**CNC Modular**
Shank for Standard Series Modular Knurling Heads

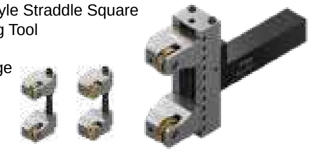
Page H-28

**CNC Modular**
Shank for SMALL Series Modular Knurling Heads

Page H-32

**SWFKT**
Single Wheel Fixed Knurling Tool
**HDSWFKT**
Heavy Duty Single Wheel Fixed Knurling Tool

Page H-40

**KTM109**
Heavy Duty Style Straddle Square Shank Knurling Tool
1.5" & 2.5"
Diameter Range

Page H-48
(See page for Interchangeable Arms)

**CNC-1-2**
1 - Light Duty 60º Diamond Cutting Knurling Head

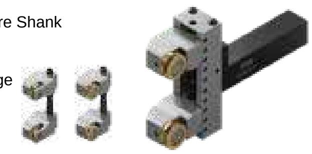
Page H-28

**SCNC-1-2**
1-SMALL Light Duty 60º Diamond Cutting Knurling Head

Page H-33

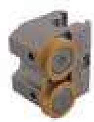
**SSWFKT**
Single Shoulder Wheel Fixed Knurling Tool

Page H-42

**KTW109**
Shoulder Style Straddle Square Shank Knurling Tool
1.5" & 2.5"
Diameter Range

Page H-49
(See page for Interchangeable Arms)

**CNC-2-R**
2 - Heavy Duty 60º Diamond Cutting Knurling Head

Page H-28

**SCNC-6-2**
6- SMALL Shoulder Forming Knurling Head

Page H-33

**FKT**
Fixed Knurling Tool

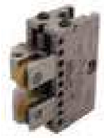
Page H-41

**KTO109**
Heavy Duty Style Straddle Square Shank Knurling Tool
4.0"Diameter

Page H-50
(See page for Interchangeable Arms)

**CNC-3-M**
3 - Extra Heavy Duty 60º Diamond Cutting Knurling Head

Page H-28

**SCNC-7-D**
7- SMALL Straddle Forming Knurling Head

Page H-33

**SFKT**
Shoulder Fixed Knurling Tool

Page H-43

**KTW109-40**
Shoulder Style Straddle Square Shank Knurling Tool
4.0"
Diameter Range

Page H-51
(See page for Interchangeable Arms)

**CNC-4-M**
4- Double Wheel Forming Knurling Head

Page H-29

**SCNC-8-2**
7- SMALL Straddle Forming Knurling Head

Page H-33

**SCKN**
Self Centering Knurling Tool
**HDSCKN**
Heavy Duty Self Centering Knurling Tool

Page H-38

**CNC109-M**
Side Mount Flange Square Shank Knurling Tool
1.5 & 2.5
Diameter Range

Page H-52
(See page for Interchangeable Arms)

**CNC-5-O**
5- Single Wheel Forming Knurling Head

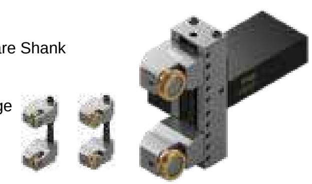
Page H-29

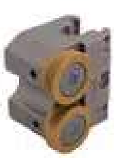
**107ST**
Straight Cutting Knurling Tool

Page H-34

**SSCK**
Shoulder Self Centering Knurling Tool

Page H-39

**CNC109-4**
Side Mount Shoulder Square Shank Knurling Tool
1.5 & 2.5
Diameter Range

Page H-53
(See page for Interchangeable Arms)

**CNC-6-4**
6- Shoulder Forming Knurling Head

Page H-29

**107ST**
Straight Cutting Shoulder Knurling Tool

Page H-35

**TIKT**
True Internal Knurling Tool

Page H-44

**3WKT**
Three Wheel Knurling Tool

Page H-57

**CNC-7-R**
7- Straddle Forming Knurling Head

Page H-29

**3SHKT**
Three Swivel Head Forming Knurling Tool

Page H-37

**SIKT**
Shoulder Internal Knurling Tool

Page H-45

**Knurling Wheels**

Page H-60

**CNC-8-2**
7- Straddle Forming Knurling Head

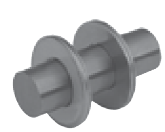
Page H-29

**FACEKT**
Single Wheel Face Forming Knurling Tool

Page H-36

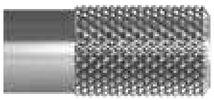
**MMKT**
Milling Machine Knurling Tool

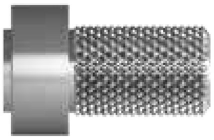
Page H-46

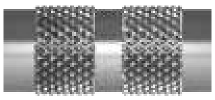
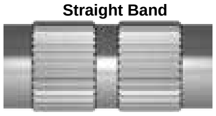
**Spare Parts**

Page H-71

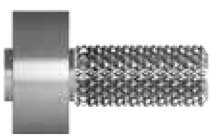
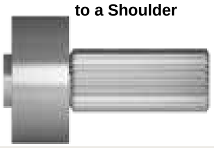
If your knurling application is not in the chart, please supply prints and information.

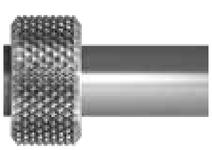
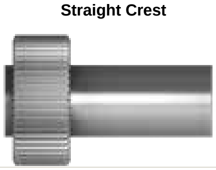
## Knurling Application — Knurling Tool Recommendation

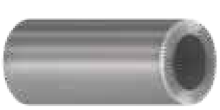
| Diamond Shoulderless | BEST | BETTER | GOOD |
|---|---|---|---|
|  | SCNC-_-1-2<br>CNC-_-1-2<br>CNC-_-2-R<br>CNC-_-3-M<br>3WKT-_-_ | SCNC-_-7-D<br>CNC-_-7-R<br>KTM109-_-M<br>KTO109-_-O<br>3SHKT-_- | SCKN-_-DW-_<br>3SHKT-_-<br>CNC-_-4-M |

| Diamond to a Shoulder | BEST | BETTER | GOOD |
|---|---|---|---|
|  | SCNC-_-6-2<br>CNC-_-6-4<br>3WKT-_-_ | KT109-_-4 | SCCK-_-DW-_<br>KTM-109-_-M |

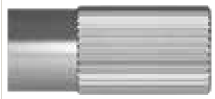
| Diamond Band / Straight Band | BEST | BETTER | GOOD |
|---|---|---|---|
| Diamond Band  Straight Band  | SCNC-_-7-D-<br>CNC-_-7-R<br>KTM109-_-M<br>KTO109-_-O<br>CNC-_-4-M<br>CNC-_-5-O | SCKN-_-DW-_<br>3SHKT-_- | SFKT-_-_<br>SWKT-_-_ |

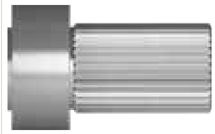
| Small Diameter Diamond to a Shoulder / Small Diameter Straight to a Shoulder | BEST | BETTER | GOOD |
|---|---|---|---|
| Small Diameter Diamond to a Shoulder  Small Diameter Straight to a Shoulder  | 3WKT-_-_ | | |

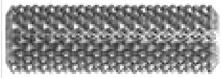
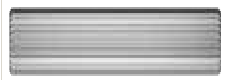
| Diamond Crest / Straight Crest | BEST | BETTER | GOOD |
|---|---|---|---|
| Diamond Crest  Straight Crest  | SCNC-_-7-D<br>CNC-_-7-R<br>KTM109-_-M<br>CNC-_-4-M<br>CNC-_-5-O | SCKN-_DW-_<br>3SHKT-_- | SFKT-_-_<br>SWKT-_-_ |

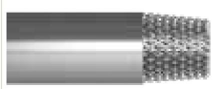
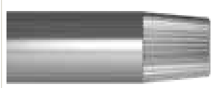
| Radio Face | BEST | BETTER | GOOD |
|---|---|---|---|
|  | Special | | |

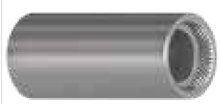
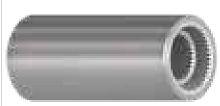
## Knurling Application — Knurling Tool Recommendation

| Straight Shoulderless | BEST | BETTER | GOOD |
|---|---|---|---|
|  | SCNC-_7-D<br>CNC-_7-R<br>KTM109-_-M<br>KTO109-_-O<br>3WKT-_-_ | 107ST-_<br>107ST-_<br>CNC-_4-M<br>SCKN-_-DW-_ | CMC-_5-O<br>SWKT-_-_ |

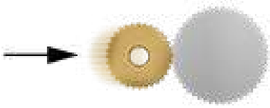
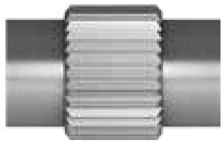
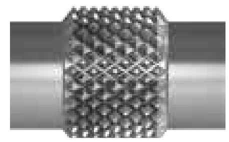
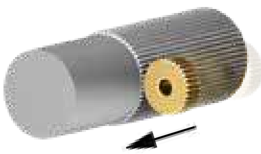
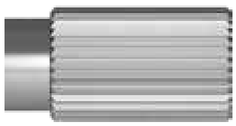
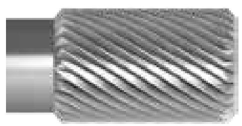
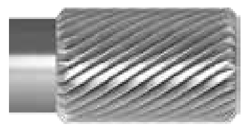
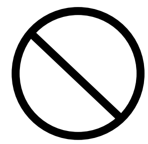
| Straight to a Shoulder | BEST | BETTER | GOOD |
|---|---|---|---|
|  | KTW109-_-4<br>3WKT-_-_ | SCNC-_-6-2<br>CNC-_-6-4 | FKT-_-_ |

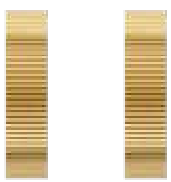
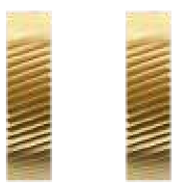
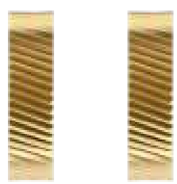
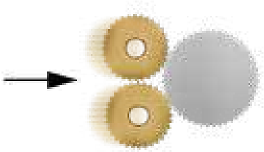
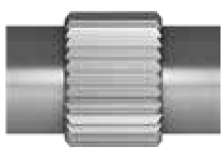
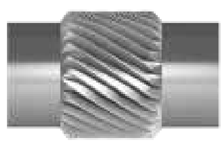
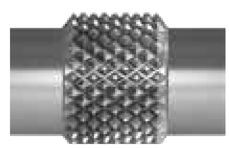
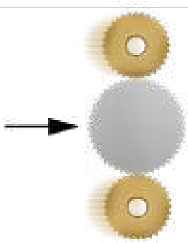
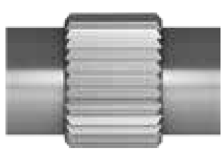
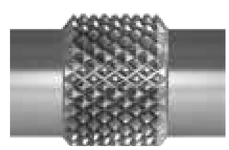
| Small Diameter Diamond Shoulderless / Small Diameter Straight Shoulderless | BEST | BETTER | GOOD |
|---|---|---|---|
| Small Diameter Diamond Shoulderless  Small Diameter Straight Shoulderless  | 3WKT-_-_ | SCNC-_-7-D<br>CNC-_-7-R | SFKT-_-_<br>SWFKT-_-_ |

| Taper Diamond / Taper Straight | BEST | BETTER | GOOD |
|---|---|---|---|
| Taper Diamond  Taper Straight  | Special | | |

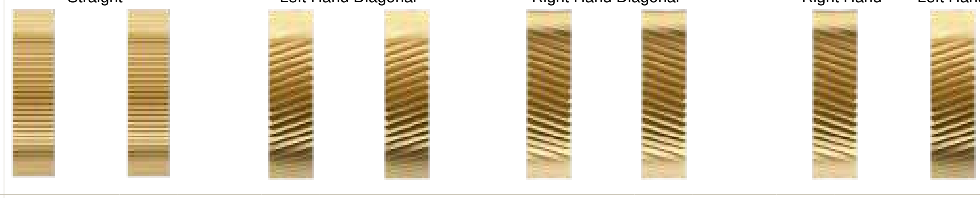
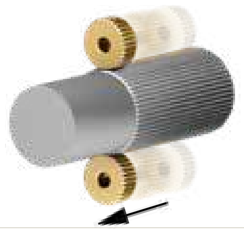
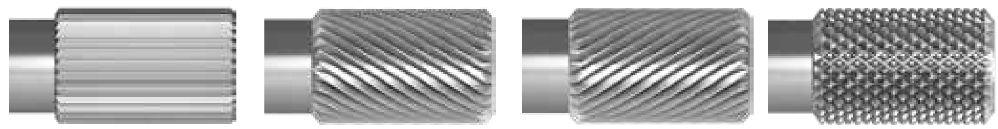
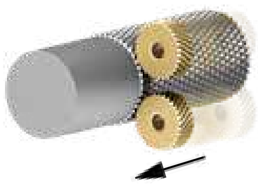
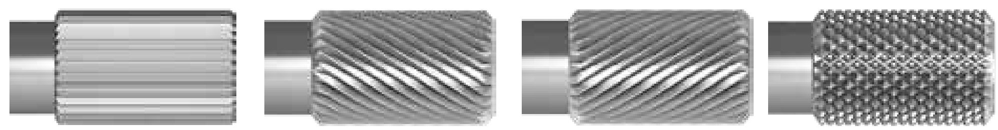
| Internal Diamond / Internal Straight | BEST | BETTER | GOOD |
|---|---|---|---|
| Internal Diamond  Internal Straight  | TIKT-_-<br>SIKT-_- | | |

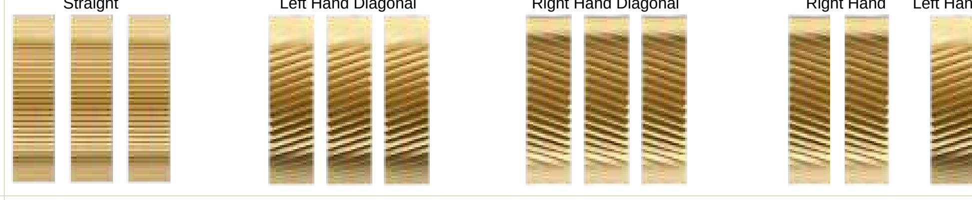
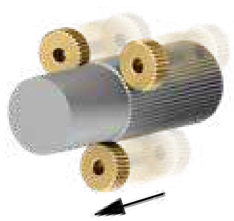
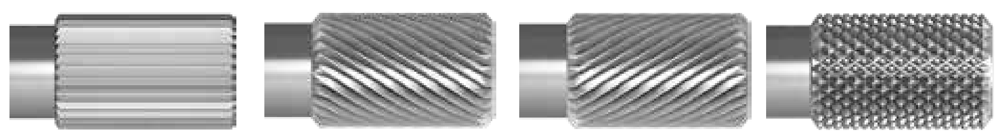
| Milling Diamond / Milling Straight | BEST | BETTER | GOOD |
|---|---|---|---|
| Milling Diamond  Milling Straight  | MMKT-_-_ | | |

| Knurling Application | Knurl Wheel Used | | | |
|---|---|---|---|---|
| **One Wheel**<br>**In-feed** (Plunge)<br>**End-feed** | Straight<br> | Left Hand Diagonal<br> | Right Hand Diagonal<br> | Female Diamond<br> |
| In-feed (Plunge) with (1) wheel fixed knurling tool holder<br> | Straight Pattern<br> | Right Hand Diagonal Pattern<br> | Left Hand Diagonal Pattern<br> | Male Diamond Pattern (Raised Points)<br> |
| End-feed with (1) wheel fixed knurling tool holder<br> | Straight Pattern<br> | Right Hand Diagonal Pattern<br> | Left Hand Diagonal Pattern<br> |  |

| Knurling Application | Knurl Wheel Used | | | |
|---|---|---|---|---|
| **Two Wheels**<br>**In-feed** (Plunge) | Straight<br> | Left Hand Diagonal<br> | Right Hand Diagonal<br> | Male Diamond<br>Right Hand  Left Hand  |
| In-feed (Plunge) with (2) wheels fixed knurling tool holder<br> | Straight Pattern<br> | Right Hand Diagonal Pattern<br> | Left Hand Diagonal Pattern<br> | Male Diamond Pattern (Raised Points)<br> |
| In-feed (Plunge) with Adjustable Straddle Style knurling tool holder<br> | Straight Pattern<br> | Right Hand Diagonal Pattern<br> | Left Hand Diagonal Pattern<br> | Male Diamond Pattern (Raised Points)<br> |

NOTE:
**In-feed** (Plunge)**:** When the knurl wheel is pushed against to the part into radial direction
**End-feed:** When the Knurl wheel moves longitudinal to the axis of the work piece

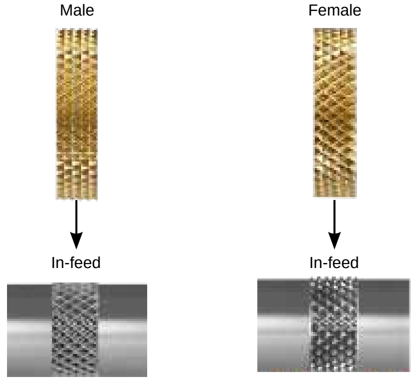
| Knurling Application | Knurl Wheel Used |
|---|---|
| **Two Wheels End-feed** |  |
| End-feed (2) wheels with adjustable straddle knurling tool holder  |  |
| End-feed (2) wheels with adjustable fixed knurling tool holder  |  |

| | |
|---|---|
| **Three Wheels End-feed** |  |
| End-feed (3) wheels with Adjustable Knurl holder cross slide  |  |

In-Feed

Male and Female Diamond knurl wheel pattern
Can be used only In-Feed

Max. knurl Diamond pattern on the workpiece is equal to the width of the knurl wheel




| Tool Depth with Standard Circular Pitch Knurl | | Circular Pitch | |
|---|---|---|---|
| | | inches | metric |
| Type of Knurl | Percentage of Depth of Knurl | 1" TPI | Pitch size (mm) |
| Straight Tooth | 35% of Circular Pitch (P) | | |
| Diagonal | 35% of Normal Circular Pitch (Pn) | | |
| Diamond | 40% of Normal Circular Pitch (Pn) | | |
| Diamond Female | 25% of Normal Circular Pitch (Pn) | | |

*Table 6* See page H-16

## For Best Knurling Performance

**Before beginning Knurling process check:**

- Diameter before knurl
- Diameter after knurl
- Knurl pitch
- Workpiece to be concentric
- Set wheels on center line of workpiece
- Use beveled edge wheels when form knurling
- Use full faced wheels when cut knurling
- Always use coolant when knurling
- The standard knurling depth is 35% of knurl circular pitch.

Inch Example: Knurling Depth of 20 TPI Knurl
Circular Pitch of 20TPI is: 1.000/20=.050"
Knurling Depth is: .050" x .035% =.0175" per side

Metric Example: Knurling Depth of 2mm Knurl
Knurling Depth is: 2mm x .035% =.7mm per side

- If the knurl double tracks, the knurl wheel is not deep enough in to workpiece, increase knurling depth

- If the knurl crest rolls over, the knurl wheel is to deep in to the workpiece, decrease knurling depth

- If the knurl is not tracking, the workpiece diameter is not correct for full number of teeth, diameter must adjusted up or down by using a tracking formula.

**In-Feed Knurling**, when the knurl wheel enter into the workpiece radially.
Once the knurl wheel has reached the depth, will take from **5 to 20** revolutions to complete the knurling operation. The revolution changes for the same size with the workpiece material hardness and knurl pitch.

**End-Feed Knurling**, when the knurl wheel enter into the workpiece axially.
The depth of the knurl wheel must be set before the wheel get in contact with the workpiece, the depth and pressure changes for the same size with the workpiece material hardness and knurl pitch.

## Forming Knurling Versus Cutting Knurl

- In Forming Knurl, the knurl wheel's axis is set parallel to the workpiece axis, and forced against workpiece displacing the material to form the knurl pattern

- A large amount of pressure is required to displace the material that forms the knurl pattern, and pressure increases with workpiece diameter, pitch size and hardness

- In a large workpiece diameter, large knurl pitch, and hard material, a multi knurling pass may be required to achieve the correct knurl pattern

- For best performance and quality in Forming Knurl, when possible, a Straddle Knurling Tool is to be used, the pressure is divided within the knurl wheels over the workpiece, and pressure against the spindle of the machine is totally neutralized.

- Use beveled edge wheel when knurl forming to protect the edge from chipping and for smooth knurling surface.

- Use full face Knurled wheel when knurl cutting, the knurl wheels axis are set on negative angle, the sharp edge will cut the knurl pattern into the workpiece

- In cutting knurl, less pressure is required for the operation, higher speed and feed can be used, (use the same cutting date of High Speed or Cobalt turning tools)

- Use full faced knurl wheel when knurl cutting.

| Use Forming Knurl Tool for: | Use Cutting Knurl Tool for: |
|---|---|
| - Small to medium workpiece diameter | - Medium to large workpiece diameter |
| - To the shoulder knurling | - To shoulderless diameter knurling |
| - To centerless workpiece | - To hard workpiece materials |
| - To band knurling application | - To long knurling application with live center |
| - When high surface finish required | - For higher productivity |

Knurling is ordinarily performed at the same speeds used as cutting operations. Use the same SFM used for high speed and cobalt tool bits to calculate speeds and feeds. 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.

### Knurling Pitch Tracking Formula (See page H-12 for formula)

| Step | Calculation | Inch |
|---|---|---|
| 1 | TPI | 10 |
| 2 | Diameter of the part after knurl | 2.130" |
| 3 | Growth after Knurl based on pitch | .038" |
| 4 | Diameter of the blank before knurl | 2.092" |
| 5 | Knurl wheel diameter and pattern (Straight) | .750" |
| 6 | Knurl wheel series | R |
| 7 | Knurl wheel tracking value | 0.033" |
| 8 | Number of teeth on the workpiece | 63.393 |
| | **Correction** | |
| 9 | Select the full number of teeth on the work piece | 64 |
| 10 | Knurl wheel tracking value | 0.033" |
| 11 | New starting diameter = number of teeth x tracking value | 2.112" |

### Knurling Pitch Tracking Formula

| Step | Calculation | Metric |
|---|---|---|
| 1 | Circular pitch | 2.5 mm |
| 2 | Diameter of the part after knurl | 50.00 mm |
| 3 | Growth after knurl based on pitch | .97 mm |
| 4 | Diameter of the blank before knurl | 49.03 mm |
| 5 | Knurl wheel diameter and pattern (Straight) | 19.00 mm |
| 6 | Knurl wheel series | R |
| 7 | Knurl wheel tracking value (.033 X 25.4) | 0,84 mm |
| 8 | Number of teeth on the workpiece | 58.49 |
| | **Correction** | |
| 9 | Select the full number of teeth on the work piece | 58 |
| 10 | Knurl wheel tracking value | 0.8382mm |
| 11 | New starting diameter = number of teeth x tracking value | 48.615mm |

## Applications of knurling

Knurling has a wide variety of applications in day-to-day use. It is most commonly used for decorative purposes and for serrating surfaces where components 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. A knurled tooth is "V" shaped.

Knurling tools are used for producing STRAIGHT, DIAGONAL or MALE and DIAMOND patterns, having teeth of uniform pitch on cylindrical sur-FEMALE, TAPER, ROUND and FLAT surface.

## Knurling and Pitch Systems

The CIRCULAR PITCH SYSTEM knurling is related to the distance between the teeth on the circumference of the work blank inch or metric In inches it usually expressed in terms of the number of teeth per inch (TPI), although sometimes erroneously referred to as Pitch.

The DIAMETRAL PITCH SYSTEM (inch system only) knurling is designed to permit work blank diameters of standard fractional stock sizes ranging from 3/32" - 1".

## In-Feed Knurling (Plunge) (CNC -"X")

Straight or diamond knurling can be produced by using either one or two knurls mounted in a holder in the front or rear of the cross slide which applies direct pressure to the work.

Diamond knurls require greater pressure than straight or diagonal knurls, sometimes placing prohibitive loads on both machine and work, causing damage to the machine.

For a better knurling, Adjustable Floating Straddle Type Holders with two knurls are used. The two opposed knurls form the knurling as they are fed onto the blank. Side pressure on the work and the machine spindle is reduced with the straddle type holders, as most of the pressure required for knurling is absorbed in the holder.

## End-Feed Knurling (To Chuck) (CNC -"Z")

Straight, diagonal, or diamond knurling may be produced with end-feed type knurling holders mounted on the compound or turret.

Knurls used for end-feed knurling should have beveled edges. Only straight and diagonal knurls can be used with the end-feeding holders.

When producing diagonal and diamond knurling, the straight knurls are swiveled in the holder to obtain 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.

End-feeding knurling method permits easier starting of the knurls with uniform raise up of material, resulting in high quality knurling.

## Speed and Feeds

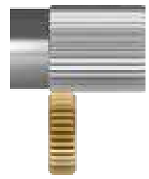
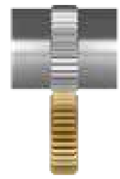
For in-feed knurling, the knurl should be fed toward the work gradually until contact is made with the blank. This can be completed within 5 to 25 work revolutions of the working piece.

For end-feed knurling, the feeds used with the turret vary considerably and are dependent on the pitch of the knurl, the material, the diameter of the work blank, and the hardness being knurled.

## Two Ways to Achieve Knurling

### (1) Forming

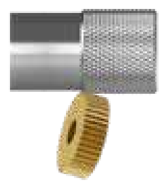
Knurl forming is achieved by pushing the knurl wheels against the blank while rotating. This will cause the material to be displaced in cold form, reproducing the same wheel pattern on the blank circumference.
The blank is increased accordingly to the Knurl Pitch. The force applied through forming is increased in larger diameters making knurling difficult and slow.


Use beveled edge wheel when knurl forming to protect the edge from chipping and for smooth knurl surface.

### (2) Cutting

Knurl cutting is achieved by using knurl wheels to actually cut instead of forming the blank. The knurl wheels are set at an angle, making the knurling edges of the knurl wheels cut into the blank. Pressure is minimized while speed and feed are increased.




Use full face Knurled wheel when knurl cutting, the knurl wheels axis are set on negative angle, the sharp edge will cut the knurl pattern into the workpiece

## For Best Knurling Results

1. Diameter of part being knurled should be turned to size and concentric to achieve a good knurling quality.
2. Knurl wheels must be exactly in center line with the work piece for an even knurl pattern.
3. Knurl wheels are to run freely and the knurl pin must be secured on the tool holder (the use of a carbide pin is recommended).
4. Use heavy flow of coolant to keep the knurl wheels cool and clean.
5. There are formulas to calculate depth of cut, tracking pitch and cutting parameter. Because of different material hardness, before starting production follow the instructions and with trial error the best result will be achieved.

## When Ordering a Knurling Tool, Specify:

1. Knurl pattern
2. Pitch style
3. Type of knurl
4. Diameter range
5. Type of material
6. Qty. of parts being knurled
7. Tool center height
8. Tool shank size
9. Right hand or Left hand

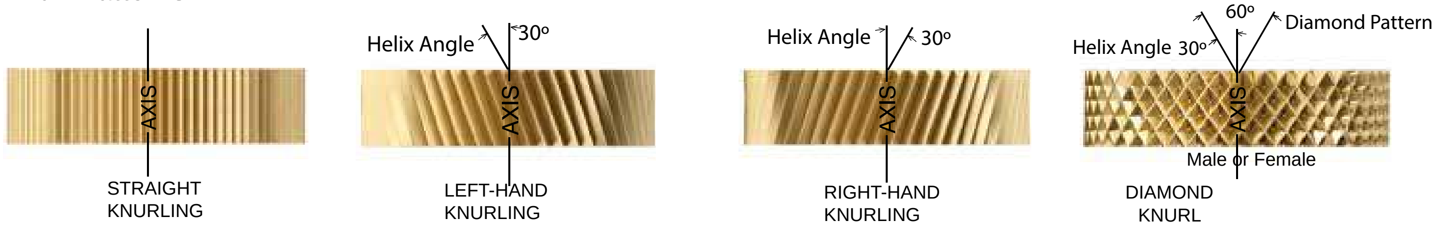
Knurling Tools Available:

1. Metric System
2. Inches System

Example: FKT20 = Metric System = 20 mm Shank

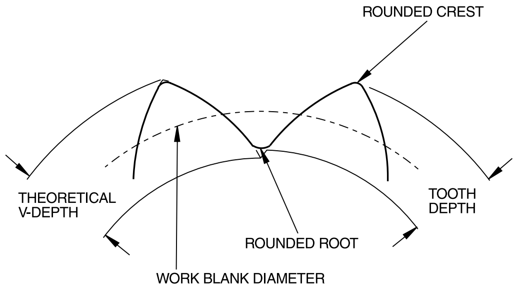
FKT75 = Inches System = 3/4 in Shank

## Knurl Patterns

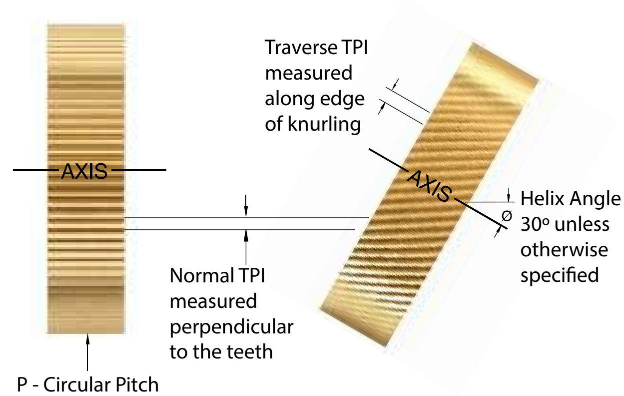



## Tooth Form

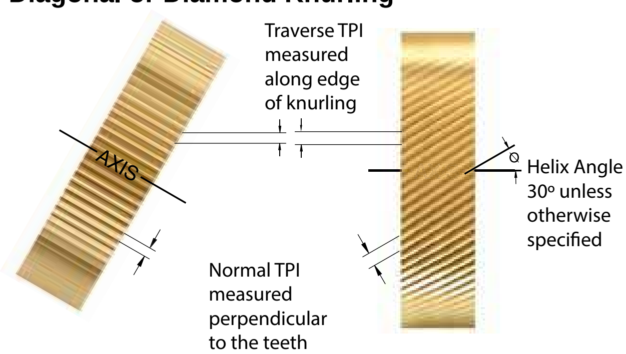
A knurled tooth is V-shaped and the depth of the tooth is less than the depth of a theoretical V-form. The tooth has a rounded root and crest. The relationship between the actual depth of tooth to the theoretical V varies with the pitch of the teeth. On finer pitches, the tooth is a smaller proportion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




## Straight Knurling

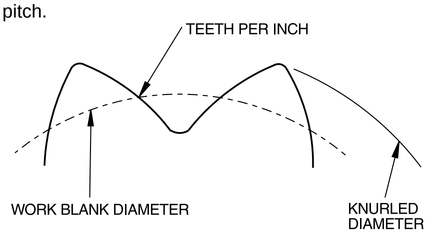



## Diagonal or Diamond Knurling



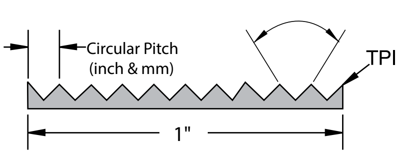

## The Circular Pitch System

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




## Number of Teeth per Inch - TPI

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 the outside diameter of the knurling for reference purposes. TPI is used and is measured perpendicular to the teeth or helix angle.




See page H-58

- **TPI system** is the number of teeth per inch (measured on a linear inch).
- **Circular pitch inch system** is the distance from tooth to tooth, or is derived from 1" divided by the number of teeth per inch.
- **Circular pitch metric system** is the distance from tooth to tooth in mm.
- **Diametral pitch system** is derived by the number of teeth on the work divided by the theoretical work blank diameter.

*Table 1*

**Pitch Relation of a Straight Knurl to 30° Transverse**

| No. of Teeth per Inch TPI | Straight Knurling Circular Pitch Inch | Straight Knurling Circular Pitch mm | Transverse TPI | Transverse Circular Pitch Inch | Transverse Circular Pitch mm |
|---|---|---|---|---|---|
| 8 | 0.125 | 3.2 | 6.93 | 0.144 | 3.7 |
| 10 | 0.100 | 2.5 | 8.66 | 0.115 | 2.9 |
| 12 | 0.083 | 2.1 | 10.40 | 0.096 | 2.4 |
| 14 | 0.071 | 1.8 | 12.13 | 0.082 | 2.1 |
| 16 | 0.063 | 1.6 | 13.86 | 0.072 | 1.8 |
| 18 | 0.056 | 1.4 | 15.59 | 0.064 | 1.6 |
| 20 | 0.050 | 1.3 | 17.33 | 0.058 | 1.5 |
| 25 | 0.040 | 1.0 | 21.66 | 0.046 | 1.2 |
| 30 | 0.033 | 0.8 | 25.99 | 0.038 | 1.0 |
| 35 | 0.029 | 0.7 | 30.32 | 0.033 | 0.8 |
| 40 | 0.025 | 0.6 | 34.65 | 0.029 | 0.7 |
| 50 | 0.020 | 0.5 | 43.31 | 0.023 | 0.6 |
| 80 | 0.013 | 0.3 | 69.30 | 0.014 | 0.4 |

## TPI and Circular Pitch Calculations

The formula for finding the Transverse Teeth Per Inch ($TPI_t$), if the Normal Teeth Per Inch ($TPI_n$) is known, is shown below.
$TPI_t = TPI_n \times \cos 30°$ (.86603)

The formula for finding the Transverse Circular Pitch ($P_t$), if the Circular Pitch (P) is known, is shown below.

$$P_t = \frac{P}{\cos 30°}$$

$\cos 30° = .86603$

## TPI and Circular Pitch Examples

Find the Transverse Pitch if the Normal Pitch is 20 TPI.

$TPI_t = TPI_n \times \cos 30° = 20 \times .86603 = 17.32\ TPI_t$

Find the Transverse Circular Pitch if the Normal Circular Pitch is .0500"

Where .0500" is the Normal Circular Pitch of 20 TPI (1 ÷.500=20)

$P_t = P_n \div \cos 30° = .0500 \div .86603 = .0577$ Circular Transverse Pitch

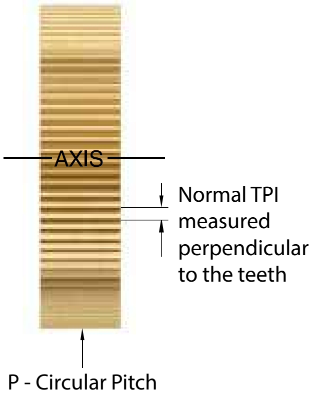
## Straight Knurl - Tooth and Pitch Calculations

$$P = \frac{1.000}{TPI} \qquad N_w = \frac{3.1416 \times D_w}{P}$$

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

**Where:**

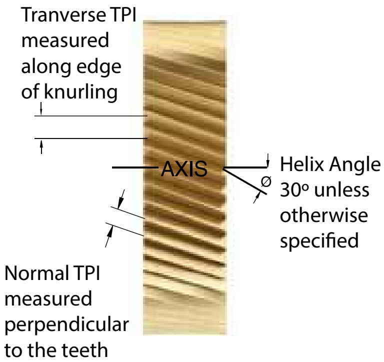
**$D_w$= Theoretical work blank diameter**
**$N_w$= Number of teeth on work**
**P= Circular pitch**
**TPI= Number of teeth per inch measured on circumference of blank diameter**



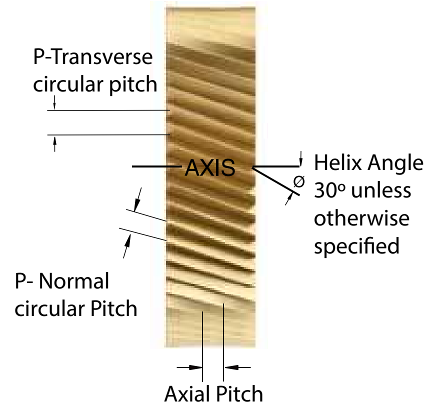

## Diagonal & Diamond Knurl Tooth & Pitch Calculations

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

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




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




$$P = \frac{1.000}{TPI} \qquad P_t = \frac{P_n}{.86603}$$

**Where:**

**$D_w$= Theoretical work blank diameter**
**$N_w$= Number of teeth on work**
**P= Circular pitch**
**$P_n$= Normal circular pitch**
**$P_t$= Transverse circular pitch**
**TPI= Number of teeth per inch measured on circumference of blank diameter**
**$TPI_n$= Normal teeth per inch**
**$TPI_t$= Transverse teeth per inch**
**Ø = Helix angle**

## 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 diameters 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 work, or P x $D_w$

$D_w$=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.

A comparison of diametral pitches, TPI, and circular pitches is in Table 2.

Diagonal and diamond knurling on work blank may be accomplished by setting the axis of straight knurls at an angle to the work axis.

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 2*

**Diametral Pitch-Increase of Blank Diameter**

| Diametral Pitch Measured in TPI and Circular Pitch | | | Approx. Increase in Knurled Diameter | | | | Min. No. of Teeth in Knurled Circumference | Work Blank Diameters | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Diametral Pitch | TPI | Circular Pitch | Straight | | 30° Diagonal | | | Diameter Range | | | | Dia. Increments | |
| | | | Inch | mm | Inch | mm | | Inch | | mm | | Inch | mm |
| 64 | 20.4 | 0.0491 | 0.024 | 0.61 | 0.021 | 0.53 | 24 | 0.375 | 1.0 | 9.53 | 25.40 | 1/64" | 0.41 |
| 96 | 30.6 | 0.0327 | 0.016 | 0.41 | 0.014 | 0.36 | 24 | 0.250 | 1.0 | 6.35 | 25.40 | 1/32" | 0.36 |
| 128 | 40.7 | 0.0245 | 0.012 | 0.30 | 0.010 | 0.25 | 18 | 0.140 | 1.0 | 3.56 | 25.40 | 1/64" | 0.41 |
| 160 | 50.9 | 0.0196 | 0.009 | 0.23 | 0.008 | 0.20 | 15 | 0.094 | 1.0 | 2.39 | 25.40 | 1/32" | 0.79 |

## Equivalent of Diametral Pitch & TPI Pitch

All Diametral Pitch Knurls made to American Standards (ASA B5.30 1958). Diametral Pitch Knurls produce the D.P. number of teeth per inch of diameter. Rolled Circular Pitch Knurls, produce the TPI number of teeth per inch of circumference measured normal to the teeth.

*Table 3*

| Diametral Pitch | Teeth Per Inch (TPI) | |
|---|---|---|
| | Straight | 30º Diagonal |
| 64 | 20.4 | 23.6 |
| 96 | 30.6 | 35.3 |
| 128 | 40.7 | 47.0 |
| 160 | 50.9 | 58.8 |

## Work Blank Diameters

Formulae for theoretical work blank diameters are as follows:

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

Where:

P=Diametral Pitch

$N_w$=Number of teeth on work, or P x $D_w$

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

For end-feed knurling with straight tooth knurls:

$$D_w=\frac{N_w}{P \times \cos\theta}$$

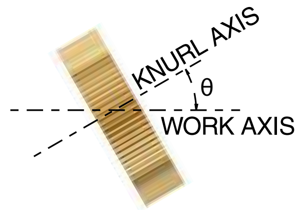
Where:

P=Diametral Pitch

$N_w$=Number of teeth on work, or P x $D_w$

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

θ =Angle between knurl axis and work axis (cos 30°=.86603)




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.

$$N_w = D_w \times P \times \cos\theta$$

Where:

P = Diametral Pitch

$N_w$= Number of teeth on work, or P x $D_w$

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

θ = 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 x 96 x cos30° = 83.14 teeth
(cos30° = 86603)

Increasing the angle between the knurl axis to approximately 30.25° 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:

$$D_w=\frac{N_w}{P \times \cos 30^\circ}=\frac{83}{96 \times .86603}= .998 \text{ inch}$$

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

Request for Diametral Blank Diameters X 50% larger

## Knurled Diameters (Knurl Forming)

The approximate increase in blank diameters for different teeth per inch with straight, diagonal, and diamond pattern knurling is shown below. 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. When the full depth of the knurl is not required (no sharp points), penetrate the work blank to displace at least 75% of the knurl tooth depth. This ensures proper tracking of the knurl on the work. Care should be exercised not to specify knurled diameters with too few teeth. Consideration should be also 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 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 4*

**Minimun Knurled Diameters**
For In-feed Rolling with Circular Pitch Knurls on General Applications

| Pitch | | Standard Width of Knurl Face | | | | | |
|---|---|---|---|---|---|---|---|
| | | 3/16" | | 1/4" | | 3/8" | |
| TPI | mm | Inch | mm | Inch | mm | Inch | mm |
| 16 | 1.6 | - | - | 0.406 | 10.3 | 0.500 | 12.7 |
| 20 | 1.2 | 0.313 | 7.9 | 0.344 | 8.7 | 0.438 | 11.1 |
| 25 | 1.0 | 0.250 | 6.4 | 0.281 | 7.1 | 0.375 | 9.5 |
| 30 | 0.8 | 0.219 | 5.6 | 0.250 | 6.4 | 0.313 | 7.9 |
| 35 | 0.7 | 0.188 | 4.8 | 0.219 | 5.6 | 0.281 | 7.1 |
| 40 | 0.6 | 0.156 | 4.0 | 0.188 | 4.8 | 0.250 | 6.4 |
| 50 | 0.5 | 0.125 | 3.2 | 0.156 | 4.0 | 0.219 | 5.6 |
| 80 | 0.3 | 0.078 | 2.0 | 0.109 | 2.8 | 0.172 | 4.4 |

*Table 5*

**Approximate Diameter Increase of Blank**
with Standard Circular Pitch Knurls

| Pitch | | Straight | | Diagonal | | Diamond on Part | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Circular Pitch | | Circular Pitch | | Male | | Female | |
| TPI | mm | Inch | mm | Inch | mm | Inch | mm | Inch | mm |
| 8 | 3.2 | 0.042 | 1.1 | 0.042 | 1.1 | 0.046 | 1.2 | - | - |
| 10 | 2.5 | 0.038 | 1.0 | 0.038 | 1.0 | 0.042 | 1.1 | - | - |
| 12 | 2.1 | 0.034 | 0.9 | 0.034 | 0.9 | 0.038 | 1.0 | 0.023 | 0.6 |
| 16 | 1.6 | 0.025 | 0.6 | 0.025 | 0.6 | 0.029 | 0.7 | 0.017 | 0.4 |
| 20 | 1.2 | 0.020 | 0.5 | 0.020 | 0.5 | 0.023 | 0.6 | 0.014 | 0.4 |
| 25 | 1.0 | 0.016 | 0.4 | 0.016 | 0.4 | 0.018 | 0.5 | 0.011 | 0.3 |
| 30 | 0.8 | 0.013 | 0.3 | 0.013 | 0.3 | 0.015 | 0.4 | 0.009 | 0.2 |
| 35 | 0.7 | 0.011 | 0.3 | 0.011 | 0.3 | 0.013 | 0.3 | 0.007 | 0.2 |
| 40 | 0.6 | 0.009 | 0.2 | 0.009 | 0.2 | 0.010 | 0.3 | 0.006 | 0.2 |
| 50 | 0.5 | 0.009 | 0.2 | 0.009 | 0.2 | 0.010 | 0.3 | 0.006 | 0.2 |
| 80 | 0.3 | 0.005 | 0.1 | 0.005 | 0.1 | 0.006 | 0.2 | 0.004 | 0.1 |
| TPI | mm | Diametral Pitch | | Diametral Pitch | | Male | | Female | |
| | | Inch | mm | Inch | mm | Inch | mm | Inch | mm |
| 64 | 0.4 | 0.024 | 0.6 | 0.021 | 0.5 | 0.024 | 0.6 | 0.015 | 0.4 |
| 96 | 0.3 | 0.016 | 0.4 | 0.014 | 0.4 | 0.016 | 0.4 | 0.010 | 0.3 |
| 128 | 0.2 | 0.012 | 0.3 | 0.010 | 0.3 | 0.012 | 0.3 | 0.007 | 0.2 |
| 160 | 0.1 | 0.009 | 0.2 | 0.008 | 0.2 | 0.009 | 0.2 | 0.005 | 0.1 |

## Tooth Depth

Depth of tooth is in direct relationship with circular pitch knurl with approximate percentages which will vary, accordingly to material, speed, and feed used in knurling.

*Table 6*

| Tool Depth with Standard Circular Pitch Knurl | | Circular Pitch | |
|---|---|---|---|
| | | inches | metric |
| Type of Knurl | Percentage of Depth of Knurl | $\frac{1"}{TPI}$ | Pitch size (mm) |
| Straight Tooth | 35% of Circular Pitch (P) | | |
| Diagonal | 35% of Normal Circular Pitch (Pn) | | |
| Diamond | 40% of Normal Circular Pitch (Pn) | | |
| Diamond Female | 25% of Normal Circular Pitch (Pn) | | |

## Tooth Depth Examples

Inch Circular Pitch: find the circular pitch and depth of tooth for a straight tooth knurl and has 20 TPI.

$$P = \frac{1"}{20\ TPI} = .0500 \text{ Circular Pitch}$$

Metric Circular Pitch: The distance from tooth to tooth

P= 1mm Circular Pitch     Tool Depth= 1x 35%= .35

The resulting depth is per side. Multiply x2 for depth on diameter.

## Tracking Calculations for Forming and Cutting knurl.

Follow the **steps 1-10** below to prepare the proper diameter to turn your diameter before knurling in order to improve the success of knurling without double tracking.

**Step 1:** Diameter of the part after knurl: ________
(skip to step 3 if the diameter before knurl is only diameter specified)

**Step 2:** Growth of material after knurling based on TPI: __________
(see Table 5)

**Step 3:** Diameter before knurl __________
(step 1 - step 2, or use diameter given on print if starting here at this step)

**Step 4:** Quick calculator value: __________
(see knurl wheel pages for your exact wheel. Example: shown below **.0330**)
PAGES H-60 to H-70

**Step 5:** Calculate number of teeth on part after knurl: _____________
(diameter of part before knurl from step 3 / quick calculator value, example: 1.138 dia / .033 = 34.5 teeth on part after knurl)

**Step 6:** Evaluate value in step 5
(fractional values can lead to double tracking. In the above example, there will be 34 teeth on the part with .5 of a tooth left over. This 1/2 tooth overtravel will most likely double track. To solve this continue to step 7)

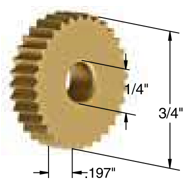
**Step 7:** Round to closest whole number _______________
(in the above example either 34 or 35 can be used)

**Step 8:** Calculate new diameter to turn material before knurl: ______
(quick calculator value x rounded number of teeth from step 7, example: .033 x 34 = 1.122 diameter of the part before knurl to track properly)

**Step 9:** Calculate diameter after knurl based on new tracking diameter: _________
(add growth value from step 2 to new tracking diameter from step 8)

**Step 10:** Verify against print tolerances

## Example for Step 4:




| Circular Knurl Pitch | | Included Tooth Angle | Knurl Pattern | R Series Knurl Wheel | Straight Cobalt TiN Coated |
|---|---|---|---|---|---|
| Inch | Metric | | | | |
| 10 (TPI) | 2,5mm | 90º | Coarse | Description | RS-10-C |
| | | | | Tracking Data | 23T / .0330" |
| | | | | Standard | 26502 |

## Traditional Formula for Step 5:

*Table 7*

**Correction Factor**

| TPI | Approx. Value of C.F. | |
|---|---|---|
| | Inch | mm |
| 12-19 | 0.010 | 0.3 |
| 20-29 | 0.007 | 0.2 |
| 30-39 | 0.005 | 0.1 |
| 40-49 | 0.003 | 0.1 |
| 50-80 | 0.002 | 0.05 |

** This value is affected somewhat by machine speeds, material hardness, relative diameters of knurl and blank.

$$\text{Teeth (on blank)} = \frac{\text{Teeth (on knurl tool)} \times \text{Diameter (Blank)}}{\text{Diameter (wheel)} + \text{Correction Factor}}$$

* Note: These formulas apply accurately only to knurls In-Fed from the cross-slide.

## Cutting Speed

**Knurling** is ordinarily performed at the same speeds used as turning operations. To calculate the cutting parameter of a knurling operation, use the same SFM used for high speed and cobalt tool bits to calculate (RPM) revolution of the workpiece and Knurling ($f_n$) feed rate.

**For in-feed knurling,** the knurl should be fed toward the work gradually until contact is made with the blank. 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 tool (5 to 20 REV)

**For end-feed knurling,** the rate of feed is governed by the type 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.

**Knurling Formula:**

$$RPM = \frac{12 \times SFM}{\pi \times DIA} \qquad SFM = \frac{(DIA \times \pi) \times RPM}{12}$$

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.

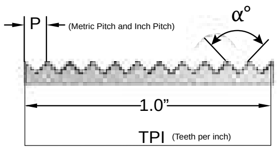
The feeds used for end-feed knurling with the turret vary considerably and are dependent upon the pitch of the knurl, material being knurled, and the nature and diameter of the work.

**-Warning-** Speeds and feeds information in the catalog are for reference only. If the operator does not feel safe using our speeds and feed recommendation, the operator should use what he or she is comfortable with. Dorian Tool is not responsible for any injuries that may occur.

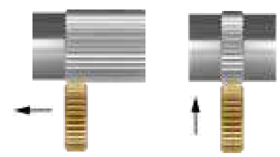
# Knurling SFM and $V_c$ parameter

*Table 8*

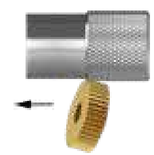
**Material and Knurl Pitch**




**Knurl Forming**



**Knurl Cutting**



| Material Description | Material Specs | TPI | Metric Pitch | Forming Speed (SFM and $V_c$) Smaller ⇦ Wheel dia. ⇨ Larger | Feed rate ($f_n$) End Feed | Feed rate ($f_n$) In Feed | Cutting Speed Smaller ⇦ Wheel dia. ⇨ Larger | End Feed |
|---|---|---|---|---|---|---|---|---|
| **Low carbon steel** | 1018 1117 1215 | >14 | >1,8 | 50-210 SFM [15-63 $V_c$ m/min] | 0.006" [0,15mm] | .001-.003" [,025-,075mm] | 100-350 SFM [30-106 m/min] | 0.009" [,23mm] |
| | | 16-20 | 1,6-1,2 | | 0.008" [0,20mm] | .002-.004" [0,050-,100mm | | 0.011" [,28mm] |
| | | 25-35 | 1,0-0,7 | | 0.010" [,25mm] | .002-.004" [,050-,100mm] | | 0.013" [,33mm] |
| | | 40> | 0,6> | | 0.012" [,30mm] | .002-.004" [,050-,100mm] | | 0.015" [,38mm] |
| **Alloy Steel Tool steels** | 4130 4140 D2 | >14 | >1,8 | 35-150 SFM [10-45 m/min] | 0.004" [,10mm] | .001-.002" [,025-,050mm] | 70-250 SFM [21-75 m/min] | 0.007" [,18mm] |
| | | 16-20 | 1,6-1,2 | | 0.005" [,13mm] | .001-.003" [,025-,075mm] | | 0.008" [,20mm] |
| | | 25-35 | 1,0-0,7 | | 0.007" [,18mm] | .001-.003" [,025-,075mm] | | 0.010" [,25mm] |
| | | 40> | 0,6> | | 0.009" [,23mm] | .001-.003" [,025-,075mm] | | 0.012" [,30mm] |
| **Stainless Steel** | 304 17-4 | >14 | >1,8 | 35-150 SFM [10-45 m/min] | 0.004" [,10mm] | .001-.002" [,025-,050mm] | 70-250 SFM [21-75 m/min] | 0.007" [,18mm] |
| | | 16-20 | 1,6-1,2 | | 0.005" [,13mm] | .001-.003" [,025-,075mm] | | 0.008" [,20mm] |
| | | 25-35 | 1,0-0,7 | | 0.007" [,18mm] | .001-.003" [,025-,075mm] | | 0.010" [,25mm] |
| | | 40> | 0,6> | | 0.009" [,23mm] | .001-.003" [,025-,075mm] | | 0.012" [,30mm] |
| **Aluminum Brass Plastic** | 6061 C360 Delrin | >14 | >1,8 | 90-390 SFM [27-118 m/min] | 0.008" [,20mm] | .002-.004" [,050-,100mm] | 110-420 SFM [33-127 m/min] | 0.011" [,28mm] |
| | | 16-20 | 1,6-1,2 | | 0.010" [,25mm] | .003-.005" [,075-,125mm] | | 0.013" [,33mm] |
| | | 25-35 | 1,0-0,7 | | 0.013" [,33mm] | .003-.005" [,075-,125mm] | | 0.016" [,40mm] |
| | | 40> | 0,6> | | 0.017" [,43mm] | .003-.005" [,075-,125mm] | | 0.020" [,50mm] |

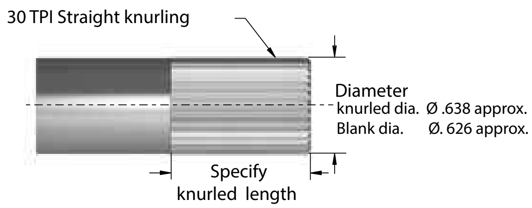
**Note: When knurling, start with low Cutting speed, to evaluate the wheel performance, (to avoid the premature life of the wheel) increase until optimum cutting speed and feed is achieved**

## Dimensioning of Diametral and Circular Pitch Knurling

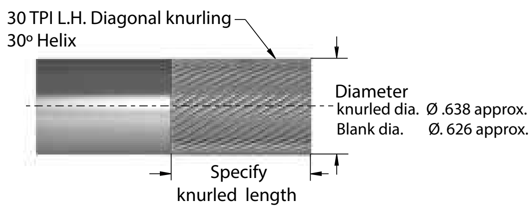
Uniform drafting practice is desirable and dimensioning should include length and knurled diameter of the knurling and specifications of the teeth. The method for dimensioning diameters and tooth specifications is important as improper use of dimensions may result in considerable confusion.

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

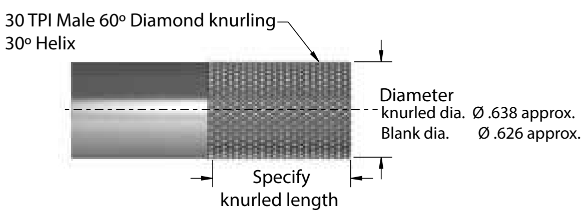
Straight




Diagonal



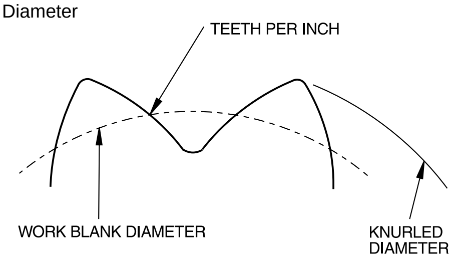

Diamond




## General Purpose Knurling

For general purpose knurling, only limited dimensions are necessary.

- TPI (Teeth Per Inch) or Coarse / Medium / Fine
- Work Blank Diameter
- Knurled Diameter




## Precision Knurling

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 trial and error.

## Knurling head center line adjustment

- Knurl tool is too low from center line.
- Top wheel is cutting a deeper R.H. Diagonal Knurl.
- Adjust center height until both wheels are on center and touching simultaneously.

- Knurl tool is too high from center line.
- Bottom wheel is cutting a deeper L.H. Diagonal Knurl.
- Adjust center height until both wheels are on center and touching simultaneously.

- Tool is on center line.
- Both wheels are touching simultaneously, forming a perfect diamond knurl.

Note: For a symmetric and even knurl pattern on the workpiece, the knurl wheels must be set on centerline of the workpiece. Both wheels must touch simultaneously