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Producing Miniature Threads

By L. K. Gillespie
and
J. M. Robb

Published November 1981

Final Report
J. M. Robb, Project Leader

Prepared for the United States Department of Energy
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**Kansas City
Division**

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J. M. Robb

Published November 1981

Final Report
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PRODUCING MINIATURE THREADS

BDX-613-2608, Final Report, Published November 1981

Prepared by L. K. Gillespie and J. M. Robb

Miniature precision actuators, timers, and switches typically utilize miniature threads to provide convenient assembly, disassembly and adjustment. Thread rolling provides high-quality external threads with greater strength and lower cost than other thread-producing techniques. Tap breakage is a significant problem when 0.5 and 0.6 Unified National Miniature (UNM) threads must be produced in hard materials such as SAE K95100 high-permeability magnetic steel. Aluminum parts can be tapped with no difficulty in these sizes. Stainless steel 0.5 UNM screws break at loads of 21 pounds (53 N). Thread failure occurs at thread heights of 62 percent full thread or lower.

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CONTENTS

Section	Page
SUMMARY.	8
DISCUSSION	9
SCOPE AND PURPOSE.	9
PRIOR WORK	9
ACTIVITY	9
<u>Production Experience and Test Results on</u> <u>Automatic Screw Machines</u>	9
<u>Production Experience on Tapped Holes.</u>	15
<u>Thread Gaging.</u>	59
<u>Finishing Miniature Threads.</u>	60
ACCOMPLISHMENTS.	60
FUTURE WORK.	61
REFERENCES	62
APPENDICES	
A. TENSILE LOAD TEST DATA	64
B. TYPICAL PROPERTIES OF WORKPIECE MATERIALS.	75
C. CALIBRATION PROCEDURE FOR UNIFIED MINIATURE THREADS.	77

ILLUSTRATIONS

Figure		Page
1	Thread Chasers and Die Head (P-109777)	10
2	Enlarged View of Thread Chaser (P-109775).	10
3	1.2 UNM Button Die for Cutting 102 Threads/Inch (P-109778).	12
4	Burrs Remaining on Thread Crests (P-108978)	13
5	Thread-Rolling Concept (R0049-1)	14
6	Thread Rolls (P-109780).	15
7	Threads Produced by Thread Rolling (P-108981)	16
8	Threaded Part Produced by Thread Rolling (P-109785)	17
9	Material Pushed Past End of Part by Thread Rolling (P-108966)	18
10	Miniature Tap (P-108335)	20
11	Enlarged View of Miniature Tap (P-108334).	21
12	Staging Fixture (P-109786)	23
13	Different Types of Miniature Taps (P-107626)	25
14	Parts Assembled Using UNM Threads (P-109781)	26
15	Miniature Screws (P-107627).	27
16	Thimble Full of 500 Miniature Screws (P-105602)	28
17	UNM Screws Compared to 4-40 Screw (P-109776)	29
18	Initial Results and Tolerance Range of Stainless Steel Screw, SAE K95100 (R0049-2).	34
19	Results of Testing 1.0 UNM Screws (R0049-3).	36

20	Results of Testing 0.8 UNM Screws (R0049-4). . .	41
21	Results of Testing 0.6 UNM Screws (R0049-5). . .	43
22	Assembly Requiring UNM Threads (P-109779). . .	45
23	Results of Testing 0.5 UNM Threads (R0049-6) . .	47
24	Calculated and Measured Properties of 1.0 UNM Threads (R0049-7)	49
25	Effects of Number of Threads Engaged (R0049-9)	50
26	Tensile Strength Characteristics of 303 Se Stainless Steel Screws in SAE K95100 Steel and Aluminum Parts (R0049-8)	51
27	Cross Section of 0.6 UNM Tapped Hole Threads (P-109626)	53
28	Magnified View of Threads Shown in Figure 27 (P-109627)	54
29	Tap Life in SAE K95100 Steel With 0.5 UNM Bottoming Taps Used to Produce Five Full Threads/Hole (R0049-10).	55
30	Tap Life in SAE K95100 Steel With 0.6 UNM Bottoming Taps Used to Produce Five Full Threads/Hole (R0049-11).	55

TABLES

Number		Page
1	Standard Types of Threading Tools	19
2	Recommended Limits of Drilled Hole Sizes as a Function of Drilled Hole Depth	22
3	Recommended Settings for Lead Screw Tapping. . .	24
4	Comparisons of Miniature Threads	30
5	Limits of Size and Tolerances for UNM Series	31
6	Limits of Size Before Threading for Different Lengths of Engagement, UNM Series	32
7	Basic and Design Sizes for UNM Series Threads.	39
8	Values Used to Calculate Stripping Loads for 1.0 UNM Threads.	48
9	Hardness of Screws Used in the Study	52
10	Thread Strengths as a Function of Spin-Up. . .	56
11	Minor Diameter Size Reduction Caused by Tapping.	57
A-1	Measured Variation in Screw Properties	65
A-2	Results of Testing 1.0 UNM Threads	66
A-3	Measured Dimensions of Tested 1.0 UNM Threads.	67
A-4	Results of Testing 0.8 UNM Threads	68
A-5	Measured Dimensions of Tested 0.8 UNM Threads.	69
A-6	Results of Testing 0.6 UNM Threads	70
A-7	Measured Dimensions of Tested 0.6 UNM Threads.	71

A-8	Results of Testing 0.5 UNM Threads	73
A-9	Measured Dimensions of Tested 0.5 UNM Threads.	74
B-1	Typical Workpiece-Material Properties.	76
C-1	UNM Thread Gage Specifications	79

SUMMARY

Many electromechanical mechanisms such as timers, actuators, and switches use miniature threaded screws. These screws permit assemblies to be disassembled easily for cleaning, adjustment, or alteration. Thread production can be a significant problem because of miniaturization and tool breakage.

Several techniques were evaluated for producing threads in 303 Se stainless steel, 15-5 PH stainless steel, 6061-T6 aluminum, and SAE K95100 high-permeability magnetic steel. Threaded shafts and threaded holes, sizes 0.5 to 1.0 unified national miniature (UNM), were studied.

Thread rolling provided better threads at less cost than by using cutting techniques. In addition to better thread appearance, tolerances were held easier, burrs were prevented, and tool life was increased by a factor of 3.

An analysis of threaded hole tapping demonstrated that breakage of 0.5 and 0.6 UNM threads is a major problem in hard materials such as SAE K95100 magnetic steel. Although increasing the drilled hole diameter reduces cutting forces, it does not necessarily prevent tap breakage. Tapping aluminum and other soft materials does not present a problem.

Tensile tests on assembled samples indicated that increasing hole diameters to the maximum recommended by Federal Handbook H28 did not reduce thread strength. Although the federal standard recommends different hole sizes for different hole depths, it does not make a distinction for deep hole requirements, nor does the published literature discuss the strength of miniature assembled connections.

DISCUSSION

SCOPE AND PURPOSE

This study was initiated to determine the capabilities and limitations of several approaches to miniature thread production. Specifically, thread rolling was investigated as a new process and the effects of hole size on thread strength and tap life were evaluated for 0.5 to 1.2 mm (0.019 to 0.046 inch) threads. Workpiece materials included stainless steel, SAE K95100 high-permeability magnetic steel, and aluminum.

PRIOR WORK

Bendix has performed three other studies on miniature threads. In the first study, basic tapping parameters were established for the conditions explored further in this study.¹ In the second study, an air gaging technique was developed for gaging 0.5 mm threads.² A third study explored allowable screw thread torques for 0.6, 0.8, and 1.0 UNM threads.³

ACTIVITY

Precision miniature thread machining is complicated by two factors: minute threads require miniature tools which break easily or distort small shafts and, because of their size, small threads require higher levels of precision than larger threads. Because of the limited industrial use of miniature threads, tooling is limited and literature on thread manufacture is nonexistent. Also, tool breakage is common.

Bendix manufactures both internal and external threads in 0.5 through 1.2 mm UNM sizes. They are produced with automatic screw machines and miniature lead screw tappers.

Production Experience and Test Results on Automatic Screw Machines

All of the UNM threads produced at Bendix on automatic screw machines were made using Peterman P7R and Tornos R10 Swiss style screw machines. A 0.6 UNM is the smallest thread produced at Bendix using these machines. Both 303 Se and 15-5 PH (H1150M) stainless steel rods have been threaded. While threading 302 stainless steel condition B was attempted, tool life was extremely poor. In this case, the workpiece material was almost as hard as the thread chasers.

Initially, Bendix parts were produced using thread chasers having a full complement of threads on each chaser insert (Figures 1 and 2). The 0.6 UNM chasers are produced by only two domestic

Figure 1. Thread Chasers and Die Head

Figure 2. Enlarged View of Thread Chaser

manufacturers, and one of these does not produce chasers in the full thread configuration. This latter manufacturer produces staggered tooth chasers. Each chaser insert has half the number of required threads/inch or 84-1/2 versus a full 169 threads/inch complement. Bendix could not produce an acceptable thread form in the materials described by using the staggered tooth design.

The study was initiated when it became apparent that Bendix would be limited to one supplier for tools if present methods were used. Initial experience indicated that long tool procurement times could be expected. Only one of every three sets of chasers tried produced acceptable thread forms, and each set of acceptable tools produced only 150 to 200 parts for each set of chasers.

Chaser thread height was a critical factor in minimizing tool pressure and perfecting thread form. The manufacturer's product thread height was too high above centerline for Bendix needs so a special chaser design was required to take exception to the manufacturer's standards. This in turn increased tool procurement lead times and cost.

Button dies (Figure 3) were tried and found to have some advantages. The button dies produced a more consistent thread form, lasted longer by producing 300 parts for each #30 die, and were less expensive than thread chasers. However, threads cut with the button dies left obvious burrs and sharp thread crests (Figure 4). The size of these threads and their tolerance precluded the use of almost all deburring processes, because deburring altered thread dimensions and frequently resulted in undersized thread dimensions. In the search for a more consistent method of producing a burr-free thread, thread rolls were evaluated.

Thread rolling cold forms rather than cuts thread forms into a bar of material (Figures 5 and 6). This approach resulted in six advantages over button dies and thread chasers.

- Thread crests were round rather than sharp. No loose burrs were produced on the threads (Figure 7).
- The surface finish on the threads was very good.
- The resulting thread form was excellent.
- The feed rate was doubled with these tools, reducing cycle time from 82 seconds for each part to 43 seconds in the case of one part made from 15-5 PH (H1150M) (Figure 8). Other parts exhibited similar production increases.
- Tool life was 1000 parts for each roll and the rolls were less expensive than button dies.

Figure 3. 1.2 UNM Button Die for Cutting
102 Threads/Inch

- Because the threads were rolled rather than cut, these threads are cold worked and, therefore, at least theoretically measurably stronger than cut threads.

Characteristics of Thread Rolls

Thread blank diameter is very important for correct threads. A $2.4 \mu\text{m}$ (0.0001 inch) increase in blank diameter increases thread form $10.1 \mu\text{m}$ (0.0004 inch).

Slightly oversized thread blanks will crack or chip thread rolls.

Both thread form and size can be varied by varying part blank size, spindle speed, and adjusting thread rolls.

It is important to start with a sufficiently undersized thread blank and then adjust it outward until a full thread form is obtained.

Thread rolling will push material out the end of the thread (Figure 9); however, this displaced material is firmly affixed and not a loose burr. This displaced material typically projects 127 to 254 μm (0.005 to 0.010 inch) past the end of the part and

Figure 4. Burrs Remaining on Thread Crests

Figure 5. Thread-Rolling Concept

is a result of the cold-forming process and the willingness of material to flow in a path of least resistance.

Tool pressures were significantly less from thread rolling, compared to cutting threads. During thread-cutting operations, the thread blanks frequently twisted off at the thread relief area as a result of cutting tool pressures. This often resulted in damaged thread-cutting tools. Thread blanks seldom twisted off during thread rolling.

Most damaged thread rolls were caused by oversized thread blanks or by metal chips falling between thread blanks and rolls, putting excessive pressure on rolls.

Basic Limitations in Tool Availability

As indicated in the previous paragraphs, the unavailability of threading tools and associated literature are major difficulties in producing miniature threads. As an example, miniature tools are available in only 7 of the 24 principal types of threading tools (Table 1).

Furthermore, the tool material is limited in some cases. As an example, dies are available only in carbon steel for the size ranges studied. Other tools are available in high-speed steel (HSS) or carbon steel. The use of carbon steel requires much slower spindle speeds and, in the indicated materials, results in significantly lower tool life. Larger tools are often chrome-plated, black oxide-coated, nitrided, or coated with a dry lubricant to increase tool life. No such choices are available for miniature tools.

Figure 6. Thread Rolls

In addition, the quality of some tools is poor for such small precision parts. As an example, Figures 10 and 11 illustrate burrs found on all taps used at Bendix. Similar burrs were found on button dies. Burrs on cutting tools normally reduce tool life.

Production Experience on Tapped Holes

The following results were taken from a previous study.¹

- Cold-drawn 303 Se stainless steel was the most difficult material to tap. Annealed material was somewhat better, but it was still difficult to tap the 0.6 UNM size.
- Photomicrographs indicated that the taps maintained concentricity with the drilled hole. Permitting the part to float ensures concentricity, but the flexibility of these small taps allows them to follow the drilled hole in the higher strength materials even when they are positioned with some eccentricity.
- The full tolerance range of the minor diameters can be used for tapping aluminum up to three diameters deep. This was the deepest tested. It could probably be extended deeper.

Figure 7. Threads Produced by Thread Rolling

Figure 8. Threaded Part Produced by Thread Rolling

- The minor diameters of all the materials tested except aluminum are critical. The upper end of the tolerance band must be used. The allowable working tolerance band narrows as depth of thread increases. Recommended minor diameter limits for each size are shown in Table 2. This table is for use with cutting type taps only.
- Fluteless taps were not satisfactory. All attempts using fluteless taps resulted in tap breakage.
- Cutting taps with ground flutes but unground threads, though considerably less expensive, had a higher breakage incidence than the ground thread taps. The cutting taps with unground threads were satisfactory for aluminum.
- Countersinking the hole prior to tapping reduces deburring time and assists in positioning the holes under the spindle.
- A staging fixture is recommended to prevent the parts from rotating and still allow at least $127.0\ \mu\text{m}$ (0.005 inch) for the part to center itself under the spindle (Figure 12). Large parts made from SAE K95100 were tapped successfully without a fixture, but the rapidity of locating parts under

Figure 9. Material Pushed Past End of Part by Thread Rolling

Table 1. Standard Types of Threading Tools

Internal Threads			External Threads		
Small American Threads	ISO Metric Threads	UNM Threads	Small American Threads	ISO Metric Threads	UNM Threads
Cutting Taps			Cutting Dies		
Taper	X	X	Solid	X	X
Plug	X	X	Split		X
Bottoming	X	X	Collapsible		
Spiral pointed (gun)	X	*	2-piece		
Fast spiral point		X	Acorn		
Spiral fluted			Solid adjustable		
Fluteless spiral point					
Interrupted thread					
Short flute			Thread roll		
Collapsing			Flat	X	
Male center removed			Rotary		X
Cold Forming Taps					
Plug					
Bottoming					
Lubricated plug					
Lubricated bottoming					
Polygon					
*Not available in sizes below 0.6 mm					

the spindle center and the simplicity of fixture design would normally justify its use. The base of the tapping machine has a tapped bolster plate for clamping fixtures.

In actual practice in hard materials, most taps break after 10 to 15 holes from misalignment or excessive tapping torque. This frequency of breakage slows production and flow times. Tools must be changed and reset, and parts having broken taps in them must be reworked by acid etching and then working out the broken tap with special tooling.

Typically, a 1.0 UNM thread, six full threads deep, is tapped in only 4 seconds in aluminum when the production lead screw tapping machine is used. At a machine setting of 25 percent full speed and 20 percent full torque, the operator has only 0.5 seconds to

Figure 10. Miniature Tap

Figure 11. Enlarged View of Miniature Tap

Table 2. Recommended Limits of Drilled Hole Sizes as a Function of Drilled Hole Depth

UNM Thread	Hole Depth as a Ratio of Hole Diameter	
	Minimum	Minimum
	(mm) (Inch)	(mm) (Inch)
0.66 Times Diameter (Drilled Hole Size)		
0.60	0.460 (0.0181)	0.483 (0.0190)
	0.612 (0.0241)	0.640 (0.0252)
	0.762 (0.0300)	0.798 (0.0314)
0.66 to 1.50 Times Diameter (Drilled Hole Size)		
0.80	0.475 (0.0187)	0.503 (0.0198)
	0.630 (0.0248)	0.668 (0.0263)
	0.785 (0.0309)	0.831 (0.0327)
1.50 to 3.00 Times Diameter (Drilled Hole Size)		
1.00	0.490 (0.0193)	0.503 (0.0198)
	0.650 (0.0256)	0.668 (0.0263)
	0.810 (0.0319)	0.831 (0.0327)

position the part under the tap once the cycle starts. A slight misalignment between part and tap can be accommodated because of the generous lead chamfer on most taps. This lead chamfer helps guide the tap into the hole, but excessive misalignment will buckle and break the tap.

Tap dulling is indicated by a clicking noise that occurs each time the tapping machine reaches a preset torque which causes the spindle to reverse. In SAE K95100 high-permeability magnetic steel with a nominal hole size, the machine may reverse four times in the first hole at a torque setting of 20 percent for a 1.0 UNM tap, but, by the tenth hole, ten reversals generally will be required to complete the threading.

When using torque limited tapping machines, the operator must inspect all holes to ensure that the desired depth has been obtained or provide a process control that will ensure the

Figure 12. Staging Fixture

desired depth has been reached. Small diameter holes will generate enough torque to prevent full depth from being reached. Table 3 illustrates some relative machine torque and spindle speed settings for equipment currently in use at Bendix.

While the long lead chamfer on taps aids in centering the parts, it can be a significant problem in short blind holes which require a relatively large number of threads. As seen in Figure 13, the taps currently in use at Bendix have a lead chamfer of up to six threads. This style of tap makes the tapping of blind shallow holes practically impossible. At the present time, however, Bendix does not have a requirement for full thread blind holes.

When the application dictates shorter lead chamfers, plug and bottoming taps are available with shorter lead chamfers. Because of their almost-square ends, centering of the part under the tap is much more critical when using plug and bottoming taps.

Staging fixtures orient parts and they can be used to position the part under the spindle. Fixtures used at Bendix do not position the part below the tap. These fixtures provide rigidity during tapping and ease of part manipulation as well as orientation. Many parts are too small to hold regardless of their

Table 3. Recommended Settings for Lead Screw Tapping

Material*	Thickness (mm) (Inch)	Thread Size (UNM)	Torque Setting	Spindle Speed Setting
6061-T6 Aluminum	0.508 (0.020)	0.6	30	53
6061-T6 Aluminum	0.508 (0.020)	1.0	30	53
6061-T6 Aluminum	1.90 (0.075)	0.6	30	53
6061-T6 Aluminum	1.90 (0.075)	1.0	30	53
17-4 H900 SS**	0.508 (0.020)	0.6	8	15
17-4 H900 SS	0.508 (0.075)	1.0	6	20
17-4 H900 SS	0.508 (0.075)	0.8	4	15
17-4 H900 SS	0.508 (0.075)	0.8†	2	10
303 SE Stainless Steel	0.508 (0.020)	0.6	5	15
303 SE Stainless Steel	1.90 (0.075)	0.6	4	12
303 SE Stainless Steel	1.90 (0.075)	1.0	5	15
SAE K95100	1.90 (0.075)***	1.0	4	15

*Tap-drilled holes on lower end of tolerance will require lower settings.

**SS denotes stainless steel. The 303 SE stainless steel parts are condition A (annealed).

***Blind holes.

†Bottoming tap.

geometry (Figure 14). Although a skilled worker can tap 100 holes a day and break only two taps, the use of an N/C positioning table would eliminate skill requirements, increase production, and reduce the number of taps broken off in parts; but the tapping equipment must have an extra-sensitive spindle and torque mechanism.

Comparative Size of Miniature Threads

The small size of some of the UNM threads is illustrated in Figures 15, 16, and 17. For relative comparison, a 4-40 UNF screw is included in Figure 17. The maximum total height of a 0.5 UNM thread is only 83.8 μm (0.0033 inch) and the minimum is 58.9 μm (0.0023 inch). The basic design size of other thread heights is presented later in this report.

There are four series of small or miniature threads and many individuals confuse the two metric series. Table 4 provides a

Figure 13. Different Types of Miniature Taps

Figure 14. Parts Assembled Using UNM Threads

general comparison. The ISO metric standard and the ISO version of the UNM standard are defined elsewhere.^{4,5} The 00, 000, and 0000 threads are unofficial industry standards. Other miniature threads are also in use in the watch industry.⁶

Size Standards for UNM Threads

Table 5 identifies the limits of size and tolerances defined by Federal Standard H28 for UNM threads.⁷ This table defines the allowable sizes for threads, but it ignores the practical difficulties that occur when deep holes are tapped. Federal Standard H28 Appendix Table A3.7 presents recommended hole size limits for different lengths of engagement. A portion of this table is reproduced in this report as Table 6. Table 6 recommends a drilled hole diameter of 1.029 to 1.075 mm (0.040 to 0.042 inch) for a 1.2 UNM thread 1.5 to 3.0 diameters deep. In contrast, the standard requirements shown in Table 5 indicate that the minor diameter must be between 0.960 and 1.052 mm (0.037 and 0.041 inch) to be acceptable.

Because Table A3.7 is only a recommendation rather than a standard, design agencies and inspection departments do not have to recognize this table. There are basic reasons for these recommendations, which allow larger hole sizes for deeper holes.

Figure 15. Miniature Screws

Figure 16. Thimble Full of 500 Miniature Screws

Figure 17. UNM Screws Compared to 4-40 Screw

Table 4. Comparisons of Miniature Threads

Thread Standard					
American		ISO Metric	UNM		
Designation	Number of Threads/ Inch*	Designation	Number of Threads/ Inch	Designation	Number of Threads/ Inch
				0.3	318
				0.35	282
				0.40	254
				0.45	254
				0.50	203
				0.55	203
				0.60	169
0000	160			0.70	145
				0.80	127
000	120			0.90	113
		M1.0 x 0.25	102	1.00	102
		M1.1 x 0.25	102	1.10	102
		M1.2 x 0.25	102	1.20	102
00	96				
		M1.4 x 0.30	85	1.40	85
0 UNF	80				
		M1.6 x 0.35	72½		
*1 inch = 25.4 mm					

Taps must work at near their breaking strength when deep holes and hard-to-machine materials are involved. Deep threaded holes provide an additional margin of safety by having more threads to support stripping loads. Some of this study effort was devoted to determining how drilled hole size affected actual stripping loads and tap breakage. The ability to use a larger drill size reduces tap breakage and provides greater drilled hole tolerance. Greater tolerance would be a significant factor if it existed. As an example of the difficulty of producing these small features, just drilling 25 of the miniature holes in the SAE K95100 magnetic steel may require 8 hours.

Table 5. Limits of Size and Tolerances for UNM Series

Thread Characteristics	Thread Designation (UNM)									
	0.50	0.60	0.80	1.00	1.20					
Pitch (mm)	0.125	0.150	0.200	0.250	0.250					
Threads/Inch	203	169	127	102	102					
External Threads										
Major Diameter Limits										
Maximum (mm) (Inch)	0.500 (0.0197)	0.600 (0.0236)	0.800 (0.0315)	1.000 (0.0394)	1.200 (0.0472)					
Minimum (mm) (Inch)	0.479 (0.0189)	0.576 (0.0227)	0.770 (0.0303)	0.964 (0.0380)	0.164 (0.0458)					
Pitch Diameter Limits										
Maximum (mm) (Inch)	0.419 (0.0165)	0.503 (0.0198)	0.670 (0.0264)	0.838 (0.0330)	1.038 (0.0409)					
Minor (mm) (Inch)	0.410 (0.0158)	0.483 (0.0190)	0.646 (0.0254)	0.812 (0.0319)	1.010 (0.0397)					
Minor Diameter Limits										
Maximum (mm) (Inch)	0.360 (0.0142)	0.432 (0.0170)	0.576 (0.0227)	0.720 (0.0283)	0.920 (0.0362)					
Minor (mm) (Inch)	0.432 (0.0170)	0.516 (0.0203)	0.684 (0.0269)	0.852 (0.0335)	1.052 (0.0414)					
Internal Threads										
Minor Diameter Limits										
Minimum (mm) (Inch)	0.380 (0.0150)	0.456 (0.0180)	0.608 (0.0239)	0.760 (0.0299)	0.960 (0.0378)					
Maximum (mm) (Inch)	0.432 (0.0170)	0.516 (0.0203)	0.684 (0.0269)	0.852 (0.0335)	1.052 (0.0414)					
Pitch Diameter Limits										
Minimum (mm) (Inch)	0.419 (0.0165)	0.503 (0.0198)	0.670 (0.0261)	0.838 (0.0330)	1.038 (0.0409)					
Maximum (mm) (Inch)	0.437 (0.0172)	0.523 (0.0206)	0.694 (0.0273)	0.866 (0.0341)	1.066 (0.0402)					
Major Diameter Limits										
Minimum (mm) (Inch)	0.509 (0.0200)	0.611 (0.0240)	0.814 (0.0321)	1.018 (0.0401)	1.218 (0.0480)					
Maximum (mm) (Inch)	0.538 (0.0212)	0.644 (0.0254)	0.856 (0.0337)	1.068 (0.0420)	1.268 (0.0499)					

Table 6. Limits of Size Before Threading for Different Lengths of Engagement,
UNM Series

Thread Characteristics	Thread Designation (UNM)				
	0.50	0.60	0.80	1.00	1.20
Pitch (mm)	0.125	0.150	0.200	0.250	0.250
Threads/Inch	203	169	127	102	102
Minor Diameter of Internal Threads					
Minimum (mm) (Inch)	0.308 (0.0150)	0.456 (0.0180)	0.608 (0.0239)	0.760 (0.0299)	0.960 (0.0378)
Basic Thread Height (Percent)	100	100	100	100	100
Maximum (mm) (Inch)	0.432 (0.0170)	0.516 (0.0203)	0.684 (0.0269)	0.852 (0.0335)	1.052 (0.0414)
Basic Thread Height (Percent)	56.7	58.3	60.4	61.7	61.7
Recommended Hole Size Limits					
Up to 0.67 Diameter					
Minimum (mm) (Inch)	0.393 (0.0155)	0.471 (0.0186)	0.627 (0.0247)	0.783 (0.0308)	0.983 (0.0387)
Maximum (mm) (Inch)	0.412 (0.0162)	0.494 (0.0194)	0.656 (0.0258)	0.818 (0.0321)	1.020 (0.0400)
0.67 to 1.5 Diameter					
Minimum (mm) (Inch)	0.406 (0.0160)	0.486 (0.0192)	0.646 (0.0254)	0.806 (0.0317)	1.006 (0.0396)
Maximum (mm) (Inch)	0.432 (0.0170)	0.516 (0.0203)	0.684 (0.0269)	0.852 (0.0335)	1.050 (0.0414)
1.5 to 3 Diameters					
Minimum (mm) (Inch)	0.419 (0.0165)	0.501 (0.0197)	0.665 (0.0261)	0.829 (0.0326)	1.029 (0.0405)
Maximum (mm) (Inch)	0.445 (0.0175)	0.531 (0.0209)	0.703 (0.0277)	0.875 (0.0344)	1.075 (0.0423)

Stripping Loads for UNM Threads

Threads in new assemblies normally fail from excessive torque, but those subjected to high shock or centrifugal loads can fail by tensile loads alone. Torque can be related to tensile loads through the coefficient of friction, but in practice it is difficult to predict the association accurately. Because torque values were measured previously,³ this study evaluated only tensile stripping loads as a function of drilled hole size.

Aluminum (6061-T6) test samples were used for 0.5 and 0.6 UNM threads. SAE K95100 magnetic steel was evaluated for 0.6, 0.8, and 1.0 UNM threads. Holes were tapped to provide at least five full threads. Because the literature and initial tests indicated that screw breakage as opposed to stripping was the typical mode of failure for normal thread heights, only a few holes were evaluated at average or large thread heights. Tensile tests of assembled threads were made at 0.85 mm/s (0.2 inch/minute). In no cases were screw heads tightened against any surface to create a preload.

Figure 18 illustrates the initial results for a 1.0 UNM thread screw (303 Se stainless steel). Microhardness measurements indicated the hardness of these screws was Knoop 246 to 256 (Brinnell 220 to 230). As seen in this illustration, the breaking strength of these screws was 298 N (67 pounds). At 50 percent full thread, one sample stripped while two failed by breaking. Even at 20 percent full thread, one sample failed by breaking rather than thread stripping. The normal minimum thread height according to the federal standard is at least 61.7 percent full thread (Table 6). The net result of this study is that results can only be described on the basis of worst-case values or some form of probability curve. In this test, axial engagements of three to four threads were used.

As seen in Figure 18, the theoretical working range is only 91.4 μm (0.0036 inch). Because of tap breakage, the large diameter side of the tolerance must be drilled. This effectively reduces the size range to 45.7 μm (0.0018 inch) or less. Because many of the tapped holes have some taper, it is difficult to identify accurately a single number that defines the actual minimum thread diameter. Even on nontapered holes it is easy to have 5.1 μm (0.0002 inch) errors in measuring size. Similarly, even though screws are assumed to be uniform in diameter, they too, vary. Measured properties of some typical screws used in these tests are shown in Table A-1 (Appendix A).

Figure 18 also illustrates the three drilled hole sizes recommended by the H28 Handbook Appendix Table A3.7 (Table 6 in this report). As illustrated, the recommended drilled hole tolerance

Figure 18. Initial Results and Tolerance Range of Stainless Steel Screw, SAE K95100

is smaller in each case than the tolerance allowed by the H28 Standard. As seen in Figure 18, the recommended hole tolerance does increase slightly as hole depth increases. Note that 1.5 times the thread diameter corresponds to 6 threads for all UNM thread sizes smaller than 1.2 UNM.

A final observation from Figure 18 is that for the worst-case condition, where the drilled hole is at its largest recommended size, the thread strength is 83 percent of full strength capability, or 83 percent of 298 N. It should be noted that the minor diameter after tapping is not the same as the drilled hole diameter. In actual practice, the thread minor diameter will be at least 12.7 μm (0.0005 inch) smaller than the drilled hole. All minor diameters described in this report refer to drilled hole diameters. Although this is standard practice, it is not explicitly stated in most references on threading.

Tensile Load Results for 1.0 UNM Threads

Figure 19 illustrates the test results of 303 Se stainless steel screws in aluminum and SAE K95100 alloy threaded holes. As seen in Figure 19 the minimum bolt breaking load was 310 N (70 pounds). At engagements of 43 percent full thread or greater, failure was always by screw breakage. For values less than 43 percent full thread, failure can occur either by screw breakage or hole stripping. The minimum percent engagement allowed by Table A3.7 in the H28 Handbook is over 50 percent (Figure 18).

For this test, the aluminum workpiece had a hardness of R_B 62, and the SAE K95100 alloy had a hardness of R_C 22 to 25. The screws had a typical hardness of R_C 29. The measured data for these tests are presented in Appendix Tables A-2 and A-3.

The results for SAE K95100 are similar to those for 6061-T6 aluminum. In no case did failure occur at loads below screw breaking loads for engagements of 37 percent or greater. The initial test indicated stripping would occur at approximately 45 percent full thread. This early stripping apparently was due to having only 3 or 4 threads engaged.

Figure 19 and subsequent test results are based on five full threads of axial engagement. Each screw was rotated one-half turn and checked to verify engagement before the additional four and one-half turns were made. When stripping occurred in the hole, at least four full threads of stripped material could be seen in the screw threads.

From Table 6, the largest minor diameter recommended by H28 Handbook Table A3.7 is 0.875 mm (0.0344 inch). As seen in Figure 19, this is well above the size at which stripping occurs.

Figure 19. Results of Testing 1.0 UNM Screws

Figure 19. Continued. Results of Testing 1.0 UNM Screws

The percent of internal thread height has been used in the previous illustrations without explanation. Variations in the method of expressing engagement make it appropriate to discuss this facet in more detail.

The percent of basic thread height for UNM threads is expressed by the following equation,

$$P_B = \frac{(0.5) (D_p - D_m) + 0.324p}{0.48p} \quad (1)$$

where

P_B = percent basic thread height,

D_p = basic pitch diameter (mm),

D_m = drilled hole diameter (mm), and

p = thread pitch (mm).

This formula is not the same as that presented in numerous publications for UNC and UNF threads.

Table 7 (compiled from H28 Handbook Tables 5.3 and 5.4) provides the basic data necessary to use Equation 1.

Because threaded fasteners involve both a threaded hole and a screw, the actual radial engagement of assembled threads depends on both the hole and the screw. In many instances, the effect of the screw dimensions can be ignored. In this study, however, data were calculated based on both internal threads and assembled thread dimensions. The equation used for the assembled unit percent of full radial depth of engagement is

$$P_A = \frac{(0.5) (D_s - D_m)}{0.48p} \quad (2)$$

where

P_A = percent of assembled thread engagement and

D_s = major diameter of screw (mm).

Consider a 0.5 UNM internal thread having a drilled hole diameter of 0.432 mm (0.0170 inch) and a screw major diameter of 0.472 mm (0.0186 inch). From Table 7, $p = 0.125$ mm and $D_p = 0.419$ mm. This results in a calculated P_B of 56.8 percent and an assembled thread engagement, P_A , of 33.8 percent.

Table 7. Basic and Design Sizes for UNM Series Threads

Size Designa- tion (UNM)	Pitch p (mm)	Threads/ Inch	Basic Major Diameter D (mm) (Inch)	Basic Pitch Diameter (mm) (Inch)	Thread Height 0.48p (mm) (Inch)	Minor Diameter Internal Threads (mm) (Inch)	Major Diameter Internal Threads (mm) (Inch)
0.30	0.080	318	0.300 (0.0118)	0.248 (0.0098)	0.0384 (0.00151)	0.223 (0.0088)	0.306 (0.0120)
0.40	0.100	254	0.400 (0.0157)	0.335 (0.0132)	0.0480 (0.00189)	0.304 (0.0120)	0.407 (0.0160)
0.50	0.125	203	0.500 (0.0197)	0.419 (0.0165)	0.0600 (0.00236)	0.380 (0.0150)	0.509 (0.0200)
0.60	0.150	169	0.600 (0.0236)	0.503 (0.0198)	0.0720 (0.00283)	0.456 (0.0180)	0.611 (0.0240)
0.80	0.200	127	0.800 (0.0315)	0.670 (0.0264)	0.0960 (0.00378)	0.608 (0.0239)	0.814 (0.0321)
1.00	0.250	102	1.000 (0.0394)	0.838 (0.0330)	0.1200 (0.00472)	0.760 (0.0299)	1.018 (0.0401)
1.20	0.250	102	1.200 (0.0472)	1.038 (0.0409)	0.1200 (0.00472)	0.460 (0.0378)	1.218 (0.0480)

If, on the other hand, the screw had a major diameter of 0.500 mm (0.0197 inch) which is the maximum allowable, then the assembled thread engagement would be 57.2 percent.

If a plot is made of strength versus percent engagement data based only on internal threads, the plot and its interpretation can be different from that of assembled threads. The data plotted in Figures 18 and 19 are based on the minor diameter of the drilled hole.

A basic question at the onset of these tests concerned the accuracy of the following statement made for UNC and UNF threads. This statement did prove to be valid for UNM threads.

"Thread strength tests clearly show that any increase in the percentage of thread over 60 percent does not increase the strength. For the vast majority of tapped hole requirements a minor diameter which provides a 55 percent to 65 percent thread is adequate."

This statement appeared in Facts About Taps and Tapping, p 43, by Greenfield Tap and Die, Greenfield, MA.

Figure 19 also illustrates the effect of plotting the test data in terms of assembled threads. As seen in Figure 19 for the SAE sample, stripping does not occur until the thread engagement falls below the 25 percent described in SAE K95100. In aluminum, hole stripping occurs at assembled engagements of 35 percent or less.

It is significant to note that failure of the SAE K95100 material resulted from screw stripping or a combination of screw and hole stripping. Determining whether SAE K95100 holes had stripped was not easy because of small burrs and fragments left in the stripped holes. Because of this, actual failure may have been by screw stripping alone.

Tensile Load Results for 0.8 UNM Threads

Figure 20 illustrates the thread load properties evaluated in the study of 0.8 UNM threads. Thread strength is high for all threads having more than 40 percent full thread. One aspect observed in this study is that when the hole was drilled to its largest possible tolerance, the screw appeared to be stronger than when tested in holes drilled to the low end of the tolerance (Tables A-4 and A-5). This anomaly is apparently the result of the absence of interacting thread stresses at small radial engagements.

To prevent tap breakage in these parts, the tapping machine was set at 20 percent full torque and 23 percent full spindle speed.

Figure 20. Results of Testing 0.8 UNM Screws

Tensile Load Results for 0.6 UNM Threads

As seen in Figure 21, hole stripping occurs in aluminum even at thread heights of 57 percent. The minimum breaking strength of these screws is 178 N (40 pounds). As seen in Appendix Table A-6 hole stripping occurred at forces above the normal screw breaking strength. Failure occurs at notably different values of thread depth in Figures 21 and 19. This is not readily explainable.

Figure 21 illustrates the results for 0.6 UNM threads in SAE K95100. The last two illustrations in Figure 21 present the same results as the first two illustrations, based on assembled threads.

In aluminum at a setting of 10 percent torque and 20 percent speed, tapping required 6 seconds for each hole. Holes in K95100 which had a 0.51 mm (0.0201 inch) diameter could not be tapped without breaking taps. Breakage occurred at every machine setting. This size corresponds to 63 percent full thread (Table A-7). Typical breakage in SAE K95100 was one tap for every three holes. In contrast, no taps were broken in 40 holes produced in aluminum.

As seen in Table 6, the maximum recommended minor hole diameter for deep 0.6 UNM holes is 0.531 mm (0.0209 inch). As seen in Figure 21, hole stripping would occur in aluminum if only five threads were engaged if this minor diameter were utilized. On deep holes, however, more than five threads would be engaged.

Figure 22 illustrates a production assembly consisting of a 6061-T6 aluminum part and a 303 Se stainless steel rolled thread. In this instance the minor diameter of the hole was 0.495 mm (0.0195 inch) and the major diameter of the screw was 0.576 mm (0.0226 inch). A magnified view of the screw threads is presented in Figure 7. In this case, which represents 41 percent thread engagement, the load required to cause stripping of the aluminum thread varied from 165 to 196 N (37 to 44 pounds). The breaking strength of this thread is 200 N (45 pounds). Note that in this case the major diameter of the screw is 0.074 mm (0.0029 inch) above the allowable maximum, and the hole minor diameter was similarly 0.063 mm (0.0025 inch) above its maximum (Table 5). This is enough that the screw can be jostled easily laterally in the hole.

In this case the thread hardness typically varied from Knoop 496 to 618 (Brinell 442 to 540) while the base material in the screw ranged from Knoop 387 to 422 (Brinell 353 to 381). Using the relationship that tensile strength (expressed in MPa units) is approximately equal to 500 times the Brinell hardness, the threads have 310 to 552 MPa (45,000 to 80,000 psi) more tensile strength than cut threads.

Figure 21. Results of Testing 0.6 UNM Screws

Figure 21 Continued. Results of Testing 0.6 UNM Screws

Figure 22. Assembly Requiring UNM Threads

Tensile Load Results for 0.5 UNM Threads

As seen in Figure 23, with the exception of one hole which stripped at 100 N (22.5 pounds) the stripping for 0.5 UNM threads began at 46 percent full thread in aluminum. The figure illustrates the fact that stripping begins at assembled engagements of 38 percent for these conditions.

Table 6 recommends a maximum minor diameter of 0.445 mm (0.0175 inch) for deep holes. As shown in Figure 23, for an engagement of five threads, hole stripping would occur for this size hole. Deep holes would, however, involve more than five thread engagements.

For the screws used in this study any minor hole diameter smaller than 0.432 mm (0.0170 inch) will result in hole stripping rather than screw breakage, if large enough loads are applied (Table A-8). Note, however, that the commercial 0.5 UNM screws purchased for this study were all smaller than allowed by Table A-9. For this study the screw major diameter was measured at the end of the screw where actual engagement occurred. For correct diameter screws, the use of more than a five-thread engagement and Table 6 recommended hole sizes should cause screw breaking, rather than hole stripping, to occur.

Predicting Tensile Load Results

Tensile test results described in this report provide useful information for the material combinations studied but only conceptual insights for other material combinations. Because of this, an attempt was made to predict stripping loads using a computer program by E. M. Alexander designed for use on ANSI Modified ISO screw threads.^{8,9} Using the values shown in Table 8, based on an SAE K95100 threaded hole and a 303 Se stainless steel screw, the values shown in Table 8 footnote were calculated.

The calculated screw breaking strength shown in the footnote is very close to the measured values (Figure 19). The data show that, for the conditions chosen, the SAE K95100 threaded hole will not strip before the screw breaks. When the calculated stripping loads are plotted against measured results, it is apparent that there is little close agreement (Figure 24). Although some of this lack of agreement may be the result of size measurement errors, Reference 4 notes that actual shear areas, which determine actual thread shearing loads, can be significantly smaller than the calculated values. In addition, the tensile strength of the screw threads varies considerably between screws in the same batch. The thread hardness data used in this study were based on representative samples rather than measurements on each screw.

Figure 23. Results of Testing 0.5 UNM Threads

Table 8. Values Used to Calculate Stripping Loads for 1.0 UNM Threads

Variable*	Value
Diameter	1.00 mm (0.039 inch)
Pitch	0.25 mm (0.0098 inch)
Internal thread minor diameter	0.875 mm (0.034 inch)
Minimum allowable internal thread minor diameter	0.76 mm (0.030 inch)
Screw major diameter	0.9778 mm (0.038 inch)
Root radius	0.027 mm (0.0011 inch)
Diameter of material around hole	2.00 mm (0.079 inch)
Countersink diameter (x times nominal diameter)	1.5 mm (0.059 inch)
Internal thread tensile strength	862 MPa (125 ksi)
Screw tensile strength	775 MPa (112 ksi)
Length of engagement in internal thread	1.00 mm (0.039 inch)

*Conditions correspond to 52 percent full thread engagement.

The calculated values for data in Table 8 are a screw-breaking load of 329 N (74 pounds), screw-stripping load of 424 N (95 pounds), and threaded hole-stripping load of 409 (92 pounds).

As seen in Figure 25, the tensile load capability varies almost linearly with thread nominal diameter for sizes above 0.5 UNM. If the same material were used for all screws, the strength should increase as the square of the screw diameter. As previously noted, the 0.5 UNM screws used in this study were slightly smaller than federal standards permit. This accounts for some of the nonuniformity seen in Figure 25. The smaller screws frequently tend to have higher strengths and hardnesses than larger sizes because the initial bar stock is drawn more severely. Although not shown, this also tends to make the distribution shown in Figure 25 more linear than the expected quadratic shape.

Figure 24. Calculated and Measured Properties of 1.0 UNM Threads

The trends were observed in the screws used in this study. The hardness (and thus strength) of the center of the screw was higher for the 0.6 and 0.8 sizes than the larger or smaller sizes (Table 9). If the data in Figure 25 are adjusted to provide hardness and strengths similar to those for the 1.0 UNM threads, then an approximate quadratic curve occurs. When the strength of

Figure 25. Effects of Number of Threads Engaged

Figure 26. Tensile Strength Characteristics of 303 Se Stainless Steel Screws in SAE K95100 Steel and Aluminum Parts

the threads, as opposed to the center of the screw, is analyzed it is apparent that the smaller threads do tend to be harder.

Effect of Number of Threads Engaged

Figure 26 illustrates a plot of thread failure as a function of number of threads engaged. As seen there, once six threads are engaged, failure for standard thread heights almost always occurs by screw breakage. Tests on larger screws indicate that bolt breaking loads can increase when only a few threads are engaged. This is a result of load interactions within the threaded assembly.

Table 9. Hardness of
Screws Used in
the Study

Thread Size (UNM)	Brinell Hardness	
	Screw Center	Threads
0.5	279 to 286	292 to 302
0.6	290 to 310	312 to 320
0.8	319 to 327	283 to 294
1.0	259 to 272	279 to 292

Effect of Tapping on Minor Diameter

Whenever holes are tapped, the minor diameter after tapping is smaller than the initial size. Handbook H28 refers to this as spin-up of material caused by negative rake on the tools. In most instances this is actually more appropriately defined to be a burr. Figures 27 and 28 illustrate scanning electron microscope (SEM) photographs of one of these holes after tapping. In some instances this material can add a small amount of additional thread strength (Table 10). In many cases the net improvement falls within the range of experimental error. Table 11 illustrates typical diameter reduction data observed in this study. Different style taps would probably produce different results.

Tool Life Test Results

A study of tap life as a function of initial hole diameter was initiated when it became obvious that 0.6 and 0.5 UNM threads were practically impossible to produce in SAE K95100 steel. Using nominal holes, tap life varied from 0 to 16 holes with typical performance being a single hole for each tap. At the drilled hole diameter recommended as nominal for depths of 0.67 to 1.5 times tap diameter, four out of five taps broke after five holes or less (Figure 29).

This breakage for 0.5 UNM threads occurred at torque settings of 3 percent and a speed setting of 20 percent. Higher torque settings resulted in immediate tap breakage. In all cases, the breakage was from excessive torque rather than tool mislocation. The lowest possible setting on this machine was 2 percent torque. At these settings a tap typically reverses 23 times for each hole.

Figure 27. Cross Section of 0.6 UNM Tapped Hole Threads

Figure 28. Magnified View of Threads Shown in Figure 27

Figure 29. Tap Life in SAE K95100 Steel With 0.5 UNM Bottoming Taps Used to Produce Five Full Threads/Hole

Figure 30. Tap Life in SAE K95100 Steel With 0.6 UNM Bottoming Taps Used to Produce Five Full Threads/Hole

Table 10. Thread Strengths as a Function of Spin-Up

Thread Size (UNM)	Drilled Hole Diameter (mm) (Inch)	Load	
		With Spin Up (N) (Pounds)	Without Spin Up (N) (Pounds)
Aluminum Sample			
0.6	0.502 (0.0198)	160 (36)	185 (41.5)
SAE K95100 Sample			
0.8	0.728 (0.0287)	254 (57)	254 (54)

Breakage of 0.6 UNM taps was similar to that of 0.5 UNM threads (Figure 30). This study was performed also at a setting of 3 percent torque and 20 percent speed. At these settings a tap typically reversed 58 times to produce a single hole. Tap life was 13 holes at a setting of 2 percent torque. The 18-hole test utilized the 3 percent setting.

Typical life of 1.0 UNM taps at a setting of 10 percent torque and 20 percent speed was greater than 75 holes for an initial hole size of 0.752 mm (0.0296 inch). Since this is 0.030 mm (0.0012 inch) smaller than the recommended hole diameter, breakage of this size tool should not be a problem at the torque settings used. This is consistent with production experience. To produce these holes, the tap reversed up to 126 times for each hole and required 40 seconds for each hole. When normal hole sizes and higher torques were used, holes were produced with only five reversals in four seconds.

Some tap breakage can be eliminated by a positive positioning system (N/C or otherwise), more uniform torque control, and stronger or more flexible taps. Some of the taps used in this study were considerably stronger than others. Taps having flexible shafts were produced in 1973 for 0-80 UNF threads and probably could be produced for these minute threads. Tools having brass tube shanks elastically bonded to the tap flex much more than conventional taps can. One of these 0-80 UNF tools reportedly produced 5000 holes in 300 series stainless steel.

To prevent tap breakage in hard materials on the 0.5 and 0.6 UNM holes, it was necessary to utilize the lowest settings possible on the tapping torque control. This represents a detection and

Table 11. Minor Diameter Size
Reduction Caused by
Tapping

Nominal Hole Size (UNM)	Typical Diameter Reduction (Inch) (μm)	Standard Deviation of Diameter Reduction (Inch) (μm)
6061-T6 Aluminum		
0.5	25.4 (0.0010)	12.7 (0.00050)
0.6	35.6 (0.0014)	6.4 (0.00025)
1.0	20.3 (0.0008)	15.6 (0.00061)
SAE K95100		
0.6	25.4 (0.0010)	8.9 (0.00035)
0.8	38.1 (0.0015)	4.9 (0.00019)
1.0	20.3 (0.0008)	4.4 (0.00017)

control of very small amounts of torque. As previously indicated, the system, which reverses the spindle when excessive torque is detected, consists of mechanical and electrical components. The mechanical components must have some built-in slip to operate, and the electrical contacts must operate precisely for the system to prevent breakage. Dirt, oil, oxidation, and wear affect the control system to such an extent that it must be readjusted continually to keep it functioning. Every machine has different characteristics at these low levels, and, as a result, skilled operators who can sense minute changes are required to make machine setups. For 1.0 UNM and larger sizes this continual readjusting is not a major problem.

Tapping torque is a function of tap geometry, workpiece material, and hole size, as shown by the following formula.¹¹

$$T_T = K_1(2dp + P \tan 2\delta - 2d_h)\sigma_s \quad (3)$$

where

T_T = tapping torque,

K_1 = material and tap constant,

dp = tap pitch diameter,

P = tap pitch,

δ = one-half included thread angle,

d_h = hole diameter, and

σ_s = maximum shear stress of workpiece.

This equation fails to note that spindle speed also affects tapping torque for some materials. Henderer and von Turkovich's data, for example, illustrate this speed effect, which occurs on a few materials at low speeds.¹² In some cases, slowing speed will decrease torque; in others it will increase cutting torque.¹³ Even when tapping torque is independent of spindle speed, increasing speed may still result in broken taps because of electric motor design. The torque for most variable speed motors increases as spindle speed increases until the design motor speed is reached. As a result, when the tapping machine is set at its lowest possible torque limit, then the only possible means of preventing further tap breakage is to begin with larger diameter holes or to reduce the spindle speed.

Effect of Torque on Tensile Load

The following equation provides an initial estimate of the torque required to produce a given tensile load on threaded fasteners.

$$T = \frac{KDW}{12} \quad (4)$$

where

T = torque,

K = a friction coefficient,

D = nominal diameter of the thread, and

W = tensile load on the screw.

As noted elsewhere,¹⁴ "Frequently used values of K for nonplated and plated steel fasteners are 0.20 and 0.15 respectively. These values are conservative and actual preload is usually slightly less than the calculated value."

For a 1.0 UNM screw, the expected torque at which tension might exceed the tensile strength is

$$T = \frac{(0.2)(1.0\text{mm})(310\text{N})}{12} = 5.17 \text{ N}\cdot\text{m} \text{ (8.8 inch-ounces)}.$$

The unused portion of tensile screw strength can be estimated by Equation 5.

$$L_u = L_F(P_T) = \frac{L_F(T_b - T_a)}{T_b} \quad (5)$$

where

L_u = the unused portion of tensile screw strength,

L_F = the failure tensile load of the screw,

P_T = percent of the allowable tightening torque which has not been used,

T_a = allowed tightening torque, and

T_b = tightening torque causing tensile failure.

In tests,¹ 1.0 UNM 303 Se stainless steel screws actually failed at 4.9 to 11.3 mm·N (7 to 16 inch-ounces). The maximum tightening torque recommended for these screws by reference 1 is 4.2 mm·N (6 inch-ounces). Thus at the minimum the expected unused tensile load for 1.0 UNM screws, fastened at 6 inch-ounces, would be

$$\frac{(8.8-6.0)}{8.8}(71 \text{ pounds}) = 22 \text{ pounds (100N)}$$

Thus, for the indicated conditions, over 100 N (22 pounds) of load would be available to accommodate centrifugal and shock loads. With these types of loads, the parts being held by the screw would have to have an effective weight of 100 N to exceed the screw tensile strength illustrated by this example. In practice, because of strain rate effects, breaking loads in shock situations would be even higher than indicated by the test data in this report.

Thread Gaging

The gaging of UNM threads is in many cases not as straightforward as for larger sizes. In many cases too many gage insertions cause the threads to go out of tolerance. In some cases only five or six uses of a gage are too much.

"Not go" thread plug gages are not advocated by the federal standard. In practice they frequently will go in a functionally acceptable part. While Bendix has used some of the "not go" gages, they are not used for acceptance inspection of production parts.

Thread gages are normal production tools in miniature sizes, and accurate gages may be nearly impossible to obtain. In some instances Bendix has waited 2 years for receipt of gages which meet gaging standard. In some cases the gages supplied are little more than a commercially produced screw. Some manufacturers list these gages as "X" tolerance and others do not indicate the tolerance class. At least two of these suppliers do not maintain off-the-shelf stocks of sizes below 0.5 UNM. In addition, some manufacturers will not remove the male centers from gages. Bendix must remove them to permit gaging in blind holes.

The H28 standard does not list gage tolerances. Table C-1 (Appendix C) describes the Bendix gage inspection and acceptance criteria. The estimated measurement uncertainty for these thread gage dimensions for Bendix inspection techniques is 1 μm (40 $\mu\text{in.}$).

Roll-formed threads produced in 303 Se stainless steel tend to stretch during forming. Because of this, the eleventh or twelfth thread pitch spacing will be out of tolerance. Because no Bendix part has thread engagements exceeding 10 threads, external thread form is evaluated for only 10 continuous threads.

Some commercial thread charts for miniature parts allow more tolerance on some features than allowed by the H28 Handbook.

Finishing Miniature Threads

As indicated by this study, the manufacture of miniature threads can be a difficult task. The production of the thread, however, is less than half of a precision thread's cost. Threaded parts must be deburred, cleaned, passivated and packaged. At least eight items such as burrs, raised metal, galled and torn surfaces, stains, dirt, and chips must be removed to allow gaging and trouble-free assembly. These can be time-consuming operations when miniature threads are involved. In many cases deburring can be considerably more time consuming than machining and is a potential source of thread damage.

ACCOMPLISHMENTS

This study shows that thread rolling can produce UNM threads as small as 0.6 UNM. This process also produces a better thread with fewer setup problems than conventional cutting. For many parts this approach requires that the threaded portion of a shaft be machined undersized before rolling. This requires a small amount of additional machining and setup time.

This study also documented the difficulty experienced in tapping 0.6 UNM and smaller holes in hard materials such as SAE K95100 magnetic steel. With existing techniques tool breakage is unavoidable. To prevent tap breakage and the lost time and scrap associated with breakage, the following requirements must be met:

- Provide a positive means of assuring alignment between the hole and the tap,
- Utilize the strongest grade of taps available,
- Utilize the drilled hole diameter recommended by H28 Handbook Table A3.6, and
- Utilize tapping machine that have appropriate sensitivities and control mechanisms.

The rule of thumb for conventional threads that 55 percent of full thread depth is sufficient to prevent hole or screw stripping is generally true for UNM threads. Actual results, however, depend upon actual screw size, material properties of both the workpiece and the screw, and the number of threads engaged.

The current literature on the subject of predicting thread strengths is based on larger thread sizes and, therefore, does not accurately predict stripping loads for UNM threads.

FUTURE WORK

This study is complete; however, additional work will be performed to obtain longer tap life. Other areas in which additional effort would be useful include development of a computer program for accurately predicting thread stripping conditions for UNM threads and improvement in control systems for miniature tappers.

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Appendix A

TENSILE LOAD TEST DATA

Table A-1. Measured Variation in Screw Properties

Nominal Size (mm) Dia. x length	Typical Hardness (Brinell)*	Major Diameter (mm)		Minor Diameter (mm)		Root Radius (mm)
		Maximum	Minimum	Maximum	Minimum	
0.5 UNM x 3.0	314	0.4704	0.4645	0.3793	0.3456	0.0254
0.5 UNM x 3.0		0.4785	0.4783	0.3841	0.3472	0.0381
0.5 UNM		0.5914	0.5609	0.3993	0.3970	0.0025
0.8 UNM x 6.0	307	0.7844	0.7734	0.5468	0.5331	0.0013
0.8 UNM x 6.0		0.7844	0.7699	0.5300	0.5255	0.0013
0.8 UNM x 6.0		0.7830	0.7676	0.5459	0.5436	0.0013
0.8 UNM x 6.0		0.8001	0.7478	0.5898	0.5670	0.0640
1.0 UNM x 7.6	265	0.9701	0.9543	0.6474	0.6352	0.0013
1.0 UNM x 7.6		0.9848	0.9527	0.6475	0.6322	0.0013
1.2 UNM x 10.0	297	1.1788	1.1468	0.8651	0.8554	0.0013
1.2 UNM x 10.0		1.1514	1.1412	0.8737	0.8687	0.0013

All entries on a line are variations within a single screw. All screws except the third 0.5 screw are purchased items. The third 0.5 UNM screw is an oversize example of the one shown in Figure 7.

*The 0.6 UNM screws typically had a hardness of Brinell 286.

Table A-2. Results of Testing 1.0 UNM Threads

Test Sequence No.	Sample No.*	Load		Screw Extension**		Type of Failure***	Number Threads Engaged
		(lbs)	(N)	(Inch)	(mm)		
1	A15	68	302	0.015	0.38	B	6
2	A20	80	355	0.046	1.17	B	5
3	H23	82	365	0.041	1.04	B	5
4	H21	86	383	0.032	0.81	B	5
5	H18	82	365	0.037	0.94	B	5
6	A21	35	156			S	4
7	A21	1	4			S	
8	A21	28	125			S	4
9	A21	27	120			S	
10	A19	71	316			S	5
11	A19	81	360	0.041	1.04	B	5
12	A19	72	320			S	5
13	A19	81	360	0.038	0.97	B	5
14	H23	82	365	0.038	0.97	B	5
15	H23	78	347	0.037	0.94	B	5
16	H23	84	374	0.038	0.97	B	5
17	A20	72	320	0.041	1.04	B	5
18	A20	69	307	0.041	1.04	S	4
19	A20	70	311	0.044	1.12	B	5
20	A20	54	240			S	4
21	A15	73	325	0.043	1.09	B	5
22	A15	75	334	0.037	0.94	B	5
23	A15	72	320	0.041	1.04	B	5
24	A15	71	316	0.040	1.00	B	5
25	H21	80	356	0.041	1.04	B	5
26	H21	77	342	0.038	0.97	B	5
27	H21	74	329	0.039	0.99	B	5
28	H21	72	320	0.043	1.09	B	5
29	A16	77	342	0.044	1.12	B	5
30	H17	16	71			S	4
31	H19	80	356			BS	5
32	H22	79	351	0.039	0.99	B	5
33	H20	59	262			BS	4
34	H22	68	302			S & BS	5
35	H24	22	98			S & BS	5
36	A16	40	178			S	5
37	H17	10	44			S	4
38	H22	73	325	0.041	1.04	B	5
39	H24	34	151			S	5
40	H20	59	262			BS	4
41	A16	58	258			S	4
42	H19	71	316	0.041	1.04	B	4
43	H22	75	334	0.039		B	5
44	H20	17	76			BS	4
45	H24	72	320	0.034		S & BS	5
46	A16	74	329	0.044		B	5
47	H24	73	325	0.041		B	5
48	H19	55	245			BS	4
49	H20	49	218			BS	4
50	H22	73	325	0.044		B	5
51	H20	54	240			BS	4
52	A16	61	271			S	4
53	H24	73	325	0.039		B	5

*Samples with an A prefix refer to aluminum samples; H indicates SAE K95100 samples.

**Deformation which occurred as a result of tensile testing. Original length of screws were 0.3 inch (7.6 mm). The screw major diameter decreases 0.0009 to 0.002 inch (22.9 to 50.8 μ m) as a result of tensile testing.

***B indicates screw broke, S indicates hole stripped, BS indicates screw stripped.

Table A-3. Measured Dimensions of Tested 1.0 UNM Threads

Test Sequence No.	Drilled Hole Diameter (Inch)	Threaded Hole Minor Diameter (Inch)	Screw Major Diameter (Inch)	Percent Full Thread (%)	Percent Assembled Engagement (%)	Change in Hole Diameter (Inch)*
1	0.0335	0.0324	0.0383	62	51	0.0011
2	0.0360	0.0355	0.0389	36	31	0.0005
3	0.0358	0.0351	0.0383	38	26	0.0007
4	0.0359	0.0350	0.0387	31	30	0.0009
5	0.0335	0.0331	0.0388	62	56	0.0004
6	0.0365	0.0362	0.0387	30	23	0.0003
7	0.0365	0.0362	0.0387	30	23	0.0003
8	0.0365	0.0362	0.0387	30	23	0.0003
9	0.0365	0.0362	0.0385	30	21	0.0003
10	0.0360	0.0355	0.0380	36	21	0.0005
11	0.0360	0.0355	0.0388	36	30	0.0005
12	0.0360	0.0355	0.0383	36	24	0.0005
13	0.0360	0.0355	0.0386	36	41	0.0005
14	0.0358	0.0351	0.0384	38	28	0.0007
15	0.0358	0.0351	0.0388	38	32	0.0007
16	0.0358	0.0351	0.0385	38	29	0.0007
17	0.0360	0.0355	0.0385	36	26	0.0005
18	0.0360	0.0355	0.0380	36	21	0.0005
19	0.0360	0.0355	0.0387	36	29	0.0005
20	0.0360	0.0355	0.0380	36	21	0.0005
21	0.0335	0.0354	0.0385	62	53	0.0019
22	0.0335	0.0354	0.0388	62	56	0.0019
23	0.0335	0.0354	0.0385	62	53	0.0019
24	0.0335	0.0354	0.0385	62	53	0.0019
25	0.0359	0.0350	0.0382	31	24	0.0009
26	0.0359	0.0350	0.0384	31	26	0.0009
27	0.0359	0.0350	0.0388	31	31	0.0009
28	0.0359	0.0350	0.0376	31	18	0.0009
29	0.0353	0.0346	0.0388	43	37	0.0007
30	0.0363	0.0363	0.0381	32	19	-
31	0.0361	0.0361	0.0387	35	28	-
32	0.0359	0.0349	0.0386	31	29	0.0010
33	0.0366	0.0366	0.0386	29	21	-
34	0.0359	0.0349	0.0379	31	21	0.0010
35	0.0361	0.0361	0.0381	35	21	-
36	0.0353	0.0353	0.0370	43	18	-
37	0.0363	0.0363	0.0382	32	20	-
38	0.0359	0.0349	0.0387	31	30	-
39	0.0361	0.0361	0.0384	35	24	-
40	0.0366	0.0366	0.0385	29	20	-
41	0.0353	0.0353	0.0385	43	34	-
42	0.0361	0.0361	0.0388	35	29	-
43	0.0359	0.0349	0.0385	31	28	0.0010
44	0.0366	0.0366	0.0379	29	14	-
45	0.0361	0.0359	0.0384	35	24	-
46	0.0353	0.0353	0.0383	43	32	-
47	0.0361	0.0361	0.0387	35	28	-
48	0.0361	0.0361	0.0383	35	23	-
49	0.0366	0.0366	0.0384	29	19	-
50	0.0359	0.0349	0.0385	31	28	0.0010
51	0.0366	0.0366	0.0384	29	19	-
52	0.0353	0.0353	0.0386	43	35	-
53	0.0361	0.0361	0.0385	35	25	-

*As a result of tapping. Dash entries indicate holes reamed after tapping in order to provide a larger minor diameter.

*0.001 inch = 25.4 μ m

Table A-4. Results of Testing 0.8 UNM Threads

Test Sequence No.	Sample No.*	Load		Screw Extension**		Type of Failure***	Number Threads Engaged
		Load (lbs)	(N)	(Inch)	(mm)		
1	H12	56	249	--	--	B	5
2	H15	58	258	--	--	BS	5
3	H16	56	249	--	--	BS	5
4	H13	57	254	0.018	0.459	B	5
5	H9	59	262	0.018	0.459	B	5
6	H10	56	249	0.020	0.51	B	4
7	H11	50	222	0.010	0.25	S & BS	3½
8	H14	59	262	0.020	0.51	B	5
9	H16	58	258	0.024	0.61	B	5
10	H15	58	258	0.017	0.43	B	5
11	H13	58	258	0.021	0.53	B	5
12	H9	57	254	0.020	0.51	B	5
13	H14	59	262	0.018	0.46	S & BS	5
14	H15	59	262	0.019	0.48	B	5
15	H15	60	267	0.021	0.53	B	5
16	H15	56	249	0.020	0.51	S & BS	5
17	H13	60	267	0.018	0.45	B	5
18	H13	61	271	0.019	0.48	B	5
19	H13	59	262	0.020	0.51	B	5
20	H9	30	133	-	-	BS	5
21	H11	56	249	-	-	BS	5
22	H11	27	120	-	-	BS	4
23	H11	43	191	-	-	BS	5
24	H16	63	280	-	-	B	5
25	H14	51	227	-	-	BS	5
26	H9	43	191	-	-	BS	5
27	H10	33	147	-	-	BS	5
28	H12	61	271	-	-	BS	5
29	H16	52	231	-	-	BS	5
30	H14	38	169	-	-	BS	5
31	H12	62	276	-	-	BS	5
32	H10	19	85	-	-	BS	5
33	H12	27	120	-	-	BS	5
34	H10	48	213	-	-	BS	5
35	H16	45	200	-	-	BS	5
36	H14	35	156	-	-	BS	5

*Samples with an A prefix refer to aluminum samples; H indicates SAE K95100 samples.

**Deformation which occurred as a result of tensile testing. Original length of threaded portion of screws was 0.120 inch (3.05 mm).

***B indicates screw broke, S indicates hole stripped, BS indicates screw stripped.

Table A-5. Measured Dimensions of Tested 0.8 UNM Threads

Test Sequence No.	Sample No.	Drilled Hole Diameter (Inch)	Threaded Hole Minor Diameter (Inch)	Screw Major Diameter (Inch)	Percent Full Thread (%)	Percent Thread Engaged (5)	Change in Hole Diameter (Inch)*
1	H12	0.0289	0.0274	0.0305	34	21	0.0015
2	H15	0.0286	0.0272	0.0300	38	19	0.0014
3	H16	0.0285	0.0270	0.0300	40	20	0.0015
4	H13	0.0286	0.0270	0.0304	38	24	0.0016
5	H9	0.0258	0.0243	0.0301	75	57	0.0015
6	H10	0.0260	0.0245	0.0307	73	62	0.0015
7	H11	0.0286	0.0271	0.0310	38	32	--
8	H14	0.0284	0.0270	0.0289	41	20	0.0014
9	H16	0.0285	0.0270	0.0302	40	22	0.0015
10	H15	0.0286	0.0274	0.0302	38	21	0.0012
11	H13	0.0286	0.0270	0.0298	38	16	0.0016
12	H9	0.0258	0.0243	0.0300			
13	H14	0.0284	0.0268	0.0306	41	29	0.0016
14	H15	0.0286	0.0274	0.0302	38	21	0.0012
15	H15	0.0286	0.0272	0.0304	38	24	0.0014
16	H15	0.0286	0.0274	0.0309	38	30	0.0012
17	H13	0.0286	0.0268	0.0313	38	36	0.0018
18	H13	0.0286	0.0268	0.0297	38	15	0.0018
19	H13	0.0286	0.0268	0.0306	38	26	0.0018
20	H9	0.0295	0.0295	0.0303	26	11	--
21	H11	0.0290	0.0290	0.0305	33	20	--
22	H11	0.0293	0.0293	0.0309	29	21	--
23	H11	0.0290	0.0290	0.0302	33	16	--
24	H16	0.0287	0.0287	0.0300	37	17	--
25	H14	0.0296	0.0296	0.0306	25	13	--
26	H9	0.0295	0.0295	0.0306	26	9	--
27	H10	0.0296	0.0296	0.0303	25	9	--
28	H12	0.0290	0.0290	0.0309	33	25	--
29	H16	0.0287	0.0287	0.0299	37	16	--
30	H14	0.0296	0.0296	0.0308	25	16	--
31	H12	0.0290	0.0290	0.0306	33	21	--
32	H10	0.0296	0.0296	0.0300	25	5	--
33	H12	0.0290	0.0290	0.0303	33	17	--
34	H10	0.0296	0.0296	0.0300	25	5	--
35	H16	0.0286	0.0286	0.0300	38	19	--
36	H14	0.0294	0.0294	0.0309	28	20	--

As a result of tapping. Dash entries indicate holes reamed after tapping in order to provide a larger minor diameter.

*0.001 inch = 25.4 μ m

Table A-6. Results of Testing 0.6 UNM Threads

Test Sequence No.	Sample No.*	Load		Screw Extension**		Type of Failure***	Number Threads Engaged
		Load (lbs)	(N)	(Inch)	(mm)		
1	H6	41	182	--	--	B	4½
2	H7	41	182	0.012	0.30	B	5
3	H7	40	178	0.012	0.30	B	4½
4	H7	41	182	0.014	0.36	B	5
5	H7	3	13	--	--	S	4½
6	H7	41	182	--	--	B	5
7	A13	14	62	--	--	S	4
8	A13	23	102	--	--	S	5
9	A12	29	129	--	--	S	5
10	A12	23	102	--	--	S	5
11	A10	35	156	--	--	S	5
12	A10	41	182	--	--	S	5
13	A10	37	165	--	--	S	5
14	A10	37	165	--	--	S	5
15	A10	38	169	--	--	S	5
16	A7	38	169	--	--	S	5
17	A7	31	138	--	--	S	5
18	A7	39	173	--	--	S	5
19	A8	36	160	--	--	S	5
20	H2	41	182	0.017	0.43	B	5
21	H1	41	182	0.020	0.51	B	5
22	A7	41	182	--	--	S	5
23	A7	42	187	--	--	S	5
24	H6	0	0	--	--	BS	5
25	H6	11	49	--	--	BS	3
26	H6	15	67	--	--	BS	4
27	H3	2.5	11	--	--	BS	4½
28	H3	1	4	--	--	BS	4½
29	H4	38	169	--	--	BS	4½
30	H4	29	129	--	--	BS	4½
31	H4	7	31	--	--	BS	5
32	H4	42	187	--	--	BS	5
33	H5	10	45	--	--	BS	5
34	H5	22	98	--	--	BS	5
35	H8	38	169	--	--	BS	5
36	H8	35	156	--	--	BS	5
37	H8	25	111	--	--	BS	4
38	H8	29	129	--	--	BS	5
39	H8	40	178	--	--	BS	5

*Samples with an A prefix refer to aluminum samples; H indicates SAE K95100 samples.

**Deformation which occurred as a result of tensile testing. Original length of threaded portion of screws was 0.060 inch (1.5 mm).

***B indicates screw broke, S indicates hole stripped, BS indicates screw stripped.

Table A-7. Measured Dimensions of Tested 0.6 UNM Threads

Test Sequence No.	Sample No.	Drilled Hole Diameter (Inch)	Threaded Hole Minor Diameter (Inch)	Screw Major Diameter (Inch)	Percent Full Thread (%)	Percent Thread Engaged (%)	Change in Hole Diameter (Inch)*
1	H6	0.0214	0.0204	0.0228	39	25	0.0010
2	H7	0.0217	0.0196	0.0227	34	18	0.0010
3	H7	0.0217	0.0196	0.0225	34	14	0.0008
4	H7	0.0217	0.0196	0.0221	34	7	0.0004
5	H7	0.0217	0.0208	0.0233	34	28	0.0016
6	H7	0.0217	0.0196	0.0230	34	23	0.0013
7	A13	0.0222	0.0212	0.0231	25	16	0.0010
8	A13	0.0222	0.0211	0.0231	25	16	0.0011
9	A12	0.0216	0.0205	0.0231	36	27	0.0011
10	A12	0.0216	0.0205	0.0230	36	25	0.0011
11	A10	0.0207	0.0192	0.0225	52	32	0.0015
12	A10	0.0207	0.0192	0.0233	52	46	0.0015
13	A10	0.0207	0.0192	0.0227	52	35	0.0015
14	A10	0.0207	0.0192	0.0227	52	35	0.0015
15	A10	0.0207	0.0192	0.0232	52	44	0.0015
16	A7	0.0203	0.0188	0.0226	59	41	0.0015
17	A7	0.0203	0.0188	0.0228	59	44	0.0015
18	A7	0.0203	0.0186	0.0231	59	49	0.0017
19	A8	0.0204	0.0186	0.0230	57	46	0.0018
20	H2	0.0201	0.0190	0.0230	62	51	0.0011
21	H1	0.0201	0.0192	0.0229	62	49	0.0009
22	A7	0.0197	0.0197	0.0227	69	53	--
23	A7	0.0199	0.0199	0.0229	66	53	--
24	H6	0.0224	0.0224	0.0231	22	12	--
25	H6	0.0224	0.0224	0.0231	22	12	--
26	H6	0.0224	0.0224	0.0230	22	11	--
27	H3	0.0219	0.0219	0.0230	30	19	--
28	H3	0.0218	0.0218	0.0230	32	21	--
29	H4	0.0216	0.0216	0.0231	36	27	--
30	H4	0.0218	0.0218	0.0228	32	18	--
31	H4	0.0218	0.0218	0.0224	32	11	--
32	H4	0.0220	0.0220	0.0233	29	23	--
33	H5	0.0218	0.0218	0.0230	32	21	--
34	H5	0.0218	0.0218	0.0231	32	23	--
35	H8	0.0220	0.0220	0.0230	29	18	--
36	H8	0.0220	0.0220	0.0225	29	9	--

Table A-7 Continued. Measured Dimensions of Tested 0.6 UNM Threads

<u>Test Sequence No.</u>	<u>Sample No.</u>	<u>Drilled Hole Diameter (Inch)</u>	<u>Threaded Hole Minor Diameter (Inch)</u>	<u>Screw Major Diameter (Inch)</u>	<u>Percent Full Thread (%)</u>	<u>Percent Thread Engaged (%)</u>	<u>Change in Hole Diameter (Inch)*</u>
37	H8	0.0220	0.0220	0.0226	29	11	--
38	H8	0.0220	0.0220	0.0230	29	18	--
39	H8	0.0220	0.0220	0.0230	29	18	--

As a result of tapping. Dash entries indicate holes reamed after tapping in order to provide a larger minor diameter.
 *0.001 inch = 25.4 μ m

Table A-8. Results of Testing 0.5 UNM Threads

Test Sequence No.	Sample No.	Load		Screw Extension		Type Of Failure
		(LBS)	(N)	(Inch)	(mm)	
1	A4	10.5	47	--	--	S
2	A1	22.5	100	--	--	S
3	A6	0.5	2	--	--	S
4	A2	21.5	96	0.019	0.48	B
5	A3	12.0	53	--	--	S
6	A5	4.5	20	--	--	S
7	A1	22.0	98	0.018	0.46	B
8	A2	21.0	93	--	--	S
9	A4	14.0	62	--	--	S
10	A6	2.0	9	--	--	S
11	A3	16.0	71	--	--	S
12	A5	0.5	2	--	--	S
13	A1	21.5	96	0.020	0.50	B
14	A2	21.5	96	--	--	S
15	A4	11.5	51	--	--	S
16	A6	2.5	20	--	--	S
17	A2	21.5	96	0.016	0.41	B
18	A6	1.5	7	--	--	S
19	A5	0.5	2	--	--	S
20	A1	21.5	96	0.018	0.46	B
21	A1	19.0	85	0.020	0.50	B
22	A5	1.0	4	--	--	S
23	A2	20.5	91	--	--	S
24	A6	0.5	2	--	--	S
25	A3	17.5	78	--	--	S
26	A4	20.0	89	--	--	S
27	A3	5.5	29	--	--	S
28	A3	15.5	69	--	--	S
29	A4	18.0	80	--	--	S

ALL tests performed at 5 turns Engagement

Table A-9. Measured Dimensions of Tested 0.5 UNM Threads

TEST SEQUENCE NO.	SAMPLE NO.	DRILLED HOLE DIAMETER (INCH)	THREADED HOLE MINOR DIAMETER (INCH)	SCREW MAJOR DIAMETER (INCH)	PERCENT FULL THREAD (%)	PERCENT ASSEMBLED ENGAGEMENT (%)	CHANGE IN HOLE DIAMETER (INCH)
1	A4	0.0175	0.0164	0.0183	46	35	0.0011
2	A1	0.0170	0.0158	0.0186	57	34	0.0012
3	A6	0.0179	0.0175	0.0187	38	17	0.0004
4	A2	0.0170	0.0156	0.0186	57	34	0.0014
5	A3	0.0175	0.0161	0.0184	46	19	0.0014
6	A5	0.0178	0.0169	0.0186	40	17	0.0006
7	A1	0.0170	0.0158	0.0188	57	38	0.0012
8	A2	0.0170	0.0158	0.0186	57	34	0.0012
9	A4	0.0175	0.0164	0.0186	46	23	0.0011
10	A6	0.0179	0.0176	0.0184	38	11	0.0003
11	A3	0.0175	0.0162	0.0185	46	21	0.0013
12	A5	0.0178	0.0175	0.0187	40	19	0.0003
13	A1	0.0170	0.0156	0.0186	57	34	0.0014
14	A2	0.0170	0.0158	0.0187	57	36	0.0012
15	A4	0.0175	0.0162	0.0184	46	19	0.0013
16	A6	0.0179	0.0173	0.0185	38	13	0.0003
17	A2	0.0170	0.0156	0.0185	57	32	0.0014
18	A6	0.0179	0.0173	0.0185	38	13	0.0003
19	A5	0.0178	0.0175	0.0185	40	15	0.0003
20	A1	0.0170	0.0158	0.0184	57	30	0.0012
21	A1	0.0170	0.0158	0.0186	57	34	0.0012
22	A5	0.0178	0.0176	0.0186	40	17	0.0002
23	A2	0.0170	0.0158	0.0187	57	36	0.0012
24	A6	0.0179	0.0176	0.0185	38	13	0.0003
25	A3	0.0175	0.0160	0.0186	46	23	0.0015
26	A4	0.0175	0.0161	0.0186	46	23	0.0014
27	A3	0.0175	0.0164	0.0182	46	15	0.0011
28	A3	0.0175	0.0163	0.0184	46	19	0.0012
29	A4	0.0175	0.0161	0.0186	46	23	0.0014

Appendix B

TYPICAL PROPERTIES OF WORKPIECE MATERIALS

Table B-1. Typical Workpiece-Material Properties

<u>Property</u>	<u>Material</u>				
	Kovar SAE K94610	SAE K95100 (Annealed)	15-5PH	303Se	BeCu
Yield Strength					
MPa	344.7	416	1034.1	413.6	654.9
KSI	50.0	60.4	150.0	60.0	95.0
Tensile Strength					
MPa	723.2	427	1137.5	1240.9	703.2
KSI	104.9	62.0	165.0	180.0	102.0
Elongation in 50.8mm or 2 Inches (Percent)	71.5	0.92	16.0	50.0	26.0
Reduction of Area (Percent)		0	58.0	55.0	
Hardness (Brinell 3000 kg)	176	235	352	160	216
Strain-Hardening Exponent	0.42	0	0.08	0.56	0.10
Modulus of Elasticity					
GP2	138	246	200	200	128
PSI x 10 ⁶	20.0	35.7	29.0	29.0	18.5

Appendix C

CALIBRATION PROCEDURE FOR UNIFIED MINIATURE THREADS

APPENDIX C
CALIBRATION PROCEDURE FOR
UNIFIED MINIATURE THREAD GAGES

1.0 PURPOSE

- 1.1 To describe the technique and method for calibration of Unified Miniature Thread (UNM) Gages, referred to herein as the gage.

2.0 CALIBRATION INTERVAL

- 2.1 150 usages.

3.0 CALIBRATION EQUIPMENT

3.1 Calibrated Instruments and Standards

- 3.1.1 Toolmaker's Microscope having split image
Accuracy: 40 microinches, .100 inch (2.54 mm) range.

3.2 Accessory Equipment

- 3.2.1 Ultrasonic Cleaner
3.2.2 Stereo Microscope
3.2.3 Brush, Fine Wire
3.2.4 Tweezers
3.2.5 Surgical Knife with Scalpel Blade No. 11

4.0 PREPARATION

4.1 Disassembly

- 4.1.1 Remove gage member from its handle.

NOTE: Retain identity of gage.

4.2 Clean

- 4.2.1 Clean gage member in ultrasonic cleaner.
4.2.2 Dry with clean compressed air.

NOTE: Always use tweezers when handling the gage member.

4.3 Visual

- 4.3.1 Inspect gage for broken or chipped threads and embedded metal using stereo microscope.

NOTE: Gages with damaged threads are to be scrapped.

- 4.3.2 Remove embedded metal with brush or surgical knife.

5.0 CALIBRATION

NOTE: The following procedure is to be performed using 12X objective lens.

Use an aperture setting for transmitted light of .08.

5.1 Thread Form

- 5.1.1 Position double image slide of the optical unit to the right.
5.1.2 Position vertical column to left and set to helix angle specified in Table C1.
5.1.3 Install shank end of gage in Toolmaker's microscope collet spindle.

NOTE: Use collet size that corresponds to size of gage.

- 5.1.4 Select thread form reticle that corresponds to gage being calibrated. Refer to Table C1.

NOTE: The reticle holder should always be installed with the single white dot facing operator.

TABLE C1
UNM THREAD GAGE SPECIFICATIONS

Size Designation (UNM)	Major Diameter		Pitch Diameter		Helix Angle		Reticle	
	Inches		Inches		Deg Min		Thread	Retainer
	Go	No Go	Go	No Go	Deg	Min	Profile	
.30	.01176/.01204	.01116/.01144	.00976/.01004	.01016/.01044	5	52	.125	8X
.40	.01566/.01594	.01496/.01524	.01316/.01344	.01356/.01384	5	26	.6	2X
.50	.01966/.01994	.01886/.01914	.01646/.01674	.01696/.01724	5	26	.75	2X
.60	.02356/.02384	.02266/.02294	.01976/.02004	.02036/.02064	5	26	.225	8X
.80	.03146/.03174	.03026/.03054	.02636/.02664	.02706/.02734	5	26	.3	8X
1.00	.03936/.03964	.03791/.03819	.03296/.03324	.03386/.03414	5	26	1.5	2X
1.20	.04716/.04744	.04571/.04599	.04086/.04114	.04176/.04204	4	23	1.5	2X

.001 inch = 25.4 μ m

- 5.1.5 Focus eyepiece ocular or reticle.
- 5.1.5.1 Close left eye and adjust the right graduated knob below eyepiece until the reticle is in sharp focus for right eye.
- 5.1.5.2 Repeat the focus adjustment for the left eye.
- 5.1.6 Focus the Toolmaker's microscope on the side of gage toward the operator.
- 5.1.7 Align the thread form on reticle normal to gage.
- 5.1.8 Position the "X" and "Y" table axis to align image of thread form near entrance end of gage with lines on the reticle referenced in paragraph 5.1.4.
- 5.1.9 Position the table to align image of thread form near center of gage with lines on the reticle.

NOTE: To be acceptable the thread form must not show signs of wear and conform to lines on the reticle.

5.2 Major Diameter - Initial Acceptance Only

- 5.2.1 Position double image slide to the left.
- 5.2.2 Position vertical column to right and set to angle referenced in Table C1.
- 5.2.3 Adjust the optics as required for critical focus on side of gage toward the operator.
- NOTE: The green image is the real image and red image is the virtue image.
- 5.2.4 Adjust table to align split image of the major diameter on the third or fourth thread from entrance end.
- 5.2.5 Zero digital readout display.

NOTE: To insure repeatability, reposition "Y" axis and repeat settings several times to obtain a good zero setting.

Settings in the "Y" (in-out) axis should always be made in same direction.

- 5.2.6 Position vertical column to left and set to angle referenced in paragraph 5.2.2.
- 5.2.7 Position table, refocus and align split image of the major diameter on opposite side of gage.
- 5.2.8 Observe digital readout display.
- 5.2.9 Reposition "Y" axis and reset image two additional times and average the three readings.

NOTE: Refer to Table C1 for acceptable limits.

- 5.3 Pitch Diameter
- 5.3.1 Position double image slide to the left.
- 5.3.2 Position vertical column to right and set to angle specified in Table C1.
- 5.3.3 Adjust the optics as required for critical focus on side of gage toward the operator.
- 5.3.4 Adjust table to align split image of the third or fourth thread form from entrance end.
- 5.3.5 Zero digital readout display.

NOTE: To insure repeatability, reposition "Y" axis and repeat settings several times to obtain a good zero setting.

- 5.3.6 Position vertical column to left and set to angle referenced in paragraph 5.3.2.
- 5.3.7 Position table, refocus and align the split image of thread form on opposite side of gage.
- 5.3.8 Observe digital readout display.
- 5.3.9 Reposition "Y" axis and reset image three additional times and average the four readings.

NOTE: Refer to Table C1 for acceptable limits.

6.0 GENERAL SUMMARY

6.1 Acceptable Gage

- 6.1.1 Complete an "Equipment Use Log" label and affix to vial.

6.2 Not Acceptable Gage

- 6.2.1 Refer any gage that is discrepant or in an abnormal condition to Gage Supervisor for disposition.

BDX-613-2608

PRODUCING MINIATURE THREADS, L. K. Gillespie and
J. M. Robb, Final, November 1981

Miniature precision actuators, timers, and switches typically utilize miniature threads to provide convenient assembly, disassembly and adjustment. Thread rolling provides high quality external threads with greater strength and lower cost than other thread producing techniques. Tap breakage is a significant problem when 0.5 and 0.6 Unified National Miniature (UNM) threads must be produced in hard materials such as SAE K95100 high-permeability magnetic steel. Aluminum parts

MECHANICAL: Miniature Threads

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Stainless steel 0.5 UNM screws break at loads of
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