TECHNICAL DATA

Knurls & Knurling

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Knurling

General Knurling Information

Description of the Process

Knurling has a wide variety of applications in the screw machine industry, many of its products having knurled surfaces. Knurling is most commonly used for decorative purposes and for serrating surfaces where component parts are locked or keyed together in unit assemblies.

The term knurling designates both the process and the knurled portion of the work. Knurling is obtained by displacement of the material when the knurl is pressed against the surface of a rotating work blank. Knurling tools are used for producing straight, diagonal or diamond knurling having teeth of uniform pitch on cylindrical surfaces.

Cylindrical knurls are used for knurling on screw machines, automatic lathes and cylindrical die thread rolling machines. The most commonly used knurls are those which produce straight, diagonal and diamond patterns on the work. Special knurls may be used, however, to produce teeth on tapered, convex or concave surfaces. Flat knurling dies are used in reciprocating types of thread rolling machines. Diamond knurling may have either a male or female pattern. Male diamond knurls have raised points and produce a female impression. Female diamond knurls have depressed points and produce a male impression. The male diamond pattern knurling with raised points on the work is most commonly used as it can easily be produced by using two diagonal knurls — one right hand and the other left hand. Single knurls with male or female diamond patterns are also used.

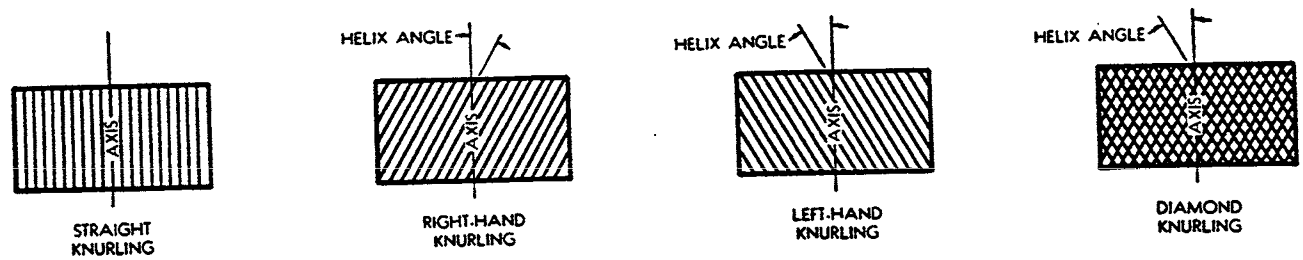


FIG. 1

Tooth Form

A knurled tooth is V-shaped and the depth of the tooth is less than the depth of a theoretical V-form. The tooth has a rounded root and crest. The relationship between the actual depth of tooth to the theoretical V varies with the pitch of the teeth. On finer pitches, the tooth is a smaller proportion of the theoretical V-depth than coarser pitches. Also, female diamond patterns have shallower tooth depth than male diamond patterns.

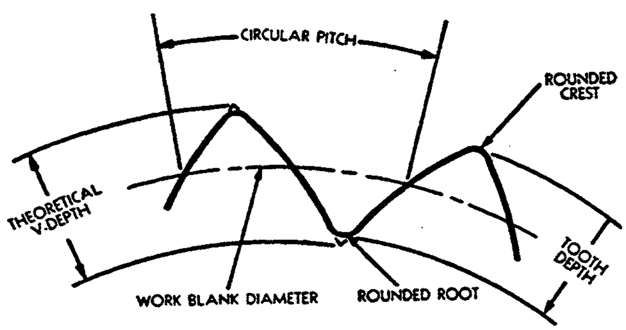


FIG. 2

Circular and Diametral Pitch Systems

Two general methods of knurling are now in use — the circular pitch and diametrical pitch systems. The circular pitch system is the older and has been in use for many years. It is based on the circular pitch and teeth per inch formulae related to the circumference of the work. The diametral pitch system is covered by the American Standard ANSI/ASME B94.6-1984. Four standard diametral pitches, 64, 96, 128, and 160 are used for work diameters ranging from 3/32" through 1". The purpose of diametral pitch knurling is to permit work blank diameters of standard fractional stock sizes to be used. The 96 and 160 diametral pitches apply to work blank diameters in 1/32" diameter increments and the 64 and 128 diametral pitches are for work blank diameters in 1/64" diameter increments. REED-RICO® cylindrical knurls are available for both systems which are fully described in separate sections of this booklet.

Methods of Applying Knurls

The sequence of operations and the tooling for knurling is dependent upon the nature of the part and the type of equipment selected. The knurling tools on automatic lathes and screw machines are mounted on the cross slides or in the turrets for either in-feed or end-feed knurling, depending upon the type of knurling and the knurl holders used.

Both one and two knurls are used for in-feed knurling, while two knurls are always necessary for end-feed knurling. The method of feeding the knurl into the work varies with the position of the knurling on the work with respect to shoulders; also the type of knurl holder and the position of the holder on the machine. The common methods of applying the knurls are illustrated below. Figures 3, 4 and 5 show application of conical, convex and concave knurls.

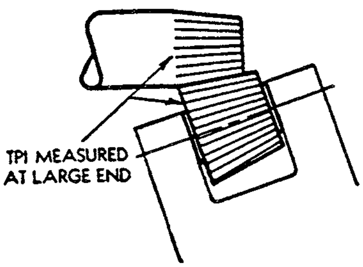


FIG. 3
Conical Knurling

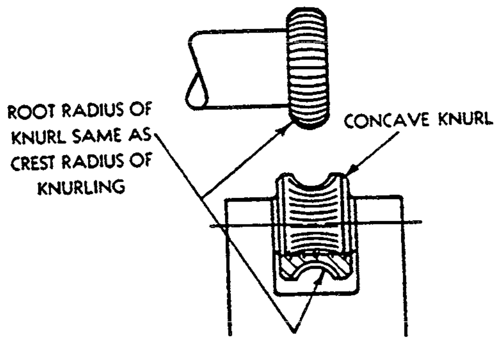


FIG. 4
Convex Knurling

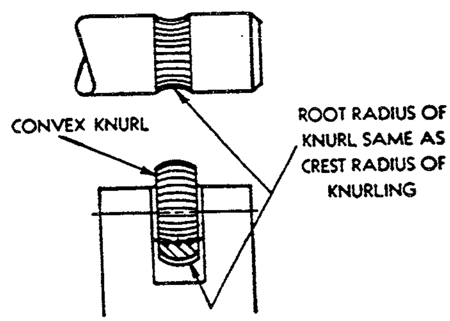


FIG. 5
Concave Knurling

Table 1

Knurling Produced from Cross Slide - One Knurl

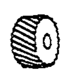
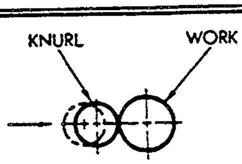
TYPE OF FEEDING	KNURLS USED			
	 STRAIGHT	 L.H. DIAGONAL	 R.H. DIAGONAL	 FEMALE DIAMOND
IN-FEED With Side Knurl Holder 	 Straight	 R.H. Diagonal	 L.H. Diagonal	 Male Diamond (Raised Points)

Table 2

Knurling Produced from Cross Slide - Two Knurls

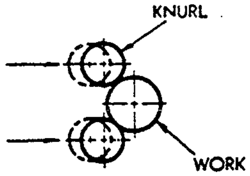
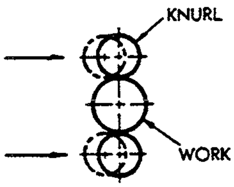
TYPE OF FEEDING	KNURLS USED			
	STRAIGHT	L.H. DIAGONAL	R.H. DIAGONAL	R. & L.H. DIAGONAL
IN-FEED With Side Knurl Holder 	Straight	R H. Diagonal	L.H. Diagonal	Male Diamond (Raised Points)
IN-FEED With Adjustable Straddle Type Holder 	Straight	R.H. Diagonal	L.H. Diagonal	Male Diamond (Raised Points)

Table 3

Knurling Produced from Turret - One Knurl

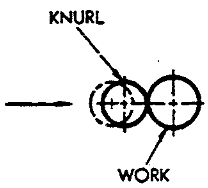
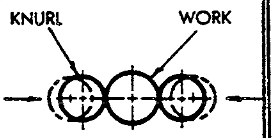
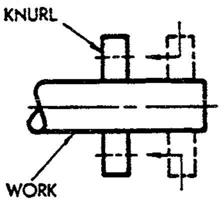
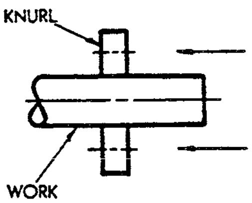
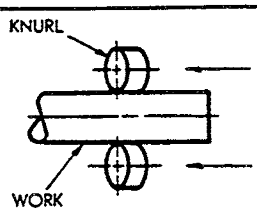
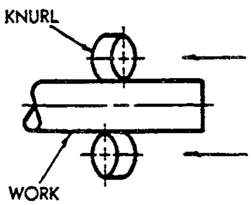
TYPE OF FEEDING	KNURLS USED			
	STRAIGHT	L.H. DIAGONAL	R.H. DIAGONAL	FEMALE DIAMOND
IN-FEED With Swing Type Knurl Holder Actuated from Cross Slide 	Straight	R.H. Diagonal	L.H. Diagonal	Male Diamond (Raised Points)

Table 4

Knurling Produced from Turret - Two Knurls

TYPE OF FEEDING		KNURLS USED			
		STRAIGHT	L.H. DIAGONAL	R.H. DIAGONAL	R. & L.H. DIAGONAL
IN-FEED With Swing Type Knurl Holders In-Feed Actuated From Cross Slide		Straight	R.H. Diagonal	L.H. Diagonal	Male Diamond (Raised Points)
END FEED With Adjustable Knurl Holder Actuated from Cross Slide		Straight	R.H. Diagonal	L.H. Diagonal	Male Diamond (Raised Points)
END-FEED With Adjustable Knurl Holder		Straight	R.H. Diagonal	L.H. Diagonal	Male Diamond (Raised Points)
END-FEED With Adjustable Swivel Type Knurl Holder		Male Diamond (Raised Points)			
END-FEED With Adjustable Swivel Type Knurl Holder		R.H. or L. H. Diagonal (R. H Diagonal Shown)	Straight	Straight	

REED-RICO® Circular Pitch Knurling

Circular pitch knurling is related to the distance between the teeth on the circumference of the work blank. It is usually expressed in terms of the number of teeth per inch, TPI, although sometimes erroneously referred to as pitch.

When knurling is used for decorative and general appearance purposes or for a hand grip, it is only necessary to specify the approximate teeth per inch, TPI, required for the knurling, thereby permitting standard knurls to be used.

Always specify the tooth pattern of the knurling, stating whether it is straight, diagonal or diamond pattern. Mention whether the diagonal knurling is right or left hand, whether diamond pattern is male or female, and indicate the angle of helix in both cases.

Knurling is sometimes referred to as coarse, medium and fine. Where no reference is made to diameters, 16-20 TPI is sometimes referred to as coarse, 25-35 as medium and 40-80 as fine. Much confusion has resulted from this practice because the size of the knurled diameter, in many instances, influences the selection of the pitch of the knurl to be used. What appears to be a coarse pitch on a small diameter may seem like a medium or fine pitch on a large diameter. We therefore recommend that the knurling be specified on the basis of TPI-teeth per inch.

Number of Teeth per inch-TPI

The number of teeth per inch is referred to as TPI. On REED-RICO® diagonal and diamond knurls "normal TPI" is used and is measured perpendicular to the teeth or helix angle.

In deciding the knurled pattern for a part, it is first necessary to determine whether straight, diagonal or diamond knurling is desired and then what TPI is best suited for the application

Table 5 will be helpful in visualizing the corresponding circular pitches for the different number of teeth per inch (TPI).

General Purpose and Precision Knurling

For general purpose knurling, only limited dimensions are necessary, as shown in Fig. 6. The TPI for straight knurling is shown in Fig. 2 and the normal TPI to be specified for REED-RICO® knurls is illustrated in Fig. 8. Omit any reference to tooth or space angles.

Table 5

TPI and Circular Pitches

for Straight, Diagonal and Diamond Knurling

Straight Knurling		Diagonal and Diamond Knurling—30° Helix Angle			
TPI (Teeth per Inch)	Circular Pitch	TPI (Teeth per Inch)		Circular Pitch	
		Normal	Transverse	Normal	Transverse
12	.0833	12	10.39	.0833	.0962
16	.0625	16	13.86	.0625	.0722
19	.0526	19	16.45	.0526	.0607
20	.0500	20	17.32	.0500	.0577
24	.0417	24	20.78	.0417	.0482
25	.0400	25	21.65	.0400	.0462
29	.0345	29	25.11	.0345	.0398
30	.0333	30	25.98	.0333	.0385
35	.0286	35	30.31	.0286	.0330
40	.0250	40	34.64	.0250	.0289
41	.0244	41	35.51	.0244	.0282
47	.0213	47	40.70	.0213	.0246
50	.0200	50	43.30	.0200	.0231
80	.0125	80	69.28	.0125	.0144

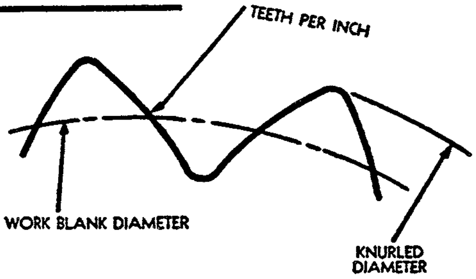


FIG. 6

In general practice, the depth of tooth of the knurling provided with REED-RICO® standard circular pitch knurls approximates the percentages of circular pitch listed.

Straight teeth - 35% of circular pitch
Diagonal teeth - 35% of normal circular pitch
Diamond pattern:
Male - 40% of normal circular pitch
Female - 25% of normal circular pitch

However, for precision straight knurling where component parts are to be fitted together, we recommend specifying only the following information. Omit any reference to tooth or space angles.

Knurled Diameter, Tooth Depth, Circular Pitch, Number of Teeth on Knurled Surface, Length of Knurled Surface

Straight Knurling

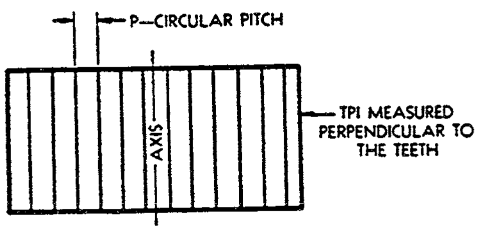


FIG. 7

$$N_w = \frac{3.1416 \times D_w}{p}$$

$$TPI = \frac{N_w}{3.1416 \times D_w}$$

$$D_w = \frac{p \times N_w}{3.1416}$$

where:

N_w = Number of teeth on work
D_w = Theoretical work blank diameter
p = Circular pitch
TPI = Number of teeth per inch measured on circumference of blank diameter

Diagonal or Diamond Knurling

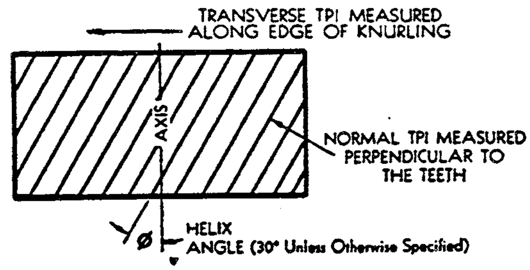


FIG. 8
Diagonal or Diamond Knurling — Teeth Per Inch — TPI

$$N_w = 3.1416 \times D_w \times TPI_t$$
$$\text{or } 3.1416 \times D_w \times TPI_n \times \cos Ø$$

$$TPI_t = \frac{N_w}{3.1416 \times D_w} \quad \text{or } TPI_n \times \cos Ø$$

$$TPI_n = \frac{N_w}{3.1416 \times D_w \times \cos Ø} \quad \text{or } \frac{TPI_n}{\cos Ø}$$

where:

N_w = Number of teeth on work
D_w = Theoretical work blank diameter
TPI_t = Transverse teeth per inch
TPI_n = Normal teeth per inch
Ø = Helix Angle (cos 30° = .86603)

TPI refers to the number of teeth per inch measured on the circumference of the work blank diameter. The approximate TPI, however, may be measured on outside diameter of the knurling for reference purposes.

For convenience in measuring the approximate TPI, the tooth pattern of the knurling may be quickly transferred to a sheet of paper. Place a piece of carbon paper (with carbon side down) on a sheet of white paper laid on a flat surface, and then roll the knurled surface of the part on the carbon paper. The impression of the knurled pattern will be transferred to the white paper for approximate measurements.

Knurled diameters and the circular pitch of the knurl are related. The circumference of the work blank should be an approximate multiple of the circular pitch for straight knurling and transverse circular pitch for diagonal and diamond knurling. Blank diameters vary with the circular pitch of the knurling selected, and should only be specified after the proper diameter of blank is determined by experimentation.

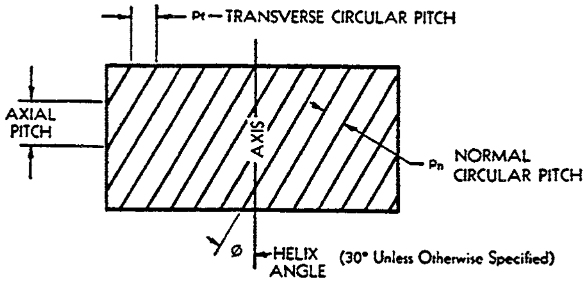


FIG. 9
Diagonal or Diamond Knurling — Circular Pitch

$$N_w = \frac{3.1416 \times D_w}{P_t} \text{ or } \frac{3.1416 \times D_w \times \cos Ø}{P_n}$$

$$D_w = \frac{P_t \times N}{3.1416} \text{ or } \frac{P_n \times N_w}{3.1416 \times \cos Ø}$$

where:

N_w = Number of teeth on work
D_w = Theoretical work blank diameter
P_t = Transverse circular pitch
P_n = Normal circular pitch
$Ø$ = Helix angle (cos 30° = .86603)

Knurled Diameters

The approximate increase in blank diameters when using REED-RICO® knurls for different teeth per inch with straight, diagonal and diamond pattern knurling is shown in Table 6. The amount of increase shown is based on knurling soft steels and should be used as a guide only. The amount of increase varies slightly with different materials.

Table 6
Approximate Increase of Blank Diameters
with Standard Reed Circular Pitch Knurls on Soft Steels

*Teeth per Inch	Straight and Diagonal** Knurling	**Diamond Knurling	
		Male (Raised Points)	Female (Depressed Points)
12	.034	.038	.023
16	.025	.029	.017
20	.020	.023	.014
25	.016	.018	.011
30	.013	.015	.009
35	.011	.013	.008
40	.009	.010	.007
50	.009	.010	.007
80	.005	.006	.004

** Refers to normal teeth per inch on diagonal and diamond knurling.*
*** With 30° helix angle.*

When the knurling to be produced does not require displacing sufficient material to fill the whole depth of the teeth on the knurl, it is usually necessary for the knurl to penetrate the work blank to a depth that will displace enough material too fill at least 75% of the knurl tooth depth to insure proper tracking of the knurl on the work.

Care should be exercised not to specify knurled diameters with too few teeth. Consideration should also be given to the length of the knurling and the pressure required to force the knurl into the work. The greatest pressures are exerted by the coarser pitches and with in-feed knurling using single knurls. Wide knurls require more pressure than narrow knurls. The following tabulation may be used as a guide in selecting the smallest knurled diameters to use for knurling with different number of teeth per inch (TPI) and widths of knurl faces.

Table 7
*** *Suggested Minimum Knurled Diameters***
For In-feed Rolling with Circular Pitch Knurls on General Applications

**TPI (Teeth per Inch)	Standard Width of Knurl Face		
	3/16	1/4	3/8
16	..	13/32	1/2
20	5/16	11/32	7/16
25	1/4	9/32	3/8
30	7/32	1/4	5/16
35	3/16	7/32	9/32
40	5/32	3/16	1/4
50	1/8	5/32	7/32
80	5/64	7/64	11/64

** Based on rolling conditions satisfactory for knurling and work being rigid and properly supported.*
*** Refers to normal TPI on diagonal knurling.*

Knurling Tolerances

For general purpose knurling of good quality, the limits and tolerances of the knurled diameters are relatively unimportant and are not specified. However, where it is necessary to specify tolerances and limits on knurled diameters for general purpose knurling, the tolerances may be expressed as 30 to 50% of the circular pitch with about 75% of the tolerances in a minus direction. Use as liberal a tolerance as possible, keeping low manufacturing cost in mind. For precision straight knurling where component parts are to fit together, the tolerances may be reduced to approximately 15 to 20% of the circular pitch of the knurling and the tolerance should be in the minus direction.

Work Blank Diameters

Since the knurls penetrate and re-form the surface of the blank, they do not remove or compress material. The material is simply squeezed out of the roots of the part and is formed up into the crests, resulting in an increase in outside diameter. It is important, therefore, that the work blank does not contain more than the correct amount of material required to form the finished knurled diameter. Otherwise, the knurls will become overloaded and excess pressures will be exerted on both the tools and equipment if attempts are made to reduce oversize knurled diameters when too large blanks are used. The knurled diameter is larger than the unknurled blank by an amount approximately equal to the tooth depth of the knurl used. Blank diameters for knurling are therefore approximately equal to the knurled diameter minus the depth of tooth. As variation in the blank diameter results in variation of knurled diameter, it is necessary that the blank diameter tolerances be controlled according to the accuracy of the knurling to be produced. Uniformity of blanks is required to produce uniform knurling. The diameter of the blank has a definite relation to the proper tracking of the knurl on its original contact with the work. The circumference of the work blank should be an approximate multiple of the circular pitch of straight knurls and the transverse circular pitch of diagonal knurls. With improper blank diameters, the teeth of the knurl as they continue to feed into the work fail to mesh with the indentations made during the first revolution of the blank. Blanks for all knurling should be free of taper and the surface of the blank reasonably smooth. Blank diameters also differ with knurling conditions such as materials and variations of practice. Improper and varying blank diameters result in reduced knurl life, poor finish, double teeth, uneven tooth profile, and inability to obtain uniformity of number of teeth and knurled diameter on the work.

With these variations possible, it will be readily appreciated that special attention must be given to careful preparation of blanks and to make sure the blank diameter is kept consistent with the predetermined size.

There are many variations entering into the knurling that make it difficult to establish a formula that will accurately predetermine exact blank diameters. The following formulae may be used, however, for determining a theoretical work blank diameter, or obtaining the circular pitch and number of teeth that may be rolled on a blank of a specified diameter. This applies to in-feed and end-feed knurling.

$$D_w = \frac{p \times N_w}{3.1416}$$

$$N_w = \frac{3.1416 \times D_w}{p}$$

$$p = \frac{3.1416 \times D_w}{N_w}$$

where:

D_w = Theoretical work blank diameter
N_w = Number of teeth on work
p = Circular pitch on work blank diameter for straight knurling. The transverse circular pitch is used for diagonal and diamond knurling.

Please note that the transverse circular pitch should be used when computing the number of teeth on the work blank with diagonal and diamond knurling.

TPI may be translated into circular pitch by referring to Table 5. Use standard REED-RICO® stock knurls wherever possible, as they are less expensive than special knurls and also available for immediate delivery.

The tolerances for work blank diameters vary with the knurling requirements. For general purpose knurling the tolerances usually range between 5 to 8% of the circular pitch, and for precise knurling, approximately 2 to 4% of the circular pitch.

The illustrations of sample knurling will assist in the selection of the TPI that can be obtained with standard REED-RICO® stock knurls. Special attention should be given to the suggested minimum diameters that should be used for various TPI as shown in Table 7.

Examples

Determine the approximate blank diameter for rolling 60 straight teeth on a knurled surface with a 20 TPI knurl.

$$D_w = \frac{p \times N_w}{3.1416} = \frac{.0500 \times 60}{3.1416} = .955 \text{ approx. blank diameter}$$

where:

p = .0500 (circular pitch for 20 TPI from Table 5)

Determine the approximate number of diagonal teeth that can be rolled on a blank .625" diameter with a 30 normal TPI knurl having 30° helix angle.

$$N_w = \frac{3.1416 \times D_w}{p} = \frac{3.1416 \times .625}{.0385} = 51 \text{ teeth}$$

where:

p = .0385 (transverse circular pitch for 30 TPI from Table 5)

Approximate theoretical blank diameters for different TPI and number of straight teeth on the work are given in Table 8.

A proportional formula frequently used for selecting the diameter and number of teeth on a knurl to produce a specified number of teeth on a given work blank diameter is also shown.

$$\frac{D_w}{N_w} = \frac{D_k}{N_k}$$

where:

D_w = Diameter of the work blank
N_w = Number of teeth on the work blank
D_k = Outside diameter of the knurl
N_k = Number of teeth on the knurl

Table 8

Theoretical Blank Diameters for Straight Tooth Knurling (continued on next page)

No. of Teeth on Knurled Circumference	Teeth per Inch							
	16	20	25	30	35	40	50	80
*15	...	...	...	...	...	...	.096	.060
16	...	...	...	...	...	...	.102	.064
17	...	...	...	...	...	...	.108	.068
18	...	...	...	...	...	.143	.115	.072
19	...	...	...	...	...	.151	.121	.076
20	...	...	...	.212	.182	.159	.127	.080
21	.418	.334	.267	.223	.191	.167	.134	.084
22	.438	.350	.280	.233	.200	.175	.140	.088
23	.458	.366	.293	.244	.209	.183	.146	.092
24	.478	.382	.306	.255	.218	.191	.153	.096
25	.497	.398	.318	.265	.227	.199	.159	.100
26	.517	.414	.331	.276	.236	.207	.166	.104
27	.537	.430	.344	.287	.246	.215	.172	.107
28	.557	.446	.356	.297	.255	.223	.178	.111
29	.577	.461	.369	.308	.264	.231	.185	.115
30	.597	.477	.382	.318	.273	.239	.191	.119
31	.617	.493	.395	.329	.282	.247	.197	.123
32	.637	.509	.407	.340	.291	.255	.204	.127
33	.657	.525	.420	.350	.300	.263	.210	.131
34	.676	.541	.433	.361	.309	.271	.216	.135
35	.696	.557	.446	.371	.318	.279	.223	.139
36	.716	.573	.458	.382	.327	.287	.229	.143
37	.736	.589	.471	.393	.337	.294	.236	.147
38	.756	.605	.484	.403	.346	.302	.242	.151
39	.776	.621	.496	.414	.355	.310	.248	.155
40	.796	.636	.509	.424	.364	.318	.255	.159
41	.816	.652	.522	.435	.373	.326	.261	.163
42	.836	.668	.535	.446	.382	.334	.267	.167
43	.855	.684	.547	.456	.391	.342	.274	.171
44	.875	.700	.560	.467	.400	.350	.280	.175
45	.895	.716	.573	.477	.409	.358	.287	.179
46	.915	.732	.586	.488	.418	.366	.293	.183
47	.935	.748	.598	.499	.427	.374	.299	.187
48	.955	.764	.611	.509	.437	.382	.305	.191
49	.975	.780	.624	.520	.446	.390	.312	.195
50	.995	.796	.637	.531	.455	.398	.318	.199
51	1.015	.812	.649	.541	.464	.406	.325	.203
52	1.035	.828	.662	.552	.473	.414	.331	.207
53	1.054	.843	.675	.562	.482	.422	.337	.211
54	1.074	.859	.687	.573	.491	.430	.344	.215
55	1.094	.875	.700	.584	.500	.438	.350	.219
56	1.114	.891	.713	.594	.509	.446	.357	.223
57	1.134	.907	.726	.605	.518	.454	.363	.227
58	1.154	.923	.738	.615	.528	.462	.369	.231
59	1.174	.939	.751	.626	.537	.470	.376	.235
60	1.194	.955	.764	.637	.546	.477	.382	.239
61	1.214	.971	.777	.647	.555	.485	.388	.243
62	1.233	.987	.789	.658	.564	.493	.395	.247
63	1.253	1.003	.802	.668	.573	.501	.401	.251
64	1.273	1.019	.815	.679	.582	.509	.407	.255
65	1.293	1.034	.827	.690	.591	.517	.414	.259
66	1.313	1.050	.840	.700	.600	.525	.420	.263
67	1.333	1.066	.853	.711	.609	.533	.427	.267
68	1.353	1.082	.866	.722	.618	.541	.433	.271
69	1.373	1.098	.878	.732	.628	.549	.439	.275
70	1.393	1.114	.891	.743	.637	.557	.446	.279
71	1.413	1.130	.904	.753	.646	.565	.452	.283
72	1.432	1.146	.917	.764	.655	.573	.458	.287
73	1.452	1.162	.929	.775	.664	.581	.465	.291
74	1.472	1.178	.942	.785	.673	.589	.471	.294
75	1.492	1.194	.955	.796	.682	.597	.478	.298
76	1.512	1.210	.967	.806	.691	.605	.484	.302
77	1.532	1.225	.980	.817	.700	.613	.490	.306
78	1.552	1.241	.993	.828	.709	.621	.497	.310
79	1.572	1.257	1.006	.838	.718	.629	.503	.314
80	1.592	1.273	1.018	.849	.728	.637	.509	.318
81	1.611	1.289	1.031	.859	.737	.645	.516	.322
82	1.631	1.305	1.044	.870	.746	.653	.522	.326
83	1.651	1.321	1.057	.881	.755	.660	.528	.330
84	1.671	1.337	1.069	.891	.764	.668	.535	.334
85	1.691	1.353	1.082	.902	.773	.676	.541	.338
86	1.711	1.369	1.095	.913	.782	.684	.548	.342
87	1.731	1.385	1.108	.923	.791	.692	.554	.346
88	1.751	1.400	1.120	.934	.800	.700	.560	.350
89	1.771	1.416	1.133	.944	.809	.708	.567	.354
90	1.791	1.432	1.146	.955	.818	.716	.573	.358
91	1.810	1.448	1.158	.966	.828	.724	.579	.362
92	1.830	1.464	1.171	.976	.837	.732	.586	.366
93	1.850	1.480	1.184	.987	.846	.740	.592	.370
94	1.870	1.496	1.197	.997	.855	.748	.598	.374
95	1.890	1.512	1.209	1.008	.864	.756	.605	.378
96	1.910	1.528	1.222	1.019	.873	.764	.611	.382
97	1.930	1.544	1.235	1.029	.882	.772	.618	.386
98	1.950	1.560	1.248	1.040	.891	.780	.624	.390
99	1.970	1.576	1.260	1.050	.900	.788	.630	.394
100	1.989	1.591	1.273	1.061	.909	.796	.637	.398
101	2.009	1.607	1.286	1.072	.918	.804	.643	.402
102	...	1.623	1.298	1.082	.928	.812	.649	.406
103	...	1.639	1.311	1.093	.937	.820	.656	.410
104	...	1.655	1.324	1.103	.946	.828	.662	.414
105	...	1.671	1.336	1.114	.955	.836	.668	.418
106	...	1.687	1.349	1.125	.964	.843	.675	.422
107	...	1.703	1.362	1.135	.973	.851	.681	.426
108	...	1.719	1.375	1.146	.982	.859	.688	.430
109	...	1.735	1.388	1.157	.991	.867	.694	.434
110	...	1.751	1.400	1.167	1.000	.875	.700	.438
111	...	1.767	1.413	1.178	1.009	.883	.707	.442
112	...	1.782	1.426	1.188	1.019	.891	.713	.446
113	...	1.798	1.438	1.199	1.028	.899	.719	.450
114	...	1.814	1.451	1.210	1.037	.907	.726	.454
115	...	1.830	1.464	1.220	1.046	.915	.732	.458
116	...	1.846	1.477	1.231	1.055	.923	.739	.462
117	...	1.862	1.489	1.241	1.064	.931	.745	.466
118	...	1.878	1.502	1.252	1.073	.939	.751	.470
119	...	1.894	1.515	1.263	1.082	.947	.758	.474
120	...	1.910	1.528	1.273	1.091	.955	.764	.478
121	...	1.926	1.540	1.284	1.100	.963	.770	.482
122	...	1.942	1.553	1.294	1.110	.971	.777	.485
123	...	1.957	1.566	1.305	1.119	.979	.783	.489
124	...	1.973	1.579	1.316	1.128	.987	.789	.493
125	...	1.989	1.591	1.326	1.137	.995	.796	.497
126	...	2.005	1.604	1.337	1.146	1.003	.802	.501
127	...	2.021	1.617	1.348	1.155	1.011	.809	.505
128	...	2.037	1.629	1.358	1.164	1.019	.815	.509
129	...	2.053	1.642	1.369	1.173	1.027	.821	.513

** Refer inquiries for less than 15 teeth to REED-RICO®.*

Table 8 (cont.)

No. of Teeth on Knurled Circumference	Teeth per Inch							
	16	20	25	30	35	40	50	80
130	...	2.069	1.655	1.379	1.182	1.034	.828	.517
131	...	2 085	1.668	1.390	1.191	1.042	.834	.521
132	...	2.101	1.680	1.401	1.200	1.050	.840	.525
133	...	...	1.693	1.411	1.210	1.058	.847	.529
134	...	...	1.706	1.422	1.219	1.066	.853	.533
135	...	...	1.719	1.432	1.228	1.074	.859	.537
136	...	...	1.731	1.443	1.237	1.082	.866	.541
137	...	...	1.744	1.454	1.246	1.090	.872	.545
138	...	...	1.757	1.464	1.255	1.098	.879	549
139	...	...	1.769	1.475	1.264	1.106	.885	.553
140	...	...	1.782	1.485	1.273	1.114	.891	.557
141	...	...	1.795	1.496	1 282	1.122	.898	.561
142	...	...	1.808	1.507	1.291	1.130	.904	.565
143	...	...	1.820	1.517	1 300	1.138	.910	.569
144	...	...	1.833	1.528	1.310	1.146	.917	.573
145	...	...	1.846	1.539	1.319	1.154	.923	.577
146	...	...	1.859	1.549	1.328	1.162	.929	.581
147	...	...	1.871	1.560	1.337	1.170	.936	.585
148	...	...	1.884	1.570	1.346	1.178	.942	.589
149	...	...	1.897	1.581	1.355	1.186	.949	.593
150	...	...	1.909	1.592	1 364	1.194	.955	.597
151	...	...	1.922	1.602	1 373	1 202	.961	.601
152	...	...	1.935	1.613	1.382	1.210	.968	.605
153	...	...	1.948	1 623	1.391	1.217	.974	.609
154	...	...	1.960	1.634	1.401	1.225	.980	.613
155	...	...	1.973	1.645	1.410	1.233	987	.617
156	...	...	1.986	1.655	1.419	1.241	.993	.621
157	...	...	1.999	1.666	1.428	1.249	1.000	.625
158	...	...	2.011	1.676	1.437	1.257	1.006	.629
159	...	...	2.024	1.687	1.446	1.265	1.012	.633
160	...	...	2.037	1.698	1.455	1.273	1.019	.637
161	...	...	2.049	1.708	1.464	1.281	1.025	.641
162	...	...	2.062	1.719	1.473	1.289	1.031	.645
163	...	...	2.075	1.729	1.482	1.297	1.038	.649
164	...	...	2.088	1.740	1.491	1.305	1.044	.653
165	...	...	2.100	1.751	1.501	1.313	1.050	.657
166	...	...	2.113	1.761	1.510	1.321	1.057	.661
167	...	...	...	1.772	1.519	1.329	1.063	.665
168	...	...	...	1.783	1.528	1.337	1.070	.669
169	...	...	...	1.793	1.537	1.345	1.076	.673
170	...	...	...	1.804	1.546	1.353	1.082	.676
171	...	...	...	1.814	1.555	1.361	1.089	.680
172	...	...	...	1.825	1.564	1.369	1.095	.684
173	...	...	...	1.836	1.573	1.377	1.101	.688
174	...	...	...	1.846	1.582	1.385	1.108	.692
175	...	...	...	1.857	1.592	1.393	1.114	.696
176	...	...	...	1.867	1.601	1.400	1.120	.700
177	...	...	...	1.877	1.610	1.408	1.127	.704
178	...	...	...	1.889	1.619	1.416	1.133	.708
179	...	...	...	1.899	1.628	1.424	1.140	.712
180	...	...	...	1.910	1.637	1.432	1.146	.716
181	...	...	...	1.920	1.646	1.440	1.152	.720
182	...	...	...	1.931	1.655	1.448	1.159	.724
183	...	...	...	1.942	1.664	1.456	1.165	.728
184	...	...	...	1.952	1.673	1.464	1.171	.732
185	...	...	...	1.963	1.682	1.472	1.178	.736
186	...	...	...	1.974	1.692	1.480	1.184	740
187	...	...	...	1.984	1.701	1.488	1.190	.744
188	...	...	...	1.995	1.710	1.496	1.197	.748
189	...	...	...	2.005	1.719	1.504	1.203	.752

Dimensioning of Circular Pitch Knurling

Uniform drafting practice is desirable and dimensioning should include length and knurled diameter of the knurling and specifications of the teeth. The method of dimensioning diameters and tooth specifications is important as improper use of dimensions may result in considerable confusion.

The designer should always allow leeway in dimensioning knurled diameters so the setup person may experiment in establishing the exact relationship between the work blank diameter and the diameters on the finished knurled product. General information on blank diameters appears on page 10. Approximate amounts to add to the blank diameters to obtain the knurled diameters for different TPI and types of knurling are given in Table 6.

Allowance for variation in number of teeth in the knurled diameter should also be made unless the use of the knurled surface demands an exact number of teeth made to a prescribed form. In such cases, precise limits on blank diameters will be required and these limits can only be determined by experimentation with precision made knurls for the specific material and work to be knurled.

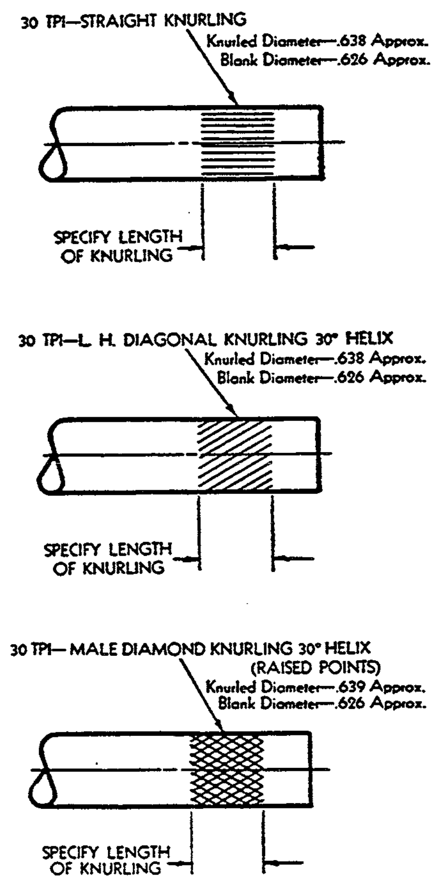


FIG. 10

Diametral Pitch Knurling

An American Standard ANSI/ASME B94.6-1984 has been issued for diametral pitch knurling and has been designed on the basis of diametral pitch instead of the commonly used circular pitch and TPI (teeth per inch) system. Diametral pitch knurling has been developed for work blank diameters that are standard fractional stock sizes in multiples of 1/64" or 1/32" depending upon the diametral pitch selected. The fractional blank diameter sizes apply to straight and diagonal knurling for both in-feed and end-feed knurling. End-feeding for diagonal knurling with the axes of straight knurls set over at a specified helix angle usually requires decimal size blank diameters as described on page 17.

Standard Diametral Pitches

The four standard diametral pitches available are 64, 96, 128 and 160. The 96 and 160 diametral pitches are for blank diameters having fractional increments of 1/32" and the 64 and 128 diametral pitches are for blank diameters having fractional increments of 1/64". The American Standard recommends that the use of the 64 diametral pitch should be avoided as much as possible, and for simplification of tools, preference be given to the use of 96 diametral pitch.

The term diametral pitch applies to the quotient of the total number of teeth in the circumference of the work divided by the basic diameter of the work blank. The diametral pitch is the ratio of the number of teeth on the work to the number of inches of basic work blank diameter and equals the number of teeth to each inch of basic blank diameter.

$$p = \frac{N_w}{D_w}$$

where:

p = Diametral pitch

N_w = Number of teeth on the work, or $p \times D_w$

D_w = Theoretical work blank diameter, or $\frac{N_w}{p}$

The diametral pitch and the number of teeth are always measured in a transverse plane which is perpendicular to the axis of rotation for diagonal as well as straight knurling as illustrated in Fig. 9.

A comparison of diametral pitches, TPI and circular pitches is shown in Table 9.

Diagonal and diamond knurling on work blank may be accomplished by setting the axes of straight knurls at an angle to the work axis as shown in Fig. 11 .

When using straight knurls to produce diagonal and diamond knurling by end-feeding, the transverse diametral pitch that is produced on the work will not be the same as that of the knurl. The diametral pitch in such instances refers to the diametral pitch on the knurl rather than the knurling produced on the work.

Table 9

Approximate Increase of Blank Diameter

Straight & Diagonal American Standard
ANSI/ASME B94.6—1984

Diametral Pitch	**Teeth per Inch Approx.	**Circular Pitch	Approx. Depth of Tooth or Increase in Knurled Diameter		Min. No. of Teeth in Knurled Circumference	Work Blank Diameters	
			Straight	Diagonal		Range	Diameter Increments
64	20.4	.0491	.024	.021	24	3/8–1	1/64
96	30.6	.0327	.016	.014	24	1/4–1	1/32
128	40.7	.0245	.012	.010	18	9/64–1	1/64
160	50.9	.0196	.009	.008	15	3/32–1	1/32

*** Refers to transverse TPI and transverse circular pitch on diagonal knurling.*

Knurling Tolerances

The American Standard ANSI/ASME B94.6-1984 for straight and diagonal knurling applies to work blank diameters up to 1" as shown in Table 10, which includes three classes of tolerances. These classes and recommended applications are as follows:

Class I. Tolerances in this classification may be applied to straight, diagonal and raised diamond knurling where the knurled outside diameter of the work need not be held to close dimensional tolerances. Such applications include knurling for decorative effect, grip on thumbscrews, and inserts for moldings and castings.

Class II. Tolerances in this classification may be applied to straight knurling only and are recommended for applications requiring closer dimensional control of the knurled outside diameter than provided for by Class I tolerances.

Class III. Tolerances in this classification may be applied to straight knurling only and are recommended for applications requiring closest possible dimensional control of the knurled outside diameter. Such applications include knurling for close fits.

Work Blank Diameters

The fractional and decimal sizes of the work blank up to 1" diameter for in-feed knurling are shown in Table 10. The formulae for theoretical work blank diameters are as follows:

$$D_w = \frac{N_w}{p}$$

where:

D_w = Theoretical work blank diameter
N_w = Number of teeth on the work
p = Diametral pitch

The theoretical work blank diameters up to 1" for end-feed diagonal and diamond knurling with straight tooth knurls are shown in Table 11 for helix angle of 30°.

For end-feed knurling with straight tooth knurls:

$$D_w = \frac{N_w}{p \times \cos \psi}$$

where:

D_w = Theoretical work blank diameter
N_w = Number of teeth on the work measured in transverse plane
p = Diametral pitch on knurl
ψ = Angle between knurl axis and work axis (cos 30° = .86603)

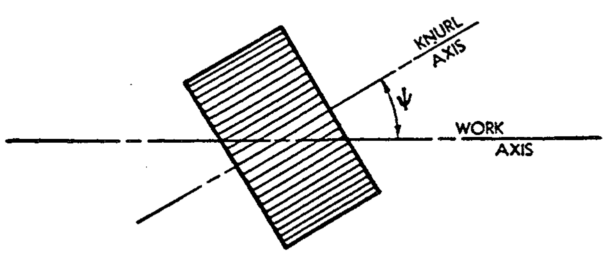


FIG. 11

The number of teeth produced on the work blank is measured in the transverse plane and may be determined with the following formula for diagonal knurling.

$$N_w = D_w \times p \times \cos \psi$$

where:

N_w = Number of teeth produced on the work blank measured in the transverse plane
D_w = Diameter of work blank
p = Diametral pitch on knurl
ψ = Angle between knurl axis and work axis

For Example: If 30° diagonal knurling were to be produced on 1" stock with a 96 diametral pitch straight knurl.

$$N_w = 1.000 \times 96 \times .86603 = 83.14 \text{ teeth}$$

Note: .86603 equals cosine of 30°.

Increasing the angle between the knurl axis and the work axis to approximately 30 1/4° would provide good tracking of the knurl and make it possible to obtain an even 83 teeth instead of 83.14.

By reducing the diameter of the work blank to a decimal size, good tracking of the knurl can be obtained for 30° diagonal knurling according to the following formula:

$$D_w = \frac{N_w}{p \times \cos \psi} = \frac{83}{96 \times .86603} = .998 \text{ inch}$$

The tolerances for work blank diameters vary with the knurling requirements. For general purpose knurling the tolerances usually range between 5 to 8% of the circular pitch and for precise knurling, approximately 2 to 4% of the circular pitch.

Dimensioning of Diametral Pitch Knurling

Uniform drafting practice is desirable and dimensioning should include length and knurled diameter of the knurling and specifications of the teeth. The method of dimensioning diameters and tooth specifications is important as improper use of dimensions may result in considerable confusion.

Always specify the tooth pattern of the knurling, stating whether it is straight, diagonal or diamond pattern (male or female). Mention whether the diagonal knurling is right or left hand, and indicate the angle of the helix.

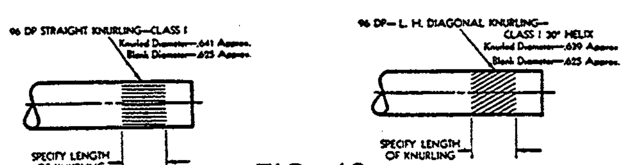


FIG. 12

Table 10

Data for Fractional Blank Diameters - In-feed Knurling

Using Straight and Diagonal Diametral Pitch Knurls for Blank Diameters up to One Inch
ANSI/ASME B94.6-1984

Diameter of Blank		64 Diametral Pitch*		96 Diametral Pitch*		128 Diametral Pitch		160 Diametral Pitch	
		Knurled Diameter	No. of Teeth in Knurled Circum.	*Knurled Diameter*	*No. of Teeth in Knurled Circum.*	Knurled Diameter	No. of Teeth in Knurled Circum.	Knurled Diameter	No. of Teeth in Knurled Circum.
3/32	0.094	...	...	...	...	...	...	0.103	15
1/8	0.125	...	...	...	...	...	...	0.134	20
9/64	0.141	...	...	...	...	0.153	18	...	...
5/32	0.156	...	...	...	...	0.168	20	0.165	25
11/64	0.172	...	...	...	...	0.184	22	...	...
3/16	0.188	...	...	...	...	0.200	24	0.197	30
13/64	0.203	...	...	...	...	0.215	26	...	...
7/32	0.219	...	...	...	...	0.231	28	0.228	35
15/64	0.234	...	...	...	...	0.246	30	...	...
1/4	0.250	...	...	*0.266*	*24*	0.262	32	0.259	40
17/64	0.266	...	...	...	...	0.278	34	...	...
9/32	0.281	...	...	*0.297*	*27*	0.293	36	0.290	45
19/64	0.297	...	...	...	...	0.309	38	...	...
5/16	0.312	...	...	*0.328*	*30*	0.324	40	0.321	50
21/64	0.328	...	...	...	...	0.340	42	...	...
11/32	0.344	...	...	*0.360*	*33*	0.356	44	0.353	55
23/64	0.359	...	...	...	...	0.371	46	...	...
3/8	0.375	0.399	24	*0.391*	*36*	0.387	48	0.384	60
25/64	0.391	0.414	25	...	...	0.403	50	...	...
13/32	0.406	0.430	26	*0.422*	*39*	0.418	52	0.415	65
27/64	0.422	0.446	27	...	...	0.434	54	...	...
7/16	0.438	0.462	28	*0.454*	*42*	0.450	56	0.447	70
29/64	0.453	0.477	29	...	...	0.465	58	...	...
15/32	0.469	0.493	30	*0.485*	*45*	0.481	60	0.478	75
31/64	0.484	0.508	31	...	...	0.496	62	...	...
1/2	0.500	0.524	32	*0.516*	*48*	0.512	64	0.509	80
33/64	0.516	0.540	33	...	...	0.528	66	...	...
17/32	0.531	0.555	34	*0.547*	*51*	0.543	68	0.540	85
35/64	0.547	0.571	35	...	...	0.559	70	...	...
9/16	0.562	0 586	36	*0.578*	*54*	0.574	72	0.571	90
37/64	0.578	0.602	37	...	...	0.590	74	...	...
19/32	0.594	0.618	38	*0.610*	*57*	0.606	76	0.603	95
39/64	0.609	0.633	39	...	...	0.621	78	...	...
5/8	0.625	0.649	40	*0.641*	*60*	0.637	80	0.634	100
41/64	0.641	0.665	41	...	...	0.653	82	...	...
21/32	0.656	0.680	42	*0.672*	*63*	0.668	84	0.665	105
43/64	0.672	0.696	43	...	...	0.684	86	...	...
11/16	0.688	0.712	44	*0.704*	*66*	0.700	88	0.697	110
45/64	0.703	0.727	45	...	...	0.715	90	...	...
23/32	0.719	0.743	46	*0.735*	*69*	0.731	92	0.728	115
47/64	0.734	0.758	47	...	...	0.746	94	...	...
3/4	0.750	0.774	48	*0.766*	*72*	0.762	96	0.759	120
49/64	0.766	0.790	49	...	...	0.778	98	...	...
25/32	0.781	0.805	50	*0.797*	*75*	0.793	100	0.790	125
51/64	0.797	0.821	51	...	...	0.809	102	...	...
13/16	0.812	0.836	52	*0.828*	*78*	0.824	104	0.821	130
53/64	0.828	0.852	53	...	...	0.840	106	...	...
27/32	0.844	0.868	54	*0.860*	*81*	0.856	108	0.833	135
55/64	0.859	0.883	55	...	...	0.871	110	...	...
7/8	0.875	0.899	56	*0.891*	*84*	0.887	112	0.884	140
57/64	0.891	0.915	57	...	...	0.903	114	...	...
29/32	0.906	0.930	58	*0.922*	*87*	0.918	116	0.915	145
59/64	0.922	0.946	59	...	...	0.934	118	...	...
15/16	0.938	0.962	60	*0.954*	*90*	0.950	120	0.947	150
61/64	0.953	0.977	61	...	...	0.965	122	...	...
31/32	0.969	0.993	62	*0.985*	*93*	0.981	124	0.978	155
63/64	0.984	1.008	63	...	...	0.996	126	...	...
1	1.000	1.024	64	*1.016*	*96*	1.012	128	1.009	160
Recommended Tolerance on Knurled Outside Diameters	Class I	+0.005 −0.012		.....	+0.004 −0.010	.....	+0.003 −0.008	.....	+0.002 −0.006
	Class II	+0.000 −0.010		.....	+0.000 −0.009	.....	+0.000 −0.008	.....	+0.000 −0.006
	Class III	+0.000 −0.006		.....	+0.000 −0.005	.....	+0.000 −0.004	.....	+0.000 −0.003
Recommended Tolerance on Work Blank Diameter Before Knurling (1)	Classes I & II	±0.0015		...	±0.0010	...	±0.0007	...	±0.0005
	Class III	+0.0000 −0.0015		...	+0.0000 −0.0010	...	+0.0000 −0.0007	...	+0.0000 −0.0005

** USE OF 64 DIAMETRAL PITCH KNURL should be avoided as much as possible. For simplification of tools it is recommended that preference be given to use of 96 Diametral Pitch shown in italics.*

(1) Recommended tolerance on Class I and II work blanks is equal to 6% of the circular pitch on the nominal diameter. Recommended tolerance on Class III work blanks is equal to 3% of the circular pitch on the nominal diameter.

For unlisted diameters refer to formulas on Page 15.

Table 11

* Theoretical Blank Diameters for Diagonal and Diamond Knurling - End-feed Knurling - with Straight Knurls

Produced by Straight Diametral Pitch Knurls with 30° Angle Between Axis of Work and Knurl Axis and for Blank Diameters up to One Inch
ANSI/ASME B94.6-1984

No. of Teeth on Work	Diametral Pitch			
	†64	†96	128	160
15	...	...	...	0.108
16	...	...	...	0.115
17	...	...	0.153	0.123
18	...	...	0.162	0.130
19	...	...	0.171	0.137
20	...	...	0.180	0.144
21	...	...	0.189	0.152
22	0.397	*0.265*	0.198	0.159
23	0.415	*0.277*	0.207	0.166
24	0.433	*0.289*	0.217	0.173
25	0.451	*0.301*	0.226	0.180
26	0.469	*0.313*	0.235	0.188
27	0.487	*0.325*	0.244	0.195
28	0.505	*0.337*	0.253	0.202
29	0.523	*0.349*	0.262	0.209
30	0.541	*0.361*	0.271	0.217
31	0.559	*0.373*	0.280	0.224
32	0.577	*0.385*	0.289	0.231
33	0.595	*0.397*	0.298	0.238
34	0.613	*0.409*	0.307	0.245
35	0.631	*0.421*	0.316	0.253
36	0.649	*0.433*	0.325	0.260
37	0.667	*0.445*	0.334	0.267
38	0.685	*0.457*	0.343	0.274
39	0.703	*0.469*	0.352	0.281
40	0.721	*0.481*	0.361	0.289
41	0.740	*0.493*	0.370	0.296
42	0.758	*0.505*	0.379	0.303
43	0.776	*0.517*	0.388	0.310
44	0.794	*0.529*	0.397	0.318
45	0.812	*0.541*	0.406	0.325
46	0.830	*0.553*	0.415	0.332
47	0.848	*0.565*	0.424	0.339
48	0.866	*0.577*	0.433	0.346
49	0.884	*0.589*	0.442	0.354
50	0.902	*0.601*	0.451	0.361
51	0.920	*0.613*	0.460	0.368
52	0.938	*0.625*	0.469	0.375
53	0.956	*0.637*	0.478	0.382
54	0.974	*0.650*	0.487	0.390
55	0.992	*0.662*	0.496	0.397
56	1.010	*0.674*	0.505	0.404

No. of Teeth on Work	Diametral Pitch			
	†64	†96	128	160
57	...	*0.686*	0.514	0.411
58	...	*0.698*	0.523	0.419
59	...	*0.710*	0.532	0.426
60	...	*0.722*	0.541	0.433
61	...	*0.734*	0.550	0.440
62	...	*0.746*	0.559	0.447
63	...	*0.758*	0.568	0.455
64	...	*0.770*	0.577	0.462
65	...	*0.782*	0.586	0.469
66	...	*0.794*	0.595	0.476
67	...	*0.806*	0.604	0.484
68	...	*0.818*	0.613	0.491
69	...	*0.830*	0.622	0.498
70	...	*0.842*	0.631	0.505
71	...	*0.854*	0.640	0.512
72	...	*0.866*	0.650	0.520
73	...	*0.878*	0.659	0.527
74	...	*0.890*	0.668	0.534
75	...	*0.902*	0.677	0.541
76	...	*0.914*	0.686	0.548
77	...	*0.926*	0.695	0.556
78	...	*0.938*	0.704	0.563
79	...	*0.950*	0.713	0.570
80	...	*0.962*	0.722	0.577
81	...	*0.974*	0.731	0.585
82	...	*0.986*	0.740	0.592
83	...	*0.998*	0.749	0.599
84	...	*1.010*	0.758	0.606
85	...	...	0.767	0.613
86	...	...	0.776	0.621
87	...	...	0.785	0.628
88	...	...	0.794	0.635
89	...	...	0.803	0.642
90	...	...	0.812	0.650
91	...	...	0.821	0.657
92	...	...	0.830	0.664
93	...	...	0.839	0.671
94	...	...	0.848	0.678
95	...	...	0.857	0.686
96	...	...	0.866	0.693
97	...	...	0.875	0.700

No. of Teeth on Work	Diametral Pitch			
	†64	†96	128	160
98	...	...	0.884	0.707
99	...	...	0.893	0.714
100	...	...	0.902	0.722
101	...	...	0.911	0.729
102	...	...	0.920	0.736
103	...	...	0.929	0.743
104	...	...	0.938	0.751
105	...	...	0.947	0.758
106	...	...	0.956	0.765
107	...	...	0.965	0.772
108	...	...	0.974	0.779
109	...	...	0.983	0.787
110	...	...	0.992	0.794
111	...	...	1.001	0.801
112	...	...	...	0.808
113	...	...	...	0.815
114	...	...	...	0.823
115	...	...	...	0.830
116	...	...	...	0.837
117	...	...	...	0.844
118	...	...	...	0.852
119	...	...	...	0.859
120	...	...	...	0.866
121	...	...	...	0.873
122	...	...	...	0.880
123	...	...	...	0.888
124	...	...	...	0.895
125	...	...	...	0.902
126	...	...	...	0.909
127	...	...	...	0.917
128	...	...	...	0.924
129	...	...	...	0.931
130	...	...	...	0.938
131	...	...	...	0.945
132	...	...	...	0.953
133	...	...	...	0.960
134	...	...	...	0.967
135	...	...	...	0.974
136	...	...	...	0.981
137	...	...	...	0.989
138	...	...	...	0.996

** Modification of these diameters may be made in order to suit various knurling conditions such as materials and variations in practice.*
† USE OF 64 DIAMETRAL PITCH KNURL should be avoided as much as possible. For simplification of tools it is recommended that preference be given to use of 96 Diametral Pitch shown in italics.

Knurling on Screw Machines and Lathes

Knurling with Cross Slide Holders

Straight or diamond knurling can be produced by using either one or two knurls mounted in a holder on the cross slide. When so used, straight knurls are limited to straight knurling. Only one diamond pattern knurl can be used for diamond knurling, whereas two diagonal knurls of opposite hands will produce a male diamond pattern on the work. Where tooling setup provides space for two knurls, the combination of right and left diagonal knurls will produce a cleaner male diamond pattern that can be obtained with a single female diamond knurl. Diamond knurls require greater pressure than straight or diagonal knurls and sometimes place prohibitive loads on both machine and work. Only a male diamond knurl, however, can produce a female diamond impression.

Knurls may be mounted on the front or rear cross slides. Various designs of knurl holders are available. The knurls in the single knurl holders usually exert direct pressure against the work and the diameter of the knurling is controlled by the size of the blank and the final positioning of the cross slide. Single knurl holders usually occupy minimum tool space and are also made for use in combination with holders for cutting operations — in such instances the knurl passes either over or under the work. Some holders have two knurls mounted in a unit which applies direct pressure to the work.

Compact adjustable floating straddle type holders with two knurls are also used on cross slides. The two opposed knurls form the knurling as they are fed on to the blank — final size of the knurling being obtained when the knurls reach the center of the work. The diameter of knurling is controlled by the size of the blank and a predetermined setting of the center distance between knurls in the holder. The cross slide travel is only used as a means of feeding the knurls to and from the work. Side pressure on the work and the machine spindle is reduced with straddle type holders as most of the pressure required for knurling is absorbed in the holder.

Knurling with Turret Holders

Straight, diagonal or male diamond knurling may be produced with swing type in-feeding holders and adjustable swivel type end-feeding knurl holders mounted in the turret. Adjustment is provided in the holder for setting the knurls for the diameter of knurling desired. Knurls used for end-feeding should have beveled edges.

Only straight and diagonal knurls can be used with the end-feeding holders. When producing diagonal and diamond knurling with straight knurls, the axes of the straight knurls are swiveled in the holder for obtaining the diagonal and diamond knurling as the knurls are fed over the blank.

Straight knurling may be produced with end-feeding holders using either straight or diagonal knurls. Of these two methods, the use of diagonal knurls of the same hand is preferred. The axes of the diagonal knurls are swiveled in the holder to obtain straight knurling as the knurls are fed over the blank. This method permits easier starting of the knurls with uniform raise up of material. Since the axes of the knurls and the work are not parallel, a burnishing action occurs resulting in higher quality knurling. Continuous full contact of the knurls with the blank is maintained for control of the depth of knurling even on long work which may spring slightly away from the centerline.

Setting the axes of knurls at an angle has the disadvantage, however, of not being able to knurl close to shoulders as the leading edges of the swiveled knurls will touch the shoulder before the points of contact of the knurls with the work have reached the shoulder. When using diagonal knurls for end-feeding, it is important to have a stiff spring for returning the turret when withdrawing the knurls from the work.

Both straight and diagonal knurls are used in the swing type in-feeding holders in the turrets. The holder is in the open position as the turret brings the knurl, or knurls, over the work and the cross slide is used to close the holder and engage the knurls with the work.

Speeds and Feeds

Knurling is ordinarily performed at the same speeds used in the cutting operations. However, where spindle speeds can be reduced without loss of production, it is recommended that spindle speeds be lowered as much as possible to increase knurl life.

For in-feed knurling, the knurl should be fed toward the work gradually until contact is made with the blank, and from there on, the feed should be progressive until the feed is at the high point of the cam. As few work revolutions as possible should be allowed for feeding the knurl into the work. The knurl should be fed to full depth as rapidly as permissible without causing undue pressure on the work, the tools and the equipment. Too many revolutions may result in a roughened or slivered tooth surface and destruction of the knurl and the knurling.

The rate of feed is governed by the kind of material being knurled, diameter and rigidity of the work, and the width and pitch of the knurl. Faster feeds are used for the softer materials and slower feeds for harder materials. Although the knurling should be normally completed within 10 to 25 work revolutions, the ability of many machine cross slides to operate at the desired high speeds prohibits the use of the preferred revolutions, especially when high work spindle speeds are used.

The cam rise must be continuous with no dwell or backing away until the high point is reached. It is desirable to have a slight dwell on the cam at the completion of the feeding which allows several revolutions of the work with the knurl at full tooth depth. The amount of dwell depends upon the nature of the work and the material. The knurl should be then withdrawn from the work quickly.

The feeds used for end-feed knurling with the turret vary considerably and are dependent upon the pitch of the knurl, material being knurled and the nature and diameter of the work.

Table 12 may be used as a guide for determining the amount of end-feed per revolution of the work. The rate of the feed for diamond pattern knurling is slower than that for straight or diagonal knurling.

Table 12
Turret Knurling Straight or Diagonal
Approximate End-feed per Revolution of Work

TPI	Material		
	Brass	Steel 10-25 Carbon	Steel 30-50 Carbon or Alloy
16-20	.010	.006	.004
25-35	.013	.008	.005
40-80	.017	.010	.006

Table 13
Bump Knurling
Approximate In-feed (cross-slide) per Revolution of Work

General Application		
TPI	Feed/Rev.	Approximate* Minimum Blank Dia.
16-20	.002	3/8"
25-35	.001	1/4"
40-80	.0006	1/8"

**Based on a minimum of 20 teeth on circumference of work and approximately 1/4" wide knurl.*
REMEMBER: Penetration is only 1/2 of the knurl tooth depth. The remaining 1/2 is displaced material.

Knurling on Thread Rolling Machines

With Reciprocating Type Machines

Flat knurling dies are used on reciprocating thread rolling machines. They may be made with either single or duplex faces. Two dies are used; one stationary, and one moving. The rolling faces of the dies are located opposite each other as shown in Fig. 13.

The knurling is rolled on the blank during the forward stroke of the machine and the number of revolutions provided for rolling the knurling is dependent upon the die length. The rate of penetration is determined by the shape of the die. Flat knurling dies are used only for in-feed knurling, and the depth of die face is usually made to suit the length of knurling required.

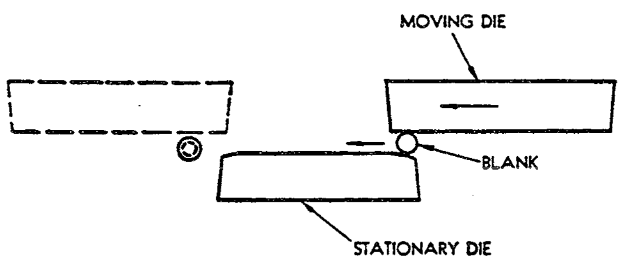


FIG. 13
Reciprocating Thread Rolling Machines
Using Flat Knurling Dies

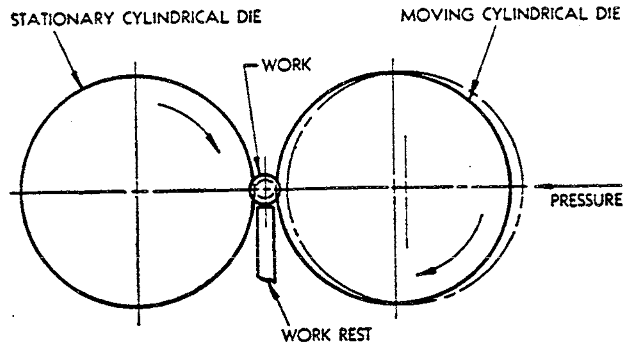


FIG. 14
Cylindrical Die Machine — 2 Die Type

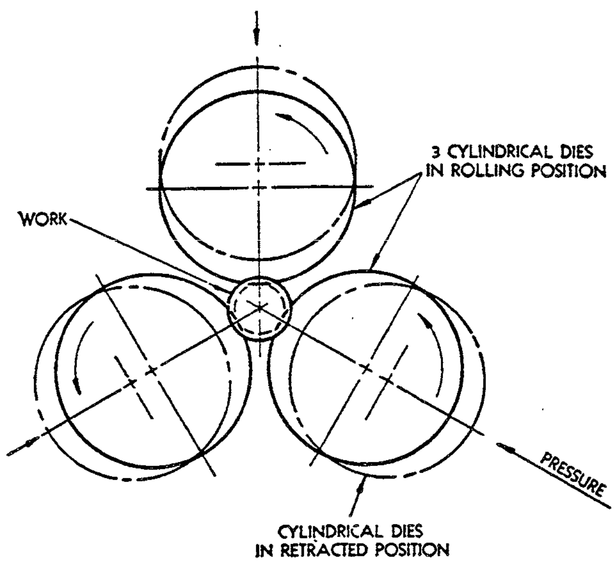


FIG. 15
Cylindrical Die Machine — 3-Die Type

With Cylindrical Die Machines

Cylindrical knurls are used on cylindrical die thread rolling machines. These machines use two or three knurls which are mounted on parallel axes and rotate in the same direction.

On the two-die type machines, the two knurls are opposed and the blank being knurled is supported on a work rest between the knurls. The center of the blank raises from the work rest as the diameter of the blank increases during the rolling of the knurled surface. On the three-die type machines, the three knurls are equally spaced around the blank which floats between them, as shown in Fig. 15.

Since knurls are circular in shape, the number of revolutions provided for knurling and the rate at which the knurls are fed into the work can be controlled by the set-up. Cylindrical die machines may be used for both in-feed and end-feed knurling.

REED-RICO® Standard Knurls

Stocked only in High Speed Steel without bevels. Bevels will be furnished without extra cost when specified.

C Series	B Series	S Series	A Series	F Series
				
DIA. 1/2" WIDTH 3/16" HOLE 3/16"	DIA. 5/8" WIDTH 1/4" HOLE 1/4"	DIA. 3/4" WIDTH 1/4" HOLE 1/4"	DIA. 3/4" WIDTH 3/8" HOLE 1/4"	DIA. 7/8" WIDTH 3/8" HOLE 1/4"
Will Fit Following Holders: Brown & Sharpe No. 185-200 (00D) 190-100 (00AA) 195-100 (00BA) 200-100 (00CA) 210-100 (00RA) Boyar-Schultz 00K, 00SK Detterbeck 00 Barnaby KT-00 R & L 00 Slitters 50-34	**Will Fit Following Holders:** Brown & Sharpe No. 185-220 (20D) 185-322 (22DA) 190-120 (20AA) 195-120 (20BA) 200-120 (20C) 210-120 (20KA) 211-222 Boyar-Schultz 2C, 0K, 0SK Detterbeck 0 Barnaby KT-0 R & L 1, 2, 3 Slitters 50-35	**Will Fit Following Holders:** Brown & Sharpe No. 185-224 (24A) 190-122 (22AA) 195-122 (22BA) 200-122 (22C) 210-122 (22KB) 211-222 Boyar-Schultz 2K, 2SK Detterbeck 2 Slitters 50-36	**Will Fit Following Holders:** Brown & Sharpe No. 185-224 (24A) 190-122 (22AA) 195-122 (22BA) 200-122 (22C) 210-122 (22KB) Armstrong No. 1K, 2K, 3K-1, 3K-2, 673, 674 All Pratt & Whitney J. H. Williams No. 1K, 2K, 3K1, 3K2 Graham No. 2, 3 Barnaby KT-2G Slitters 50-1, 50-2, 50-3, 50-36	**Will Fit Following Holde--:** Brown & Sharpe 26 Slitters 50- 50-3, 50-

SA Series	Swiss
DIA. 3/4" WIDTH 1/2" HOLE 1/4"	DIA. 5/16" WIDTH 5/32" HOLE 1/8"

STRAIGHT TOOTH KNURLS

On all listings, ANGLE indicated is INCLUDED angle of teeth.

C Series	B Series	S Series	A Series	F Series	SA Series	Swiss
	BS 12 — 12 T.P.I. 23 Teeth 90°		AS 12 — 12 T.P.I. 28 Teeth 90°			
	BS 16 — 16 T.P.I. 31 Teeth 90°	SS 16 — 16 T.P.I. 38 Teeth 90°	AS 16 — 16 T.P.I. 38 Teeth 90°			
	BS 19 — 19 T.P.I. 37 Teeth 90°	SS 19 — 19 T.P.I. 45 Teeth 90°				
CS 20 — 20 T.P.I. 31 Teeth 90°	BS 20 — 20 T.P.I. 39 Teeth 90°	SS 20 — 20 T.P.I. 47 Teeth 90°	AS 20 — 20 T.P.I. 47 Teeth 90°	FS 20 — 20 T.P.I. 55 Teeth 90°	SAS 20 — 20 T.P.I. 47 Teeth 90°	
	BS 24 — 24 T.P.I. 47 Teeth 90°	SS 24 — 24 T.P.I. 57 Teeth 90°				
CS 25 — 25 T.P.I. 38 Teeth 90°	BS 25 — 25 T.P.I. 49 Teeth 90°	SS 25 — 25 T.P.I. 59 Teeth 90°	AS 25 — 25 T.P.I. 59 Teeth 90°	FS 25 — 25 T.P.I. 69 Teeth 90°		
	BS 29 — 29 T.P.I. 56 Teeth 90°	SS 29 — 29 T.P.I. 68 Teeth 90°				
CS 30 — 30 T.P.I. 47 Teeth 90°	BS 30 — 30 T.P.I. 59 Teeth 90°	SS 30 — 30 T.P.I. 71 Teeth 90°	AS 30 — 30 T.P.I. 71 Teeth 90°	FS 30 — 30 T.P.I. 82 Teeth 90°	SAS 30 — 30 T.P.I. 71 Teeth 90°	
CS 35 — 35 T.P.I. 55 Teeth 90°	BS 35 — 35 T.P.I. 68 Teeth 90° or 70°	SS 35 — 35 T.P.I. 82 Teeth 90°	AS 35 — 35 T.P.I. 82 Teeth 90°			
CS 40 — 40 T.P.I. 63 Teeth 90°	BS 40 — 40 T.P.I. 78 Teeth 90°	SS 40 — 40 T.P.I. 94 Teeth 90°	AS 40 — 40 T.P.I. 94 Teeth 90°			SWS 40 — 40 T.P.I. 39 Teeth 90°
CS 41 — 41 T.P.I. 65 Teeth 90°	BS 41 — 41 T.P.I. 81 Teeth 90°					
CS 47 — 47 T.P.I. 73 Teeth 90°	BS 47 — 47 T.P.I. 92 Teeth 90°					
CS 50 — 50 T.P.I. 79 Teeth 70°	BS 50 — 50 T.P.I. 98 Teeth 70°	SS 50 — 50 T.P.I. 117 Teeth 70°	AS 50 — 50 T.P.I. 117 Teeth 70°			SWS 50 — 50 T.P.I. 49 Teeth 70°
CS 53 — 53 T.P.I. 84 Teeth 70°						
CS 60 — 60 T.P.I. 94 Teeth 70°						SWS 60 — 60 T.P.I. 59 Teeth 70°
CS 70 — 70 T.P.I. 109 Teeth 70°						SWS 70 — 70 T.P.I. 69 Teeth 70°
CS 80 — 80 T.P.I. 125 Teeth 70°	BS 80 — 80 T.P.I. 155 Teeth 70°	SS 80 — 80 T.P.I. 189 Teeth 70°	AS 80 — 80 T.P.I. 189 Teeth 70°			SWS 80 — 80 T.P.I. 79 Teeth 70°

C Series	B Series	S Series	A Series
DIA. 1/2"	DIA. 5/8"	DIA. 3/4"	DIA. 3/4"
WIDTH 3/16"	WIDTH 1/4"	WIDTH 1/4"	WIDTH 3/8"
HOLE 3/16"	HOLE 1/4"	HOLE 1/4"	HOLE 1/4"

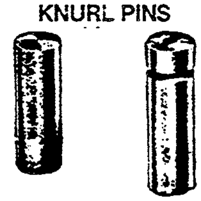
DIAGONAL TOOTH KNURLS — 30° SPIRAL

			AD 12R 12 T.P.I. 25 Teeth 90°
	BD 16R 16 T.P.I. 27 Teeth 90°		AD 16R 16 T.P.I. 33 Teeth 90°
CD 20R 20 T.P.I. 27 Teeth 90°	BD 20R 20 T.P.I. 34 Teeth 90°	SD 20R 20 T.P.I. 41 Teeth 90°	AD 20R 20 T.P.I. 41 Teeth 90°
CD 25R 25 T.P.I. 34 Teeth 90°	BD 25R 25 T.P.I. 42 Teeth 90°	SD 25R 25 T.P.I. 51 Teeth 90°	AD 25R 25 T.P.I. 51 Teeth 90°
CD 30R 30 T.P.I. 40 Teeth 90°	BD 30R 30 T.P.I. 52 Teeth 90°	SD 30R 30 T.P.I. 61 Teeth 90°	AD 30R 30 T.P.I. 61 Teeth 90°
	BD 35R 35 T.P.I. 59 Teeth 90°		AD 35R 35 T.P.I. 71 Teeth 90°
CD 40R 40 T.P.I. 55 Teeth 90°	BD 40R 40 T.P.I. 68 Teeth 90°	SD 40R 40 T.P.I. 81 Teeth 90°	AD 40R 40 T.P.I. 81 Teeth 90°
CD 50R 50 T.P.I. 68 Teeth 70°	BD 50R 50 T.P.I. 86 Teeth 70°	SD 50R 50 T.P.I. 102 Teeth 70°	AD 50R 50 T.P.I. 102 Teeth 70°
			AD 12L 12 T.P.I. 25 Teeth 90°
	BD 16L 16 T.P.I. 27 Teeth 90°		AD 16L 16 T.P.I. 33 Teeth 90°
CD 20L 20 T.P.I. 27 Teeth 90°	BD 20L 20 T.P.I. 34 Teeth 90°	SD 20L 20 T.P.I. 41 Teeth 90°	AD 20L 20 T.P.I. 41 Teeth 90°
CD 25L 25 T.P.I. 34 Teeth 90°	BD 25L 25 T.P.I. 42 Teeth 90°	SD 25L 25 T.P.I. 51 Teeth 90°	AD 25L 25 T.P.I. 51 Teeth 90°
CD 30L 30 T.P.I. 40 Teeth 90°	BD 30L 30 T.P.I. 52 Teeth 90°	SD 30L 30 T.P.I. 61 Teeth 90°	AD 30L 30 T.P.I. 61 Teeth 90°
	BD 35L 35 T.P.I. 59 Teeth 90°		AD 35L 35 T.P.I. 71 Teeth 90°
CD 40L 40 T.P.I. 55 Teeth 90°	BD 40L 40 T.P.I. 68 Teeth 90°	SD 40L 40 T.P.I. 81 Teeth 90°	AD 40L 40 T.P.I. 81 Teeth 90°
CD 50L 50 T.P.I. 68 Teeth 70°	BD 50L 50 T.P.I. 86 Teeth 70°	SD 50L 50 T.P.I. 102 Teeth 70°	AD 50L 50 T.P.I. 102 Teeth 70°

DIAMOND KNURLS — 30° SPIRAL

	BF 20 20 T.P.I. 34 Teeth 90° Female	SF 20 20 T.P.I. 41 Teeth 90° Female	AF 20 20 T.P.I. 41 Teeth 90° Female
	BF 25 25 T.P.I. 42 Teeth 90° Female	SF 25 25 T.P.I. 51 Teeth 90° Female	AF 25 25 T.P.I. 51 Teeth 90° Female
FEMALE knurls have DEPRESSED points and produce a male impression. Diamond MALE knurls have RAISED points and produce a female impression. PITCH IS MEASURED PERPENDICULARLY to the TEETH.	BF 30 30 T.P.I. 52 Teeth 90° Female	SF 30 30 T.P.I. 61 Teeth 90° Female	AF 30 30 T.P.I. 61 Teeth 90° Female
	BF 50 50 T.P.I. 86 Teeth 70° Female	SF 50 50 T.P.I. 102 Teeth 70° Female	AF 50 50 T.P.I. 102 Teeth 70° Female
	BM 20 20 T.P.I. 34 Teeth 90° Male	SM 20 20 T.P.I. 41 Teeth 90° Male	AM 20 20 T.P.I. 41 Teeth 90° Male
	BM 25 25 T.P.I. 42 Teeth 90° Male	SM 25 25 T.P.I. 51 Teeth 90° Male	AM 25 25 T.P.I. 51 Teeth 90° Male
	BM 30 30 T.P.I. 52 Teeth 90° Male	SM 30 30 T.P.I. 61 Teeth 90° Male	AM 30 30 T.P.I. 61 Teeth 90° Male
	BM 50 50 T.P.I. 86 Teeth 70° Male	SM 50 50 T.P.I. 102 Teeth 70° Male	AM 50 50 T.P.I. 102 Teeth 70° Male

KNURL PINS



STOCK SIZES

CARBIDE PINS
11/16" × 1/4"
1" × 1/4"

PLAIN PINS
11/16" × 3/16"
11/16" × 1/4"
1" × 1/4"

SHOULDER PINS
13/16" × 3/16"
13/16" × 1/4"

REEED-RICO® Standard Knurls

C Series	B Series	S Series	A Series	F Series
DIA. 1/2" WIDTH 3/16" HOLE 3/16"	DIA. 5/8" WIDTH 1/4" HOLE 1/4"	DIA. 3/4" WIDTH 1/4" HOLE 1/4"	DIA. 3/4" WIDTH 3/8" HOLE 1/4"	DIA. 7/8" WIDTH 3/8" HOLE 1/4"
DIAMETRAL PITCH KNURLS — STRAIGHT				
CS-64 DP	BS-64 DP	SS-64 DP	AS-64 DP	FS-64 DP
CS-96 DP	BS-96 DP	SS-96 DP	AS-96 DP	FS-96 DP
CS-128 DP	BS-128 DP	SS-128 DP	AS-128 DP	
CS-160 DP	BS-160 DP	SS-160 DP	AS-160 DP	
DIAMETRAL PITCH KNURLS — DIAGONAL 30° SPIRAL				
	BDR-64 DP	SDR-64 DP	ADR-64 DP	
CDR-96 DP	BDR-96 DP	SDR-96 DP	ADR-96 DP	
CDR-128 DP	BDR-128 DP	SDR-128 DP	ADR-128 DP	
CDR-160 DP	BDR-160 DP	SDR-160 DP	ADR-160 DP	
	BDL-64 DP	SDL-64 DP	ADL-64 DP	
CDL-96 DP	BDL-96 DP	SDL-96 DP	ADL-96 DP	
CDL-128 DP	BDL-128 DP	SDL-128 DP	ADL-128 DP	
CDL-160 DP	BDL-160 DP	SDL-160 DP	ADL-160 DP	

Comparison of REED-RICO Circular and Diametral Pitch Straight Knurling

Circular Pitch System			Diametral Pitch System			
Samples of Knurling	Common TPI	Circular Pitch	Samples of Knurling	Diametral Pitch	TPI	Circular Pitch
	12	.0833				
	16	.0625				
	20	.0500		64	20.4	.0491
	25	.0400				
	30	.0333		96	30.6	.0327
	35	.0286				
	40	.0250		128	40.7	.0245
	50	.0200		160	50.9	.0196
	80	.0125				

Notes