fit	0.040	6.65	4.0
7	5A4	5A4	No	0.5	Line Fit	0.040	11.2	3.2
8	5A5	5A5	Yes	0.5	Line Fit	0.040	5.1	0.5
9	5F1	5F1	No	20	0.0002	0.080	21.0	13.4
10	5F2	5F2	Yes	20	0.0002	0.080	1.75	0.4
11	5F3	5F3	No	0.5	0.0002	0.080	33.5	3.0
12	5F5	5F5	Yes	0.5	0.0002	0.080	33.25	7.5
13	5B8	5B8	No	20	Line Fit	0.080	12.0	13.6
14	5B10	5B10	Yes	20	Line Fit	0.080	8.5	11.7
15	5B3	5B3	No	0.5	Line Fit	0.080	7.42	4.4
16	5B6	5B6	Yes	0.5	Line Fit	0.080	3.5	5.2

*1 in/min = 0.4 mm/s

**1 in = 25.4 mm

***1 pound-force = 4.448 Newtons

Table A-6. Test 1B Data, Using 0.060-Inch-Diameter (1.52 mm) Pins, Collar Material of Hyperco 50 (Heat-Treated), and Pin Material of 420 Stainless Steel (Annealed)

Test Number	Pin Sample Number	Collar Sample Number	Collar Thickness (Inch)*	Alcohol Lubed	Press Rate (In/Min)**	Interference (Inch)	Collar Outside Diameter (Inch)	Max Press-In Force (Lb)***	Push-Out Force (Lb)
1	5L1	5L1	0.020	No	20	0.0002	0.080	4.0	2.25
2	5S1	5S1	0.100	No	20	0.0002	0.080	14.5	1.4
3	5L2	5L2	0.020	Yes	20	0.0002	0.080	3.5	3.0
4	5S2	5S2	0.100	Yes	20	0.0002	0.080	14.0	3.0
5	5L3	5L3	0.020	No	0.5	0.0002	0.080	5.0	2.5
6	5S3	5S3	0.100	No	0.5	0.0002	0.080	12.0	5.0
7	5L4	5L4	0.020	Yes	0.5	0.0002	0.080	6.0	3.0
8	5S5	5S5	0.100	Yes	0.5	0.0002	0.080	15.5	12.5
9	5J1	5J1	0.020	No	20	0.0007	0.080	6.0	5.5
10	5Q1	5Q1	0.100	No	20	0.0007	0.080	18.0	2.3
11	5J6	5J6	0.020	Yes	20	0.0007	0.080	9.5	4.6
12	5Q2	5Q2	0.100	Yes	20	0.0007	0.080	18.0	5.8
13	5J3	5J3	0.020	No	0.5	0.0007	0.080	9.75	5.75
14	5Q3	5Q3	0.100	No	0.5	0.0007	0.080	14.5	10.2
15	5J4	5J4	0.020	Yes	0.5	0.0007	0.080	14.0	2.5
16	5Q5	5Q5	0.100	Yes	0.5	0.0007	0.080	31.5	10.75
17	5M1	5M1	0.020	No	20	0.0002	0.125	4.0	4.8
18	5T1	5T1	0.100	No	20	0.0002	0.125	64.0	51.75
19	5M2	5M2	0.020	Yes	20	0.0002	0.125	45.5	15.5
20	5T2	5T2	0.100	Yes	20	0.0002	0.125	42.0	55.0
21	5M5	5M5	0.020	No	0.5	0.0002	0.125	2.0	0.75
22	5T4	5T4	0.100	No	0.5	0.0002	0.125	31.5	26.0
23	5M4	5M4	0.020	Yes	0.5	0.0002	0.125	13.0	10.25
24	5T6	5T6	0.100	Yes	0.5	0.0002	0.125	23.0	24.5
25	5K1	5K1	0.020	No	20	0.0007	0.125	35.0	17.75
26	5R1	5R1	0.100	No	20	0.0007	0.125	87.0	53.75
27	5K3	5K3	0.020	Yes	20	0.0007	0.125	19.0	8.0
28	5R2	5R2	0.100	Yes	20	0.0007	0.125	62.0	77.0
29	5K4	5K4	0.020	No	0.5	0.0007	0.125	26.0	8.25
30	5R3	5R3	0.100	No	0.5	0.0007	0.125	56.0	55.0
31	5K5	5K5	0.020	Yes	0.5	0.0007	0.125	25.5	7.25
32	5R5	5R5	0.100	Yes	0.5	0.0007	0.125	63.5	53.0

*1inch = 25.4 mm

**1 inch/min = 0.4 mm/s

***1 pound-force = 4.448 Newtons

Table A-7. Analysis of Variance for Test 2A,
Press-In Force

Source of Variation	Estimate of Effect	Degrees of Freedom	Mean Square
1*	1.275000	1	6.502500
2**	-0.900000	1	3.240000
12	2.175000	1	18.922500
3***	-6.675000	1	178.222500†
13	-1.200000	1	5.760000
23	0.725000	1	2.102500
123	-1.800000	1	12.960000
4****	0.975000	1	3.802500
14	-0.350000	1	0.490000
24	-0.025000	1	0.002500
124	1.650000	1	10.890000
34	-0.850000	1	2.890000
134	0.425000	1	0.722500
234	-0.850000	1	2.890000
1234	-3.875000	1	60.062500
*Lubrication test **Press test ***Interference test ****Collar-outside-diameter test †Significant effect

Figure A-3. Press-In Force Versus Diametral Interference for Test 2A

Table A-8. Analysis of Variance for Test 2A, Push-Out Force

Source of Variation	Estimate of Effect	Degrees of Freedom	Mean Square	F-Ratio
1*	2.425000	1	23.522500	1.05
2**	-1.487500	1	8.850625	0.40
12	2.312500	1	21.390625	0.96
3***	-6.975000	1	194.602500	8.73†
13	-2.175000	1	18.922500	0.85
23	0.462500	1	0.855625	0.04
123	-2.187500	1	19.140625	0.86
4****	1.175000	1	5.522500	0.25
14	1.325000	1	7.022500	0.31
24	0.437500	1	0.765625	0.03
124	2.737500	1	29.975625	1.34
34	-1.225000	1	6.002500	0.27
134	0.275000	1	0.302500	0.01
234	-0.462500	1	0.855625	0.04
1234	-3.912500	1	61.230625	2.75

Estimate of σ^2 used in F-Test was 22.3 lb (99.2 N) using 3rd- and 4th- order interactions.

*Factor 1 is evaluation of lubrication effects.

**Factor 2 is evaluation of press-rate effects.

***Factor 3 is evaluation of interference-fit effects.

****Factor 4 is evaluation of effects of changing collar outside diameter.

†Significant effect

Figure A-4. Push-Out Force Versus Diametral Interference for Test 2A

Table A-9. Analysis of Variance for Test 2B,
Press-In Force

Source of Variation	Estimate of Effect	Degrees of Freedom	Mean Square
1*	30.978125	1	7677.153828†
2**	4.740625	1	179.788203
12	4.528125	1	164.031328
3***	0.953125	1	7.267578
13	-5.884375	1	277.006953
23	-3.396875	1	92.310078
123	-0.434375	1	1.509453
4****	22.428125	1	4024.166328†
14	6.578125	1	346.173828
24	-4.496875	1	161.775078
124	-3.896875	1	121.485078
34	2.415625	1	46.681953
134	-4.609375	1	169.970703
234	-3.659375	1	107.128203
1234	-6.384375	1	326.081953
5*****	20.153125	1	3249.187578†
15	9.428125	1	711.116328
25	2.853125	1	65.122578
125	-1.921875	1	29.548828
35	-2.184375	1	38.171953
135	-1.584375	1	20.081953
235	-1.384375	1	15.331953
1235	-1.984375	1	31.501953
45	5.790625	1	268.250703
145	0.753125	1	4.537578
245	-6.234375	1	310.939453
1245	-5.321875	1	226.578828
345	-2.571875	1	52.916328
1345	-4.784375	1	183.121953
2345	-1.796875	1	25.830078
12345	-4.709375	1	177.425703
*Collar-thickness test **Lubrication test ***Press test ****Interference test *****Collar-outside-diameter test †Significant effect

Figure A-5. Comparison of Variables for High and Low Collar Outside Diameter, Test 2B, Press-In Force

Table A-10. Analysis of Variance for Test 2B, Push-Out Force

Source of Variation	Estimate of Effect	Degrees of Freedom	Mean Square	F-Ratio
1*	44.046875	1	15521.017578	25.47†
2**	19.484375	1	3037.126953	4.98†
12	18.515625	1	2742.626953	4.50††
3***	-7.296875	1	425.955078	0.70
13	-5.328125	1	227.111328	0.37
23	-1.953125	1	30.517578	0.05
123	-1.921875	1	29.548828	0.05
4****	8.359375	1	559.033203	0.92
14	3.765625	1	113.439453	0.19
24	-5.734375	1	263.064453	0.43
124	-4.890625	1	191.345703	0.31
34	-11.953125	1	1143.017578	1.88
134	-7.546875	1	455.642578	0.75
234	-13.484375	1	1454.626953	2.39
1234	-11.515625	1	1060.876953	1.74
5*****	21.453125	1	3681.892578	6.04†
15	19.796875	1	3135.330078	5.15†
25	11.421875	1	1043.673828	1.71
125	10.328125	1	853.361328	1.40
35	-13.546875	1	1468.142578	2.41
135	-12.078125	1	1167.048828	1.92
235	-6.890625	1	379.845703	0.62
1235	-7.484375	1	448.126953	0.79
45	-2.640625	1	55.783203	0.09
145	-4.234375	1	143.439453	0.24
245	-9.421875	1	710.173828	1.17
1245	-8.703125	1	605.955078	0.99
345	-6.703125	1	359.455078	0.59
1345	-4.546875	1	165.392578	0.27
2345	-10.796875	1	932.580078	1.53
12345	-9.953125	1	792.517578	1.30

Estimate of σ^2 used in F-Test was 609.37 lb (2.7 kN) using 3rd-, 4th- and 5th- order interactions. The significant effects are starred.

*Collar-thickness test

**Lubrication test

***Press test

****Interference test

*****Collar-outside-diameter test

†Significant effect

††Possibly significant effect

Figure A-6. Comparison of Variables for High and Low Collar Outside Diameter, Test 2B, Push-Out Force

Table A-11. Test 2A Data, Using 0.020-Inch-Diameter (0.508 mm) Pins, Collar Material of 6061 Aluminum (T-6 Condition), and Pin Material of 17-4 Stainless Steel (H-900 Condition)

Test Number	Pin Sample Number	Collar Sample Number	Alcohol Lubed	Press Rate (In/Min)*	Interference (Inch)**	Collar Outside Diameter (Inch)	Max Press-In Force (Lb)***	Push-Out Force (Lb)
1	6E1	6E1	No	20	0.0002	0.040	6.5	5.3
2	6E2	6E2	Yes	20	0.0002	0.040	11.3	11.0
3	6E3	6E3	No	0.5	0.0002	0.040	5.6	4.6
4	6E5	6E5	Yes	0.5	0.0002	0.040	7.3	6.0
5	6A1	6A1	No	20	Line Fit	0.040	2.8	2.8
6	6A2	6A2	Yes	20	Line Fit	0.040	0.2	0.15
7	6A3	6A3	No	0.5	Line Fit	0.040	0.9	0.5
8	6A5	6A5	Yes	0.5	Line Fit	0.040	3.5	0.45
9	6F1	6F1	No	20	0.0002	0.080	13.8	12.4
10	6F4	6F4	Yes	20	0.0002	0.080	6.0	6.9
11	6F6	6F6	No	0.5	0.0002	0.080	3.5	0.2
12	6F7	6F7	Yes	0.5	0.0002	0.080	14.7	17.0
13	6B1	6B1	No	20	Line Fit	0.080	1.5	0
14	6B2	6B2	Yes	20	Line Fit	0.080	3.5	2.9
15	6B3	6B3	No	0.5	Line Fit	0.080	2.3	0
16	6B4	6B4	Yes	0.5	Line Fit	0.080	0.6	0.8
<p>*1 inch/min = 0.4 mm/s **1 inch = 25.4 mm ***1 pound-force = 4.448 Newtons</p>								

Table A-12. Test 2B Data, Using 0.060-Inch-Diameter (1.52 mm) Pins, Collar Material of 6061 Aluminum (T-6 Condition), and Pin Material of 303Se Stainless Steel (Annealed)

Test Number	Pin Sample Number	Collar Sample Number	Collar Thickness (Inch)*	Alcohol Lubed	Press Rate (In/Min)**	Interference (Inch)	Collar Outside Diameter (Inch)	Max Press-In Force (Lb)***	Push-Out Force (Lb)
1	6L1	6L1	0.020	No	20	0.0002	0.080	6.0	1.75
2	6S1	6S1	0.100	No	20	0.0002	0.080	24.4	11.0
3	6L2	6L2	0.020	Yes	20	0.0002	0.080	4.5	1.25
4	6S3	6S3	0.100	Yes	20	0.0002	0.080	26.5	5.0
5	6L5	6L5	0.020	No	0.5	0.0002	0.080	12.0	3.0
6	6S5	6S5	0.100	No	0.5	0.0002	0.080	15.0	17.5
7	6L7	6L7	0.020	Yes	0.5	0.0002	0.080	3.75	3.5
8	6S6	6S6	0.100	Yes	0.5	0.0002	0.080	23.25	41.0
9	6J1	6J1	0.020	No	20	0.0007	0.080	11.5	6.0
10	6Q1	6Q1	0.100	No	20	0.0007	0.080	35.0	26.5
11	6J2	6J2	0.020	Yes	20	0.0007	0.080	11.0	7.5
12	6Q2	6Q2	0.100	Yes	20	0.0007	0.080	50.5	44.0
13	6J3	6J3	0.020	No	0.5	0.0007	0.080	27.5	5.0
14	6Q3	6Q3	0.100	No	0.5	0.0007	0.080	43.0	25.0
15	6J5	6J5	0.020	Yes	0.5	0.0007	0.080	19.5	3.0
16	6Q5	6Q5	0.100	Yes	0.5	0.0007	0.080	50.5	55.0
17	6M1	6M1	0.020	No	20	0.0002	0.125	6.5	0.75
18	6T1	6T1	0.100	No	20	0.0002	0.125	34.5	40.0
19	6M3	6M3	0.020	Yes	20	0.0002	0.125	21.0	1.0
20	6T2	6T2	0.100	Yes	20	0.0002	0.125	55.3	101.0
21	6M7	6M7	0.020	No	0.5	0.0002	0.125	11.5	0.5
22	6T3	6T3	0.100	No	0.5	0.0002	0.125	26.0	5.0
23	6M4	6M4	0.020	Yes	0.5	0.0002	0.125	10.0	7.5
24	6T4	6T4	0.100	Yes	0.5	0.0002	0.125	65.5	121.0
25	6K1	6K1	0.020	No	20	0.0007	0.125	25.3	12.25
26	6R1	6R1	0.100	No	20	0.0007	0.125	83.0	59.0
27	6K2	6K2	0.020	Yes	20	0.0007	0.125	25.5	15.0
28	6R8	6R8	0.100	Yes	20	0.0007	0.125	97.0	154.0
29	6K4	6K4	0.020	No	0.5	0.0007	0.125	37.5	4.5
30	6R5	6R5	0.100	No	0.5	0.0007	0.125	88.5	54.0
31	6K5	6K5	0.020	Yes	0.5	0.0007	0.125	44.25	2.75
32	6R7	6R7	0.100	Yes	0.5	0.0007	0.125	55.0	21.0
*1 inch = 25.4 mm **1 inch/min = 0.4 mm/s ***1 pound-force = 4.448 Newtons									

Table A-13. Analysis of Variance for Test 3A, Press-In Force

Source of Variation	Estimate of Effect	Degrees of Freedom	Mean Square
1*	2.543750	1	25.882656
2**	1.581250	1	10.001406
12	0.106250	1	0.045156
3***	-7.893750	1	249.245156*****
13	0.718750	1	2.066406
23	0.456250	1	0.832656
123	0.581250	1	1.351406
4****	-2.181250	1	19.031406
14	-1.343750	1	7.222656
24	-0.231250	1	0.213906
124	1.556250	1	9.687656
34	0.793750	1	2.520156
134	3.481250	1	48.476406
234	-0.306250	1	0.375156
1234	1.831250	1	13.413906
<p>*Factor 1 is evaluation of lubrication effects. **Factor 2 is evaluation of press-rate effects. ***Factor 3 is evaluation of interference-fit effects. ****Factor 4 is evaluation of collar-outside-diameter effects. *****Significant effect</p>

Figure A-7. Press-In Force Versus Diametral Interference for Test 3A

Table A-14. Analysis of Variance for Test 3A, Push-Out Force

Source of Variation	Estimate of Effect	Degrees of Freedom	Mean Square	F-Ratio
1*	3.450000	1	47.610000	2.78
2**	-1.375000	1	7.562500	0.42
12	-0.300000	1	0.360000	0.02
3***	-5.150000	1	106.090000	5.96
13	-3.975000	1	63.202500	3.55
23	1.650000	1	10.890000	0.61
123	0.025000	1	0.002500	0.0001
4****	-2.700000	1	29.160000	1.64
14	-3.725000	1	55.502500	3.12
24	-1.200000	1	5.760000	0.32
124	-0.225000	1	0.202500	0.01
34	2.375000	1	22.562500	1.27
134	4.450000	1	79.210000	4.45
234	1.425000	1	8.122500	0.46
1234	0.600000	1	1.440000	0.08
<p>Estimate of σ^2 used in F-test was 17.8 lb (79.2 N) using 3rd- and 4th- order interactions. No effects were significant.</p> <p>*Collar-thickness test</p> <p>**Lubrication test</p> <p>***Press test</p> <p>****Interference test</p>				

Table A-15. Analysis of Variance for Test 3B, Press-In Force

Source of Variation	Estimate of Effect	Degrees of Freedom	Mean Square
1*	30.331250	1	7359.877812†
2**	5.831250	1	272.027813
12	6.606250	1	349.140312
3***	12.768750	1	1304.327812
13	1.418750	1	16.102813
23	-2.706250	1	58.590313
123	-1.356250	1	14.715312
4****	19.981250	1	3194.002812
14	5.706250	1	260.490312
24	-9.793750	1	767.340312
124	-6.268750	1	314.377813
34	-4.356250	1	151.815312
134	-9.206250	1	678.040312
234	-15.331250	1	1880.377813
1234	-11.231250	1	1009.127812
5*****	15.793750	1	1995.540312
15	10.018750	1	803.002812
25	6.268750	1	314.377813
125	5.793750	1	268.540312
35	9.706250	1	753.690312
135	7.106250	1	403.990313
235	-4.018750	1	129.202813
1235	-3.168750	1	80.327812
45	1.918750	1	29.452812
145	1.643750	1	21.616312
245	-3.856250	1	118.965312
1245	-6.581250	1	346.502813
345	-7.668750	1	470.477812
1345	-7.768750	1	482.827812
2345	-11.143750	1	993.465313
12345	-15.043750	1	1810.515312

*Collar-thickness test

**Lubrication test

***Press test

****Interference test

*****Collar-outside-diameter test

†Significant effect

††Possibly significant with a better estimate of experimental error

Table A-16. Analysis of Variance for Test 3B, Push-Out Force

Source of Variation	Estimate of Effect	Degrees of Freedom	Mean Square	F-Ratio
1*	34.365625	1	9447.969453	7.33 [†]
2**	11.365625	1	1033.419453	0.80
12	10.615625	1	901.531953	0.70
3***	8.334375	1	555.694453	0.43
13	6.896875	1	380.535078	0.30
23	-7.228125	1	417.966328	0.32
123	-7.228125	1	417.966328	0.32
4****	11.490625	1	1056.275703	0.82
14	8.990625	1	646.650703	0.50
24	-5.009375	1	200.750703	0.16
124	-6.946875	1	386.072578	0.30
34	-10.540625	1	888.838203	0.69
134	-13.915625	1	1549.156953	1.20
234	-20.415625	1	3334.381953	2.59
1234	-22.853125	1	4178.122578	3.24
5*****	21.021875	1	3535.353828	2.74
15	16.459375	1	2167.288203	1.68
25	7.459375	1	445.138203	0.35
125	8.084375	1	522.856953	0.41
35	12.240625	1	1198.663203	0.93
135	10.803125	1	933.660078	0.72
235	-2.696875	1	58.185078	0.05
1235	-4.571875	1	167.216328	0.13
45	-8.103125	1	525.285078	0.41
145	-9.603125	1	737.760078	0.57
245	-9.728125	1	757.091328	0.59
1245	-10.540625	1	888.838203	0.69
345	-7.571875	1	458.666328	0.36
1345	-9.946875	1	791.522578	0.61
2345	-19.946875	1	3183.022578	2.47
12345	-16.759375	1	2247.013203	1.74

Estimate of σ^2 used in F-Test was 1288.22 lb (573.21 N) using 3rd-, 4th- and 5th- order interactions.

*Collar-thickness test

**Lubrication test

***Press test

****Interference test

*****Collar-outside-diameter test

[†]Significant effect

Figure A-8. Push-Out Force Versus Length of Engagement for Test 3B

Table A-17. Test 3A Data, Using 0.020-Inch-Diameter (0.508 mm) Pins, Collar Material of 7075 Aluminum (T-6 Condition), and Pin Material of 303Se Stainless Steel (Annealed)

Test Number	Pin Sample Number	Collar Sample Number	Alcohol Lubed	Press Rate (In/Min)*	Interference (Inch)**	Collar Outside Diameter (Inch)	Max Press-In Force (Lb)***	Push-Out Force (Lb)
1	7E1	7E1	No	20	0.0002	0.040	11.1	1.5
2	7E2	7E2	Yes	20	0.0002	0.040	17.0	16.6
3	7E3	7E3	No	0.5	0.0002	0.040	11.4	0.6
4	7E4	7E4	Yes	0.5	0.0002	0.040	18.8	16.7
5	7A1	7A1	No	20	Line Fit	0.040	2.0	1.6
6	7A2	7A2	Yes	20	Line Fit	0.040	7.2	1.0
7	7A3	7A3	No	0.5	Line Fit	0.040	8.65	2.3
8	7A4	7A4	Yes	0.5	Line Fit	0.040	5.7	0.4
9	7F1	7F1	No	20	0.0002	0.080	12.6	6.4
10	7F2	7F2	Yes	20	0.0002	0.080	9.4	6.8
11	7F3	7F3	No	0.5	0.0002	0.080	13.6	1.9
12	7F5	7F5	Yes	0.5	0.0002	0.080	10.8	0
13	7B1	7B1	No	20	Line Fit	0.080	2.4	0.7
14	7B2	7B2	Yes	20	Line Fit	0.080	5.1	0.8
15	7B3	7B3	No	0.5	Line Fit	0.080	1.2	1.1
16	7B4	7B4	Yes	0.5	Line Fit	0.080	9.3	1.4
<p>*1 inch/min = 0.4 mm/s **1 inch = 25.4 mm ***1 pound-force = 4.448 Newtons</p>								

Table A-18. Test 3B Data, Using 0.060-Inch-Diameter (1.52 mm) Pins, Collar Material of 7075 Aluminum (T-6 Condition), and Pin Material of 303Se Stainless Steel (Annealed)

Test Number	Pin Sample Number	Collar Sample Number	Collar Thickness (Inch)*	Alcohol Lubed	Press Rate (In/Min)**	Interference (Inch)	Collar Outside Diameter (Inch)	Max Press-In Force (Lb)***	Push-Out Force (Lb)
1	7L1	7L1	0.020	No	20	0.0002	0.080	11.5	1.0
2	7S1	7S1	0.100	No	20	0.0002	0.080	29.5	4.75
3	7L2	7L2	0.020	Yes	20	0.0002	0.080	9.0	8.25
4	7S3	7S3	0.100	Yes	20	0.0002	0.080	32.0	3.5
5	7L4	7L4	0.020	No	0.5	0.0002	0.080	8.0	7.5
6	7S4	7S4	0.100	No	0.5	0.0002	0.080	21.5	4.5
7	7L8	7L8	0.020	Yes	0.5	0.0002	0.080	20.5	0.25
8	7S5	7S5	0.100	Yes	0.5	0.0002	0.080	31.0	2.0
9	7J1	7J1	0.020	No	20	0.0007	0.080	19.0	5.5
10	7Q1	7Q1	0.100	No	20	0.0007	0.080	55.0	35.0
11	7J2	7J2	0.020	Yes	20	0.0007	0.080	20.0	4.25
12	7Q6	7Q6	0.100	Yes	20	0.0007	0.080	47.0	63.5
13	7J4	7J4	0.020	No	0.5	0.0007	0.080	41.0	2.75
14	7Q7	7Q7	0.100	No	0.5	0.0007	0.080	51.5	34.0
15	7J5	7J5	0.020	Yes	0.5	0.0007	0.080	25.0	9.0
16	7Q8	7Q8	0.100	Yes	0.5	0.0007	0.080	49.0	35.0
17	7L10	7K5	0.020	No	20	0.0002	0.125	12.0	11.5
18	7T1	7T1	0.100	No	20	0.0002	0.125	16.0	13.0
19	7L9	7K9	0.020	Yes	20	0.0002	0.125	14.5	6.25
20	7T2	7T2	0.100	Yes	20	0.0002	0.125	25.5	24.5
21	7P2	7K10	0.020	No	0.5	0.0002	0.125	23.0	6.0
22	7T3	7T3	0.100	No	0.5	0.0002	0.125	34.5	35.0
23	7P7	7K12	0.020	Yes	0.5	0.0002	0.125	21.5	6.0
24	7T4	7T4	0.100	Yes	0.5	0.0002	0.125	127.0	163.0
25	7K1	7K1	0.020	No	20	0.0007	0.125	22.2	6.25
26	7R1	7R1	0.100	No	20	0.0007	0.125	48.0	10.0
27	7K2	7K2	0.020	Yes	20	0.0007	0.125	23.5	8.0
28	7R2	7R2	0.100	Yes	20	0.0007	0.125	110.0	117.0
29	7K3	7K3	0.020	No	0.5	0.0007	0.125	43.5	13.75
30	7R5	7R5	0.100	No	0.5	0.0007	0.125	114.0	108.0
31	7K4	7K4	0.020	Yes	0.5	0.0007	0.125	40.0	17.75
32	7R6	7R6	0.100	Yes	0.5	0.0007	0.125	48.0	11.6
*1 inch = 25.4 mm **1 inch/min = 0.4 mm/s ***1 pound-force = 4.448 Newtons

Figure A-9. Comparison of Variables for High and Low Collar Outside Diameter, Test 3B, Press-In Force

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