Machine Shop
Part 5 -Lathe

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Safety Notice

- You must complete safety instruction before using tools and equipment in the Medical Device Center, ME Student Shop and CSE Workshops.
- All machinery can be dangerous. You must have a trained individual instruct you first when using unfamiliar equipment.
- Only authorized and trained individuals may operate CNC equipment.
- Code examples shown are for illustration purposes only, and are not meant for operation or programming actual equipment. They may be incomplete or contain errors.
- Always abide by shop safety instructions and never engage in horseplay.
- Remember to wear OSHA approved eye and ear protection in the shop, short sleeves, leather or steel toed shoes, and secure long hair, avoid loose clothing, and take off rings, watches and bracelets when using power equipment.
- These slides are part of the “Introductory Medical Device Prototyping” course at the University of Minnesota, and are not meant for any other purpose.

Eye Protection & First Aid

- Always wear OSHA approved eye protection.
- Familiarize yourself with the shop first aid kit, location of telephone, and emergency phone numbers.

Right: Image courtesy of Copper Safety

Tools of the Trade

- Lathe
  - Lathe features.
  - Chucks
  - Collets
  - Tools & tool holders
  - Tailstock and drilling
  - Steady and traveling rests
  - Lathe operations
  - Spindle and cutting speeds
  - Lubricants/coolants
- Cleanup
- Appendix
  - Formulas & Tables

Lathe Features

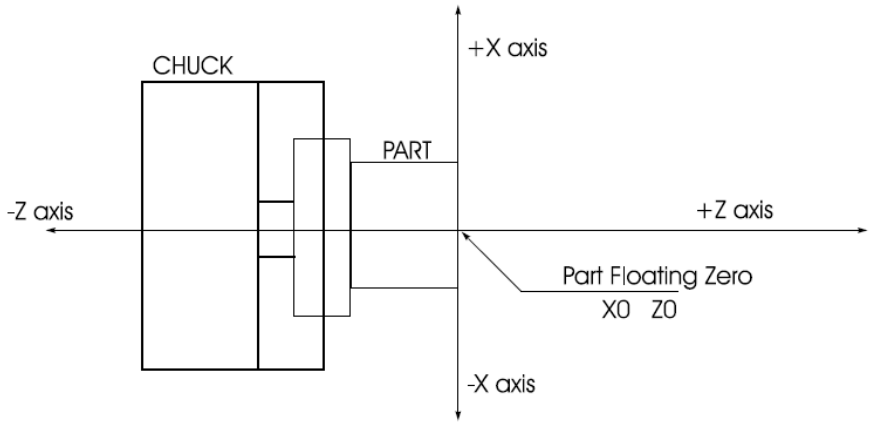
Emco Compact 5

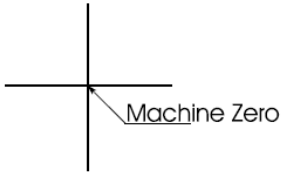
Similar to Other Lathes…

MDC lathe.

ME Hardinge lathe.

X & Z Axis





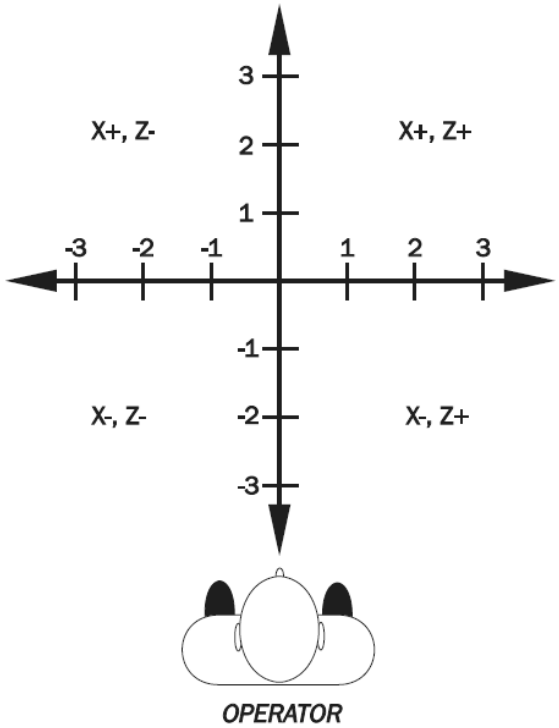
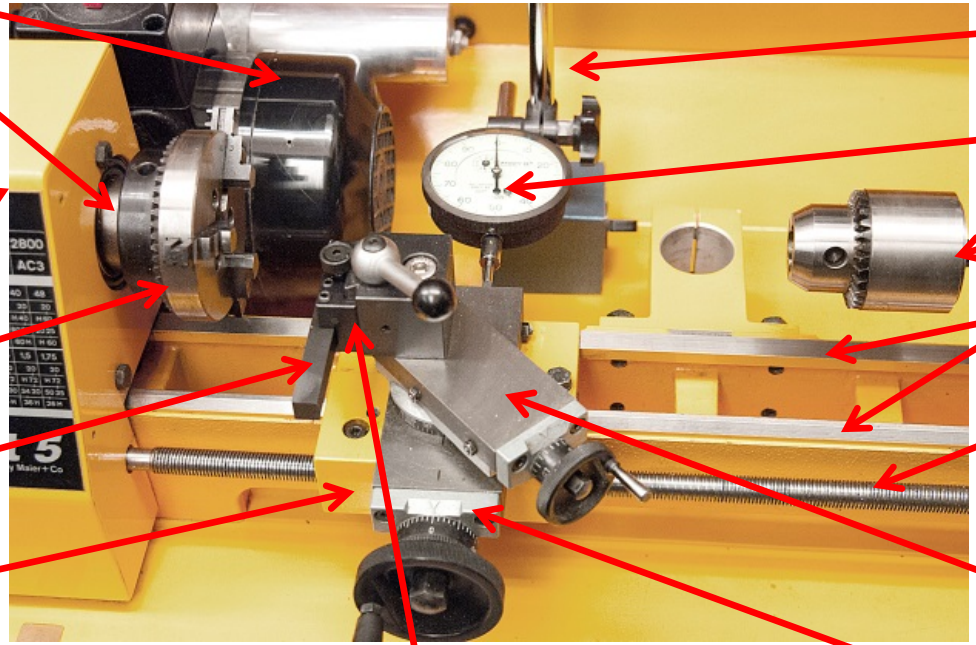
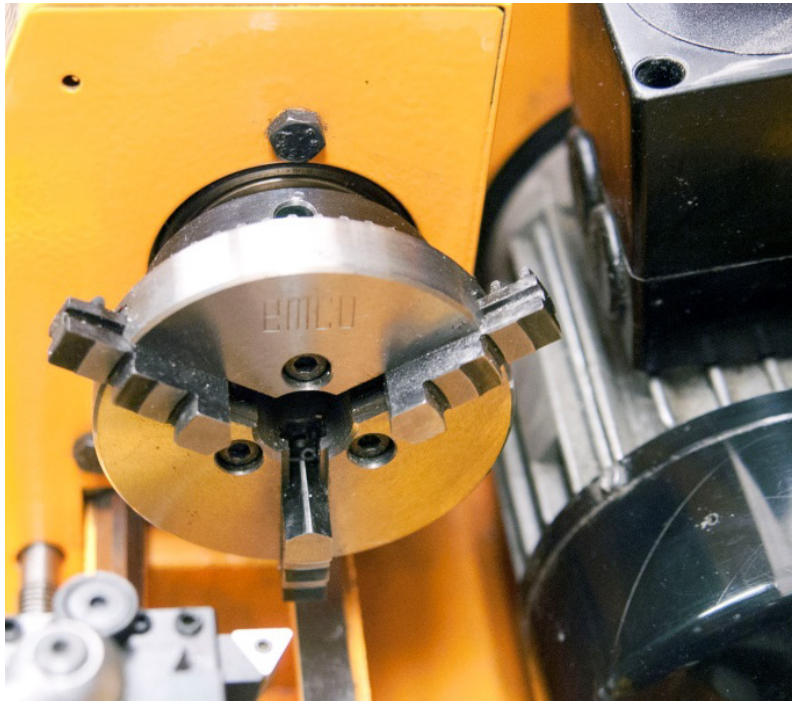


Image courtesy of Productivity and Haas

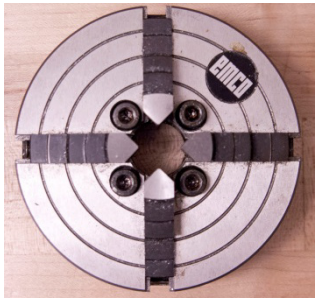
Lathe Components

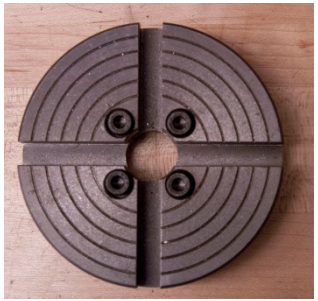


Chucks…



3-Jaw chuck for round and hex stock.

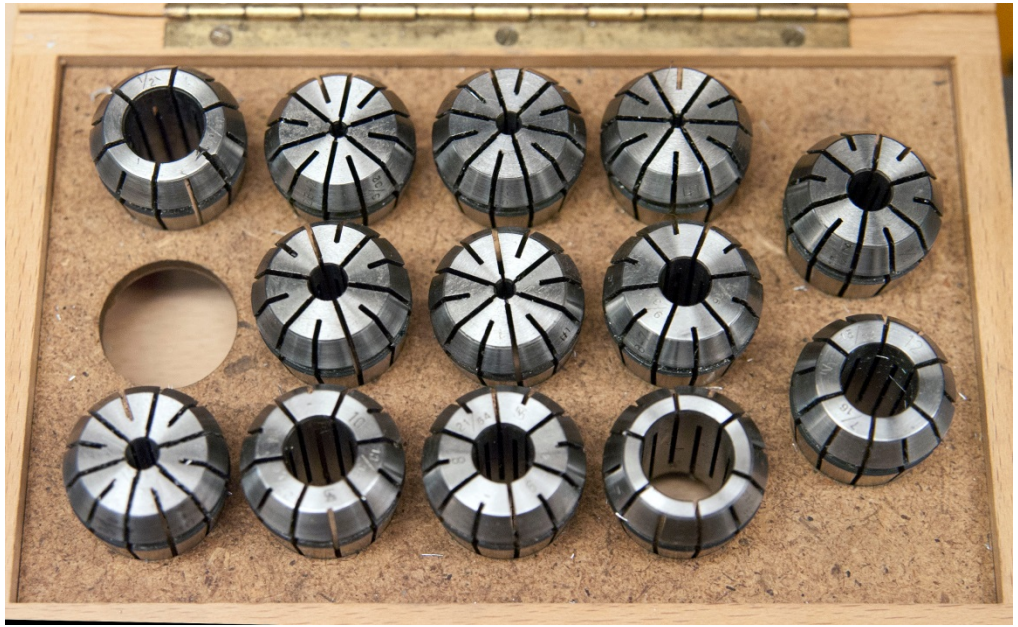




4-Jaw and face plate chucks.

Collet holder.

Fractional Compression Collet Set…

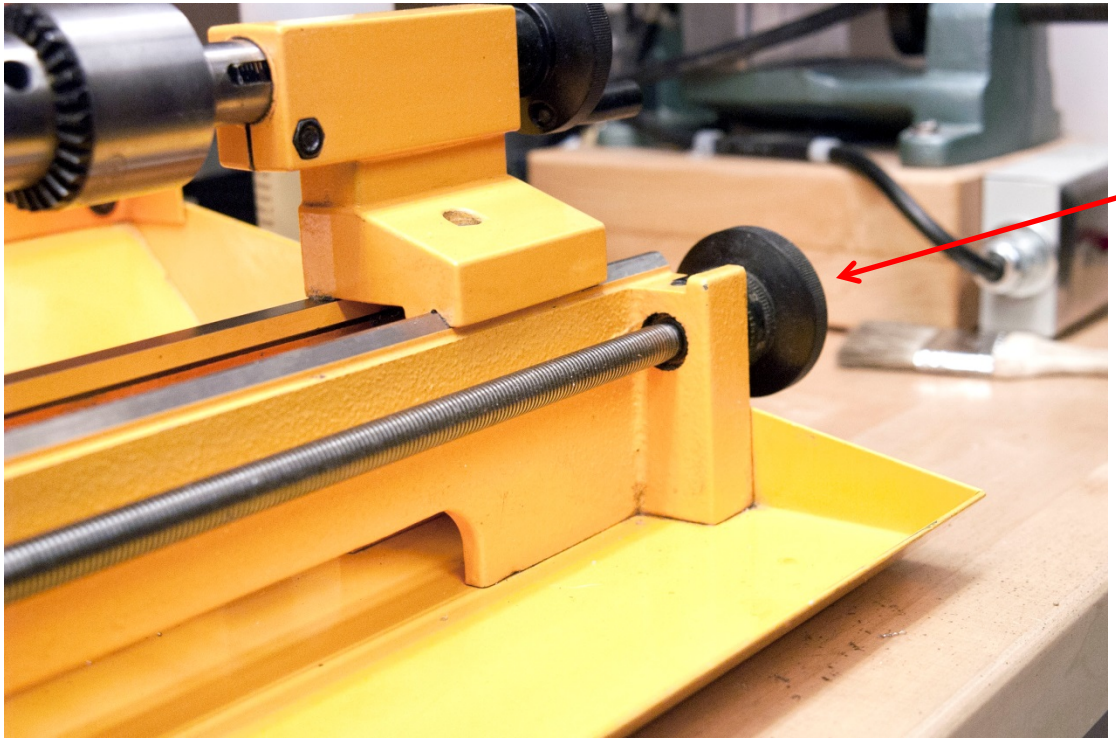


Each collet accepts a small range of stock diameters.

Chuck Key…

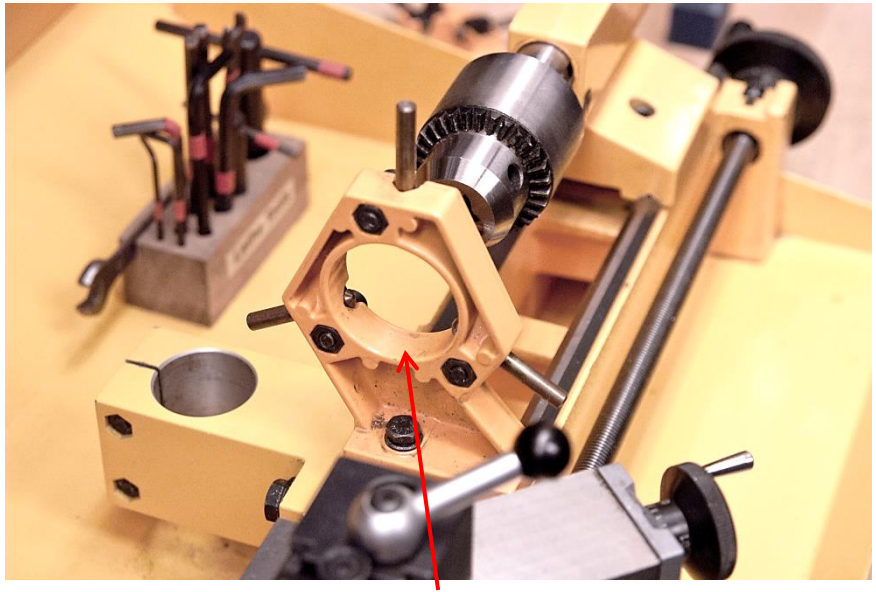
Tighten work piece in chuck and remove key immediately!

Z-Axis/Lead Screw Handle…

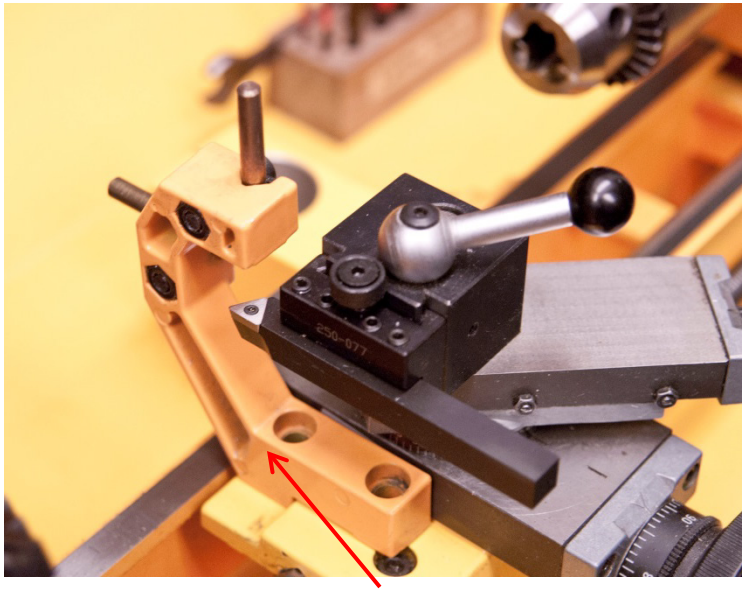


Turn to move carriage.

Steady and Traveling Rest...

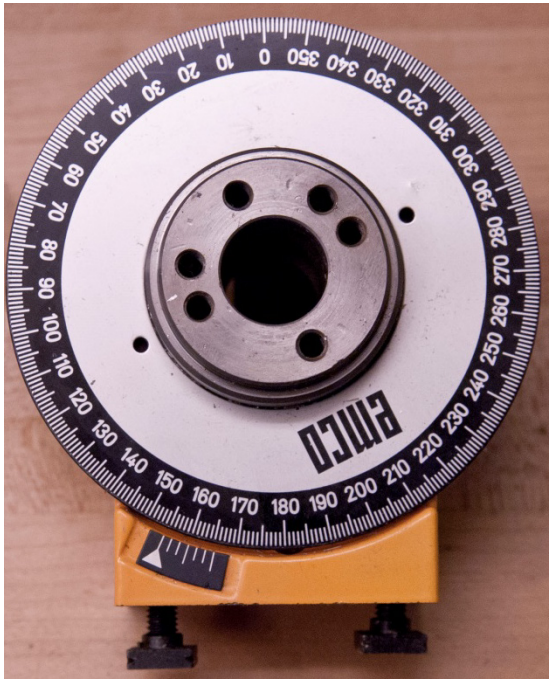


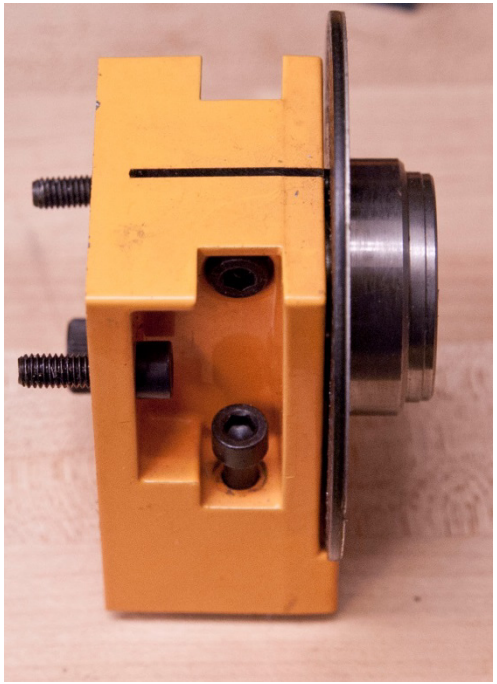
Steady rests attaches to ways.



Traveling rest moves with carriage.

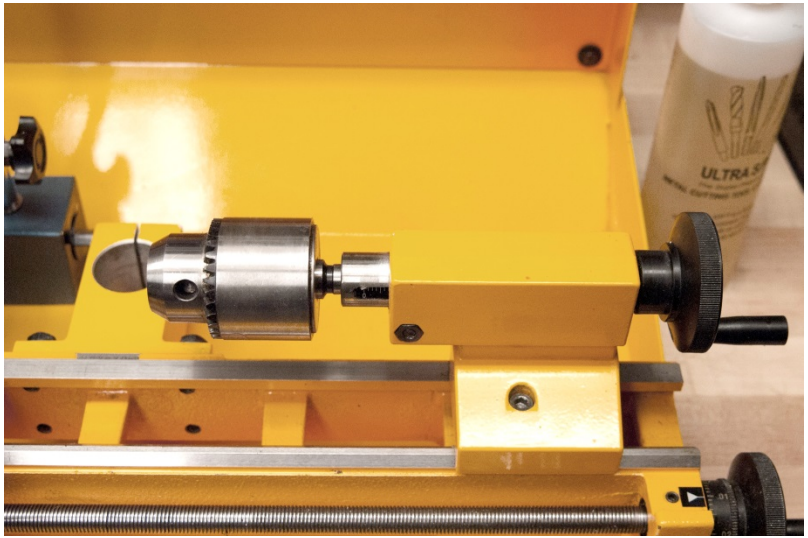
Circular Indexer…

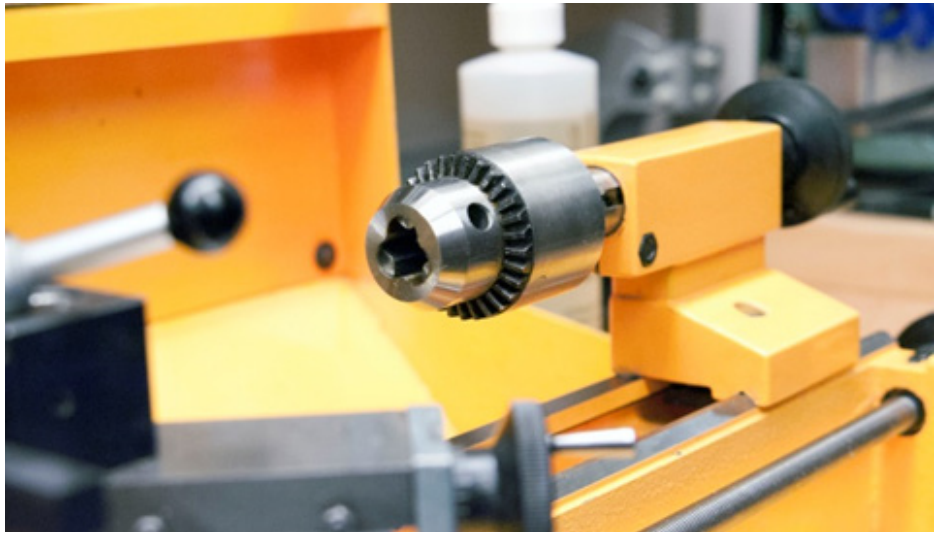




- Used in conjunction with integrated mill (not shown).
- Chucks and collet holder can be attached.

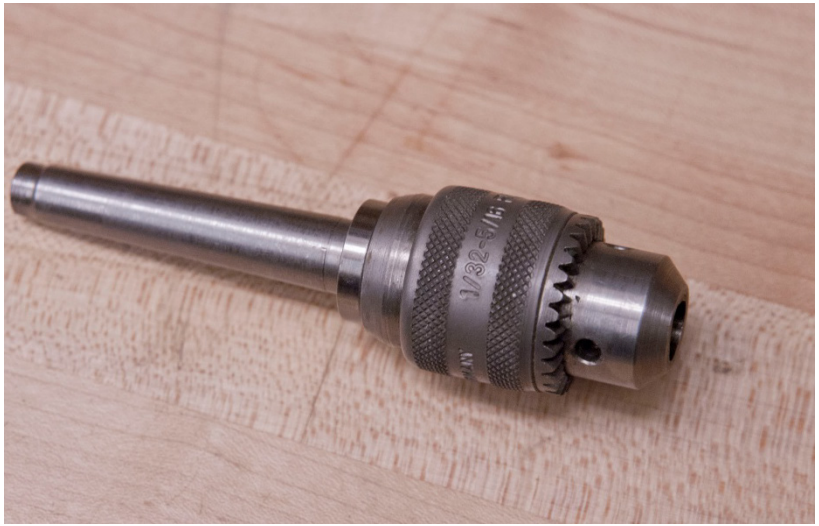
Tailstock & Drill Chuck…





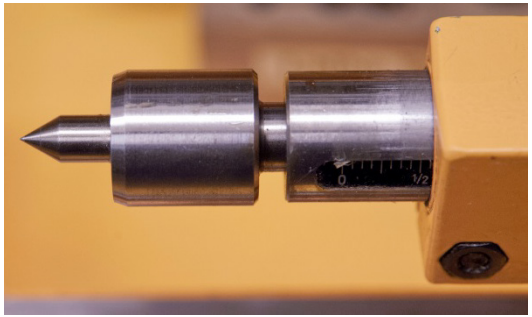
- Chuck attaches with a Jacob 33 to M2 taper adaptor.
- To drill, move tailstock to work and turn handle slowly.

Chuck to M2 Taper Adaptors…



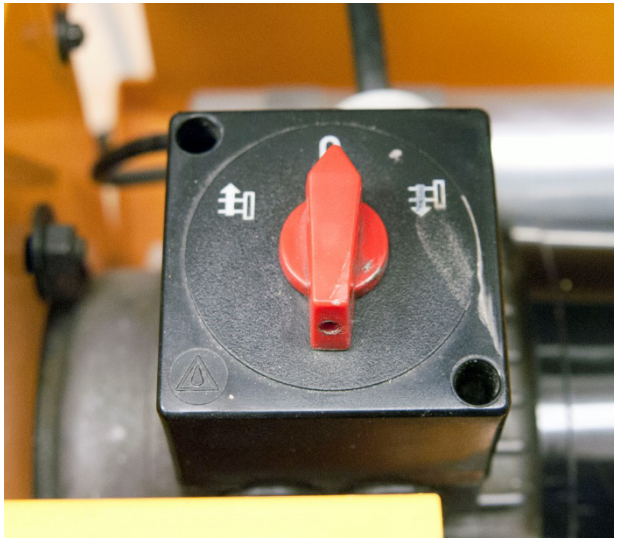
Optional chuck sizes for different drill bits.

Tailstock Centers…



- Use when affixing work at the chuck and tailstock.
- Shown are different taper center points, and rotating or “live” center.
- It is best to spot drill in the center face of the work so that the center is firmly making contact.

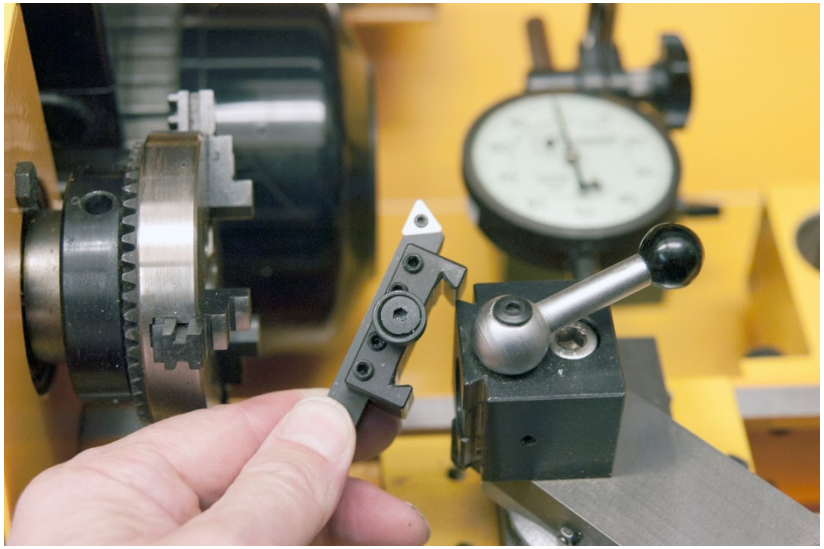
Power Control…

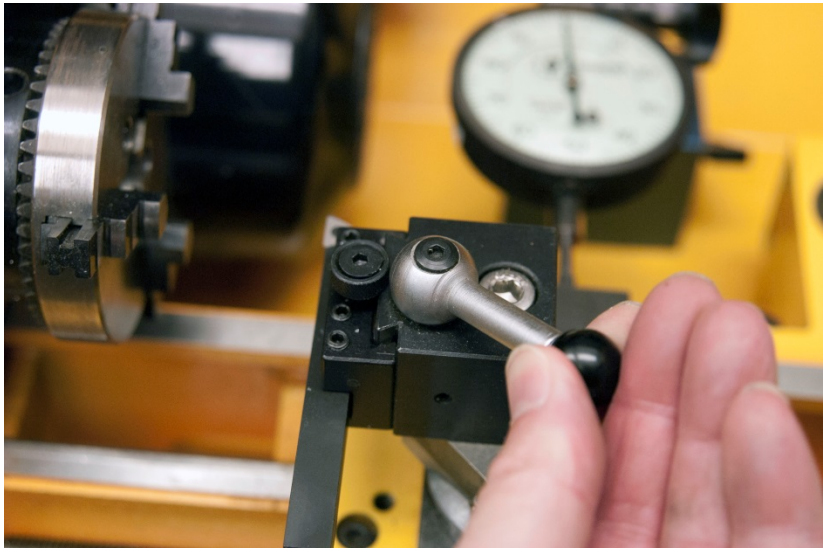


Reverse-OFF-Forward

Motor and motor capacitor.

Tool Holder…





Quick change tool post.

Tool, Tool Post, Cross and Top Slides…

Quick change tool post

Tool holder

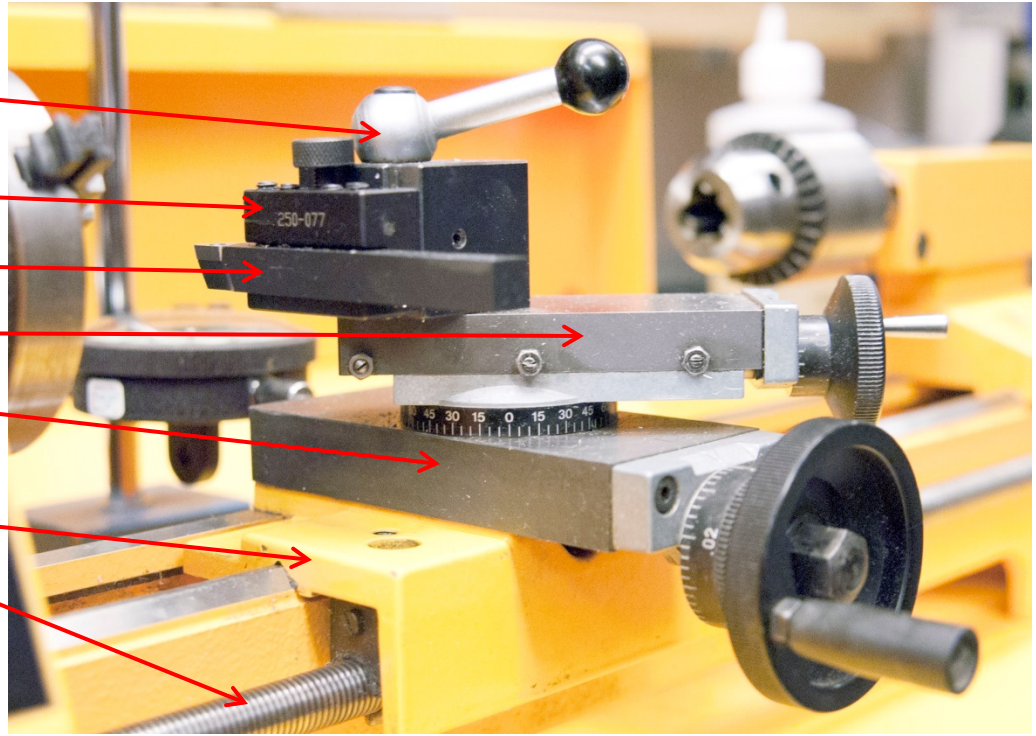
Tool

Top slide

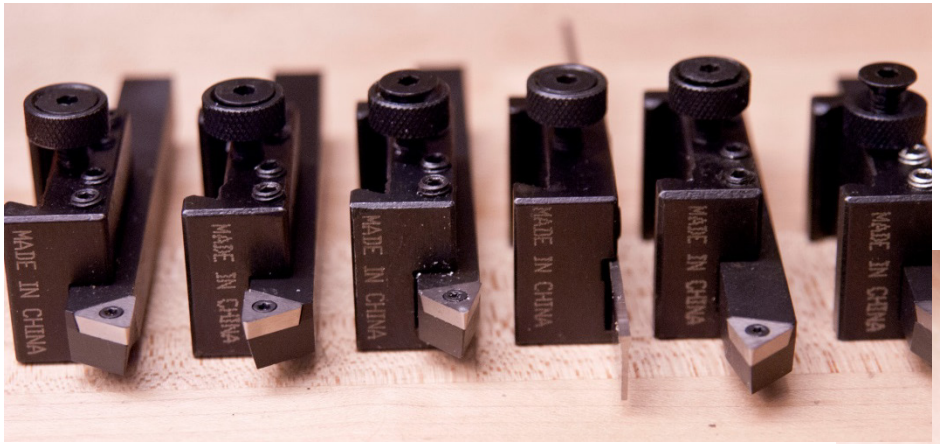
Cross slide (X axis)

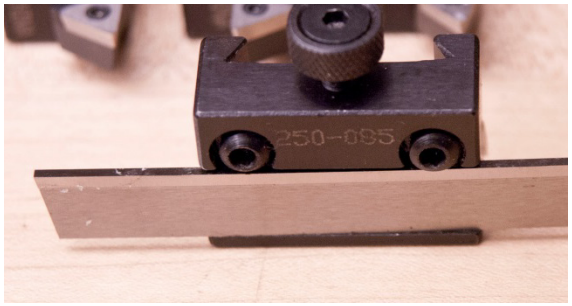
Carriage

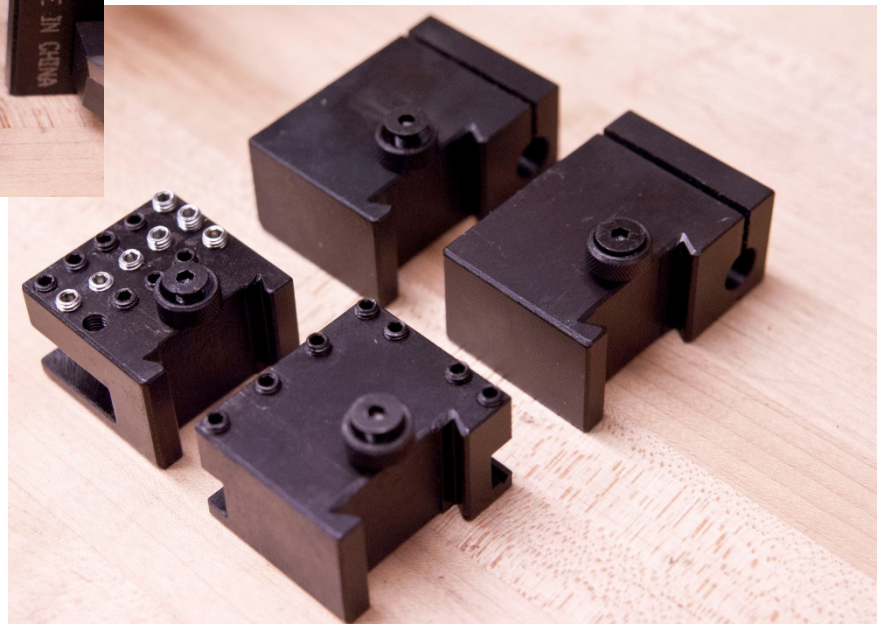
Lead screw (Z axis)



Tools, Tool Holders & HSS Inserts

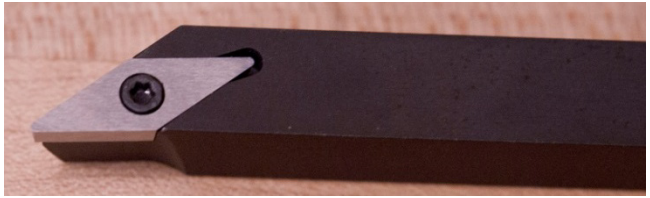






Boring, Profiling and Threading Tools…

Boring tool.



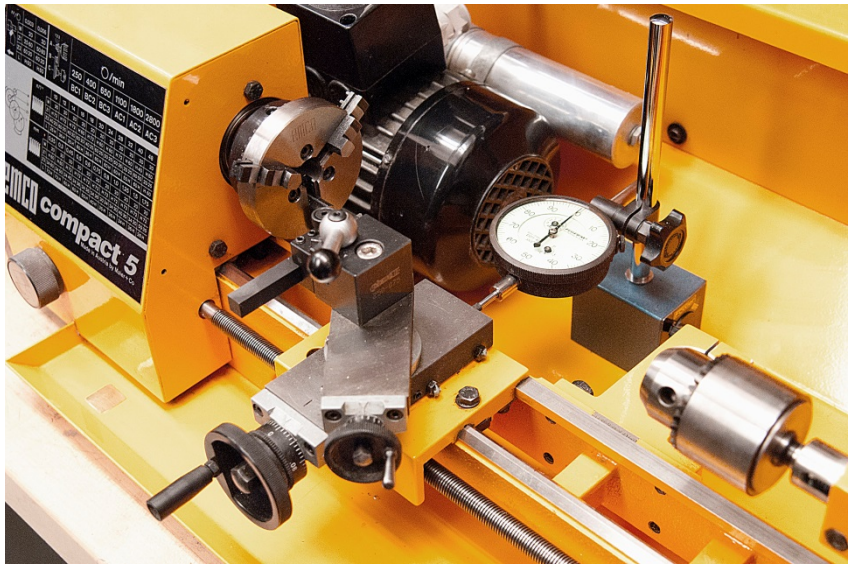
Profiling tool.

Internal & external threading tool.

These tools have HSS inserts. Carbide inserts are also available.

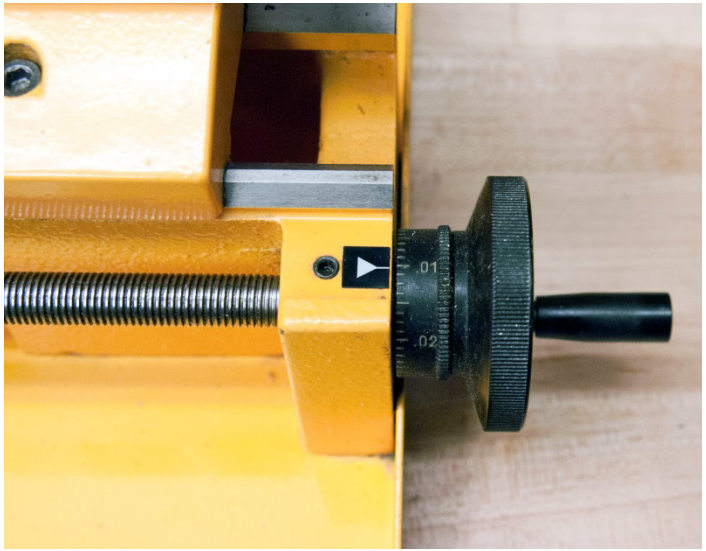
Ground HSS Tools…

Traveling Dial Indicator (When no DRO)…



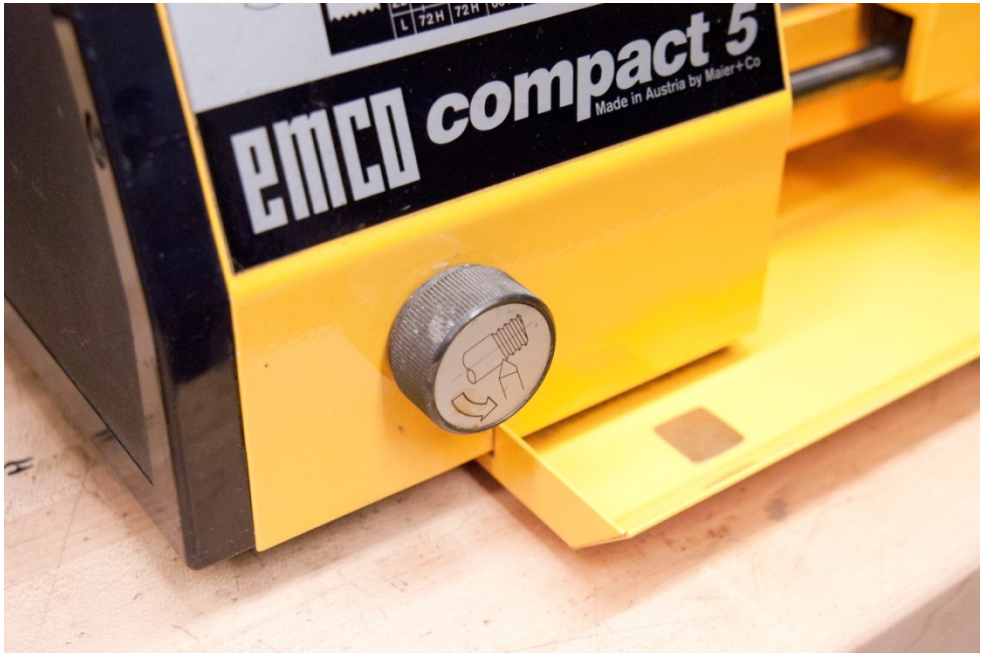
If you do not have a digital readout (DRO), you can first layout the part with Dykem blue, or use traveling dial indicators on the Z and/or X axis if distances are short (a few inches).

Handle Micrometers…



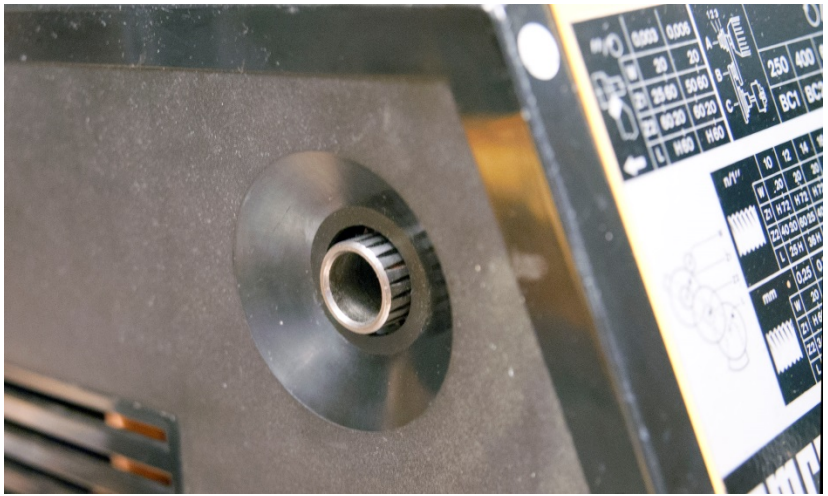
The cross slide micrometer is marked in "diameters" (2 x the actual movement).

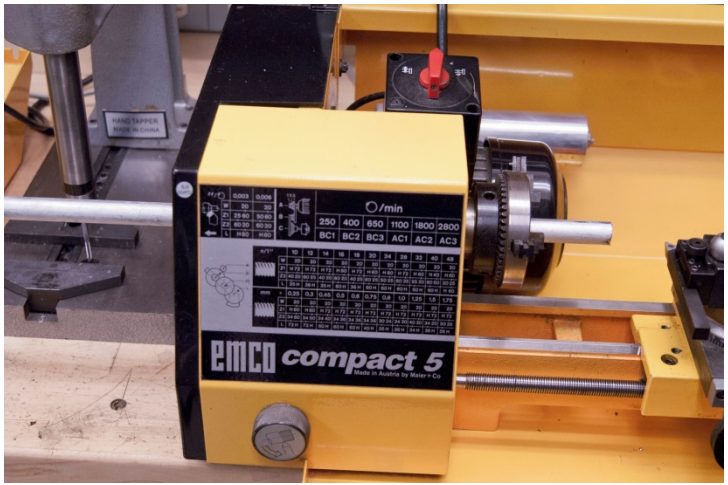
Power Feed Engage for Threading…



- This moves the carriage to the left by power feed.
- Excellent for finish turning or making threads.

Spindle Bore…



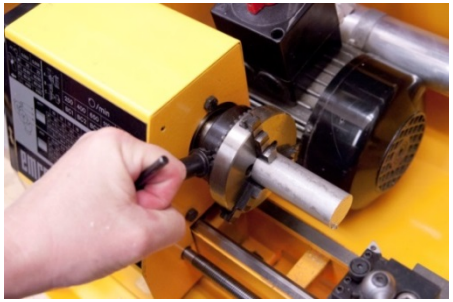


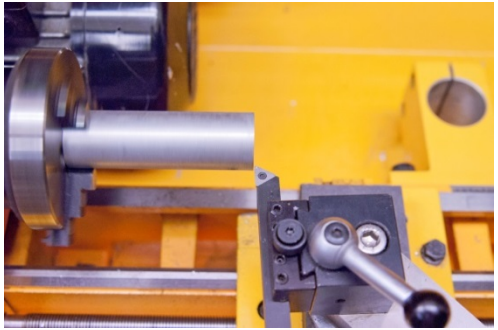
Stock extends through spindle. Typically use with collet and long stock.

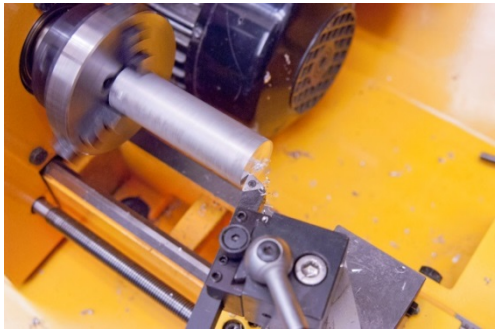
Common Lathe Operations

- Facing
- Center Drilling
- Turning to a diameter
- Turning to a left or right shoulder
- Drilling
- Knurling
- Filing
- Parting
- Chamfering
- Grooving
- Boring
- Threading – advanced topic for later

Facing Operation…

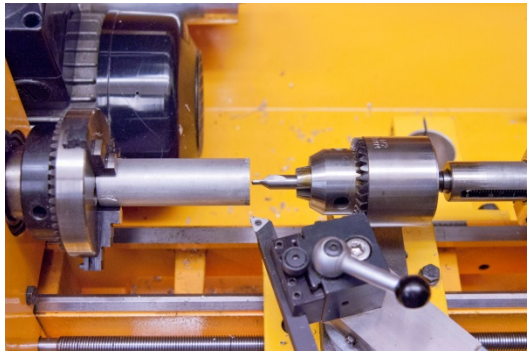


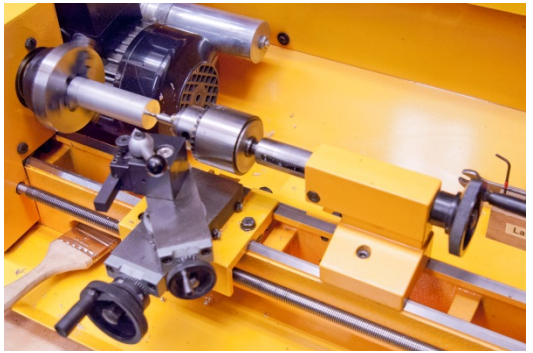


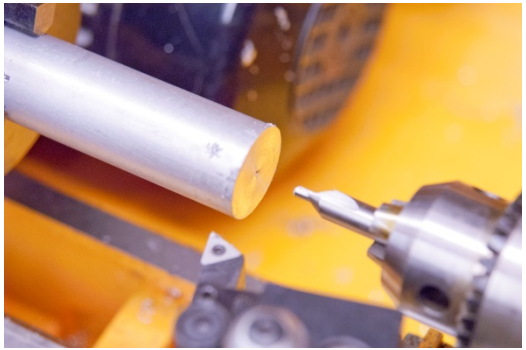


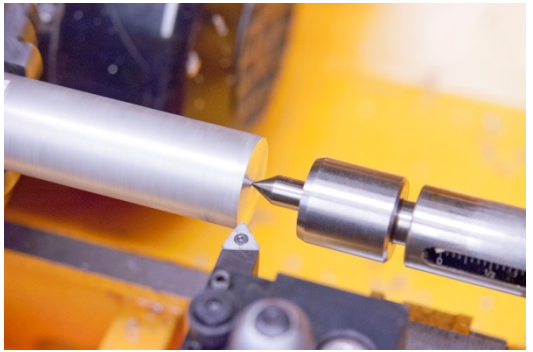
Angle of tool holder is set to allow tool tip only to cut across the face of the work. Work is unsupported here – better to temporarily use a fixed steady rest. Once faced, center drill and use a live center.

Center Drilling Operation…



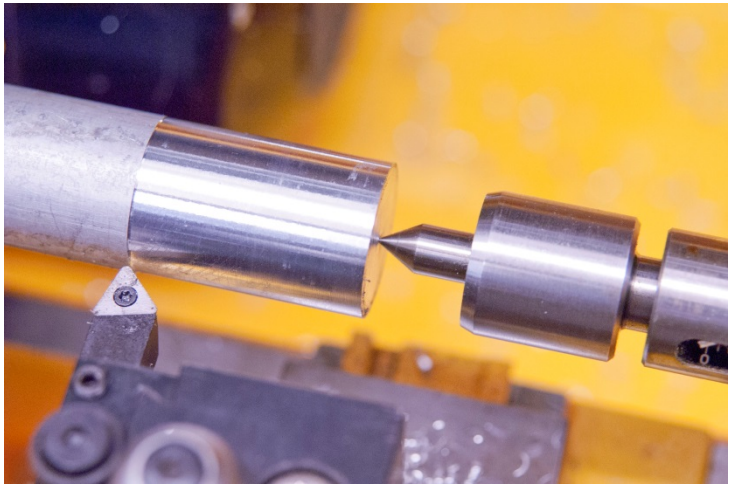






Make sure carriage is out of the way. Place spotting drill (center drill) in the tailstock chuck and turn the tailstock handle to advance drill into work. Replace chuck with a live center, and align with center hole.

Turning to a Diameter…

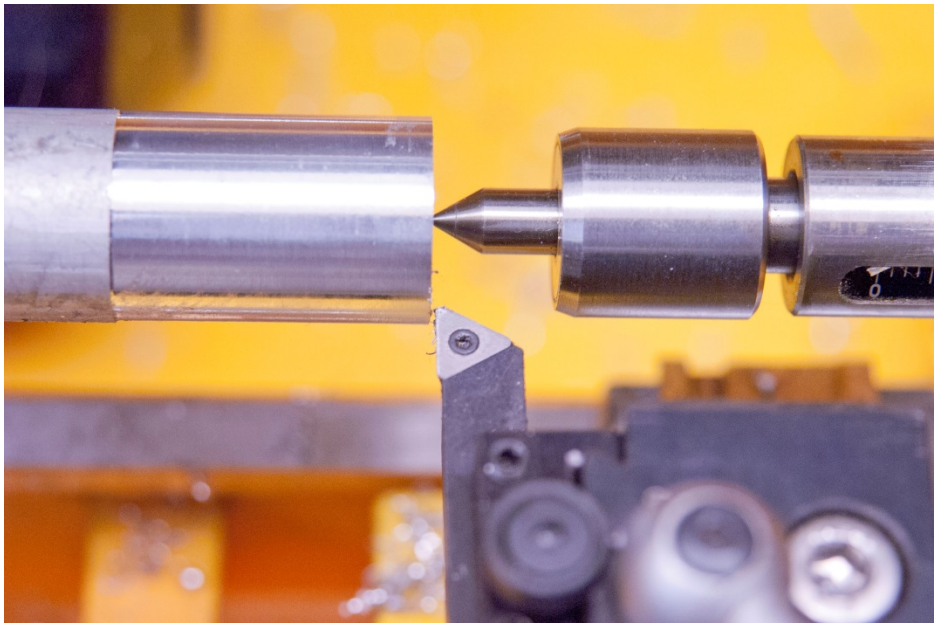


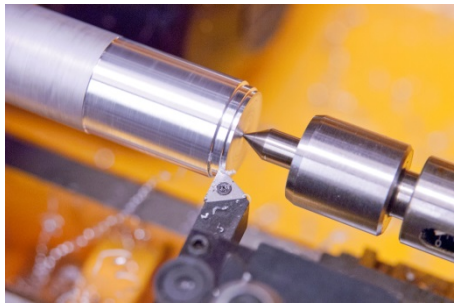
Using a left hand tool, take off small amounts at a time and make multiple passes.

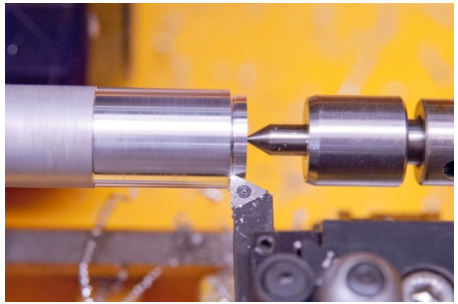
Checking Progress with a Caliper…

Always turn lathe OFF when using the caliper or a micrometer!

Turning to a Left Shoulder…

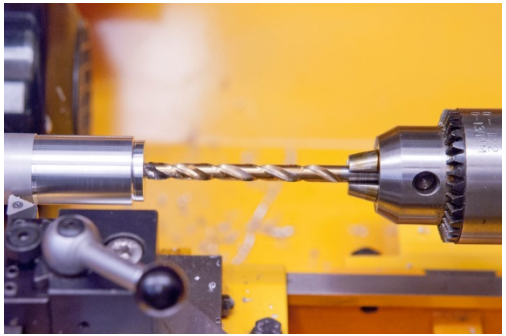




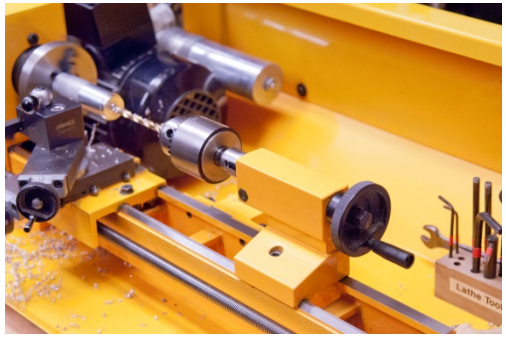


Notice the left hand tool with perpendicular insert.

Drilling Operation…

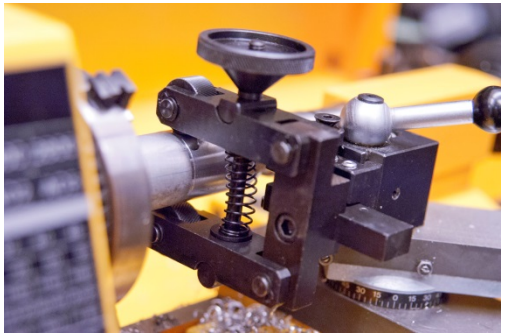


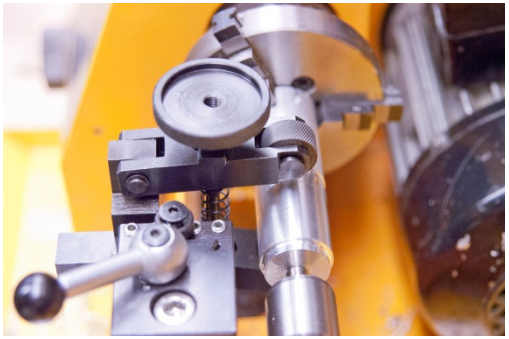
Drill bit is stationary while work turns.

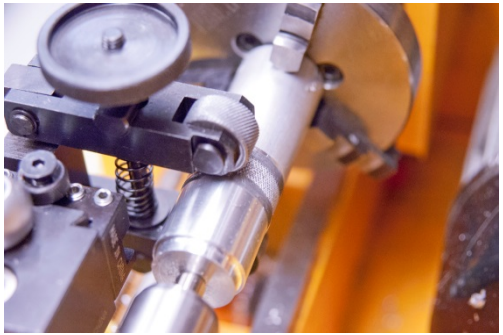


First center drill if not already done. Rotate tailstock handle to advance drill into rotating part. Peck drill (in and out) to clear chips).

Knurling Operation…





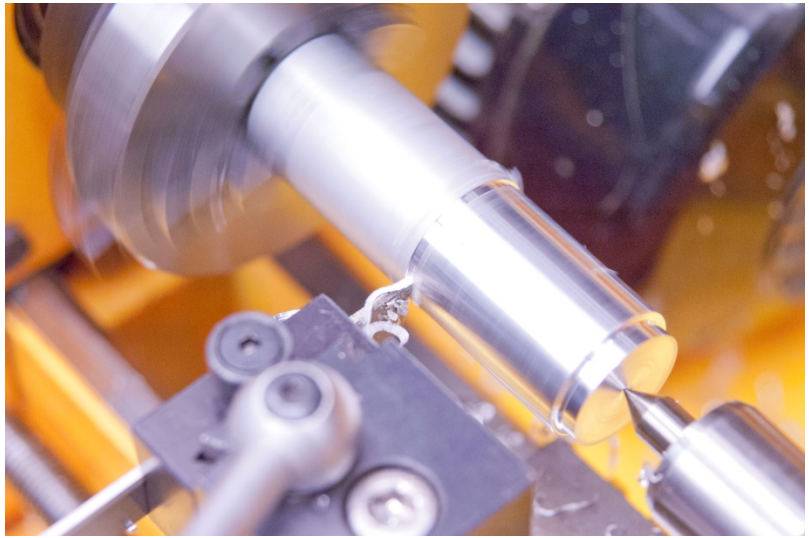


Ideally support work with live center on tailstock.

Filing Burrs…

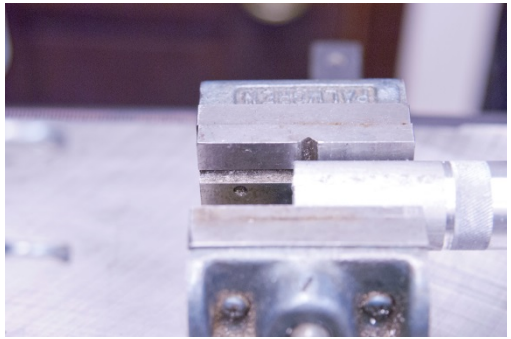
If not chamfering edge, optionally deburr with a file. Hold file on both ends, approach part and move slight forward as part turns.

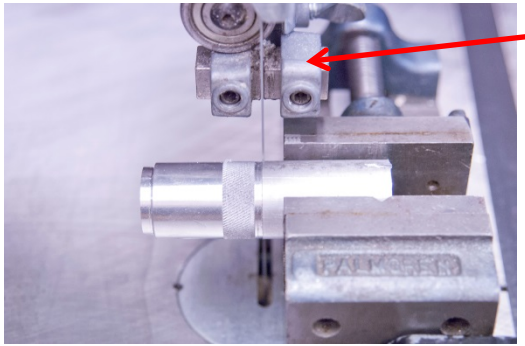
Parting Operation…



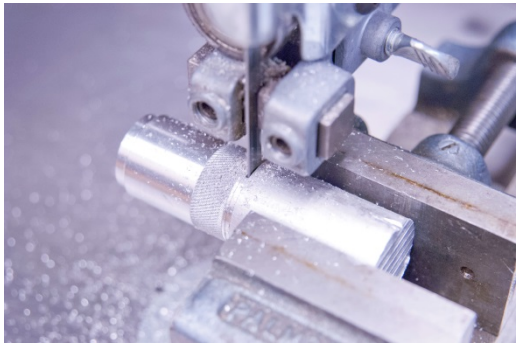
- Check that the tool is aligned and secure in the holder and tool post.
- Check your clearances and distance to center of work.
- Lubricant is essential for metals.
- Part is being pushed sideways and could jam in a small lathe. Consider a small groove, then taking the part out and using the band saw.

Sawing Round Stock with a Band Saw…





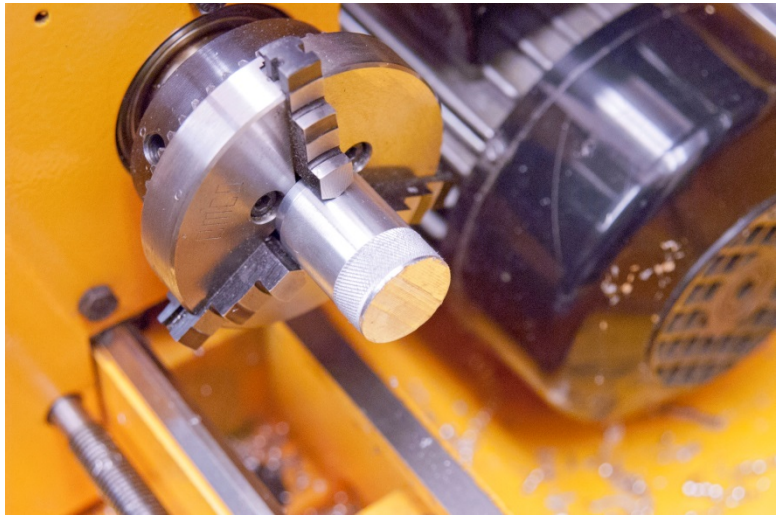
Blade guide.

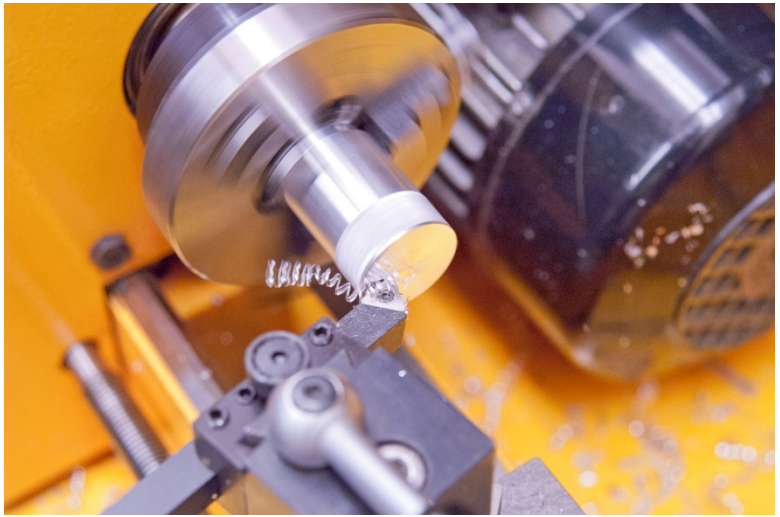


Pusher

Notice that the vise has a groove for cylindrical stock. Blade guide height is set to allow vise clearance. Hands should be away from the travel of the blade – holding vise face firmly to the pusher (clamp if able). Advance work slowly.

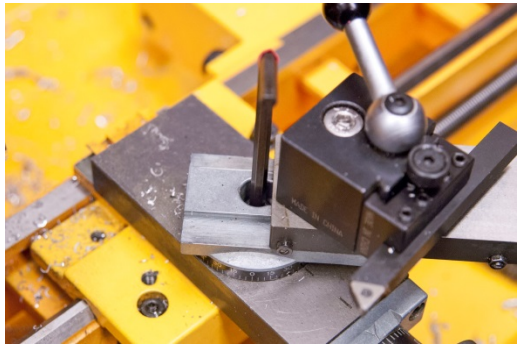
Facing the Other End…

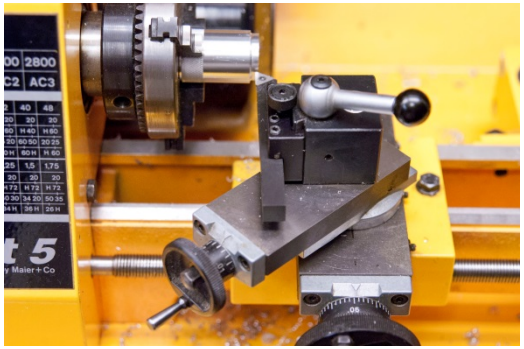


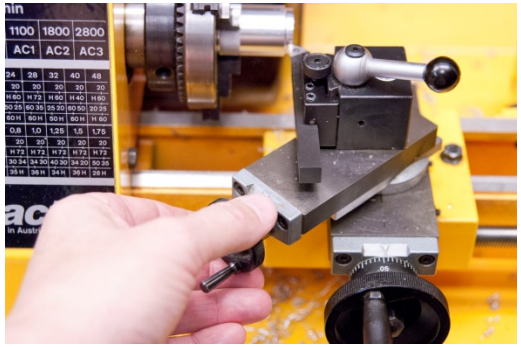


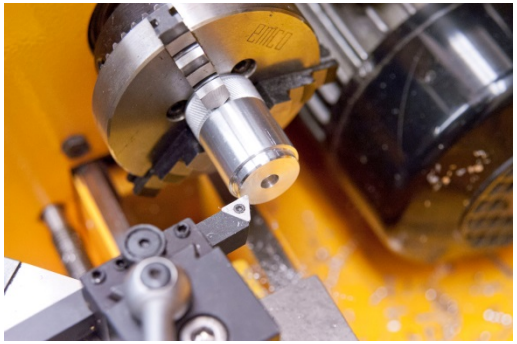
Notice slight angle of the tool holder and left hand tool.

Chamfering Operation…



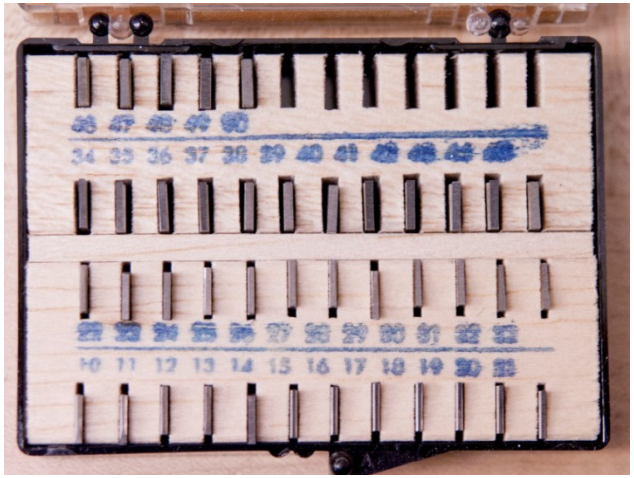






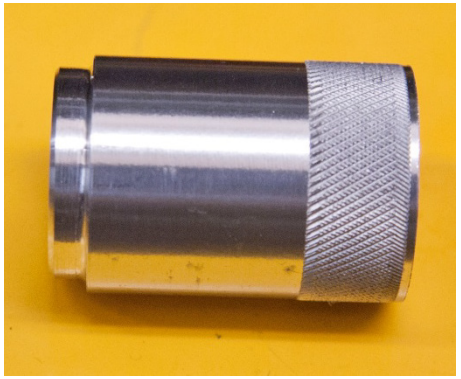
Top (compound) slide is rotated to the left to 45º, and the tool holder realigned. Slowly rotate top slide handle, machining across edge of work. Advance by slowly turning the cross slide handle.

Grooving Tool and Tool bits…

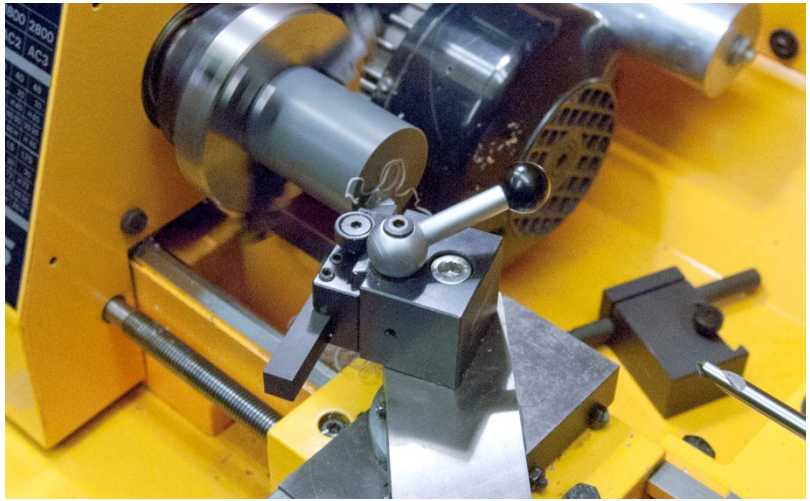


Use for precision grooving – e.g. shaft “e” clips and “o” rings.

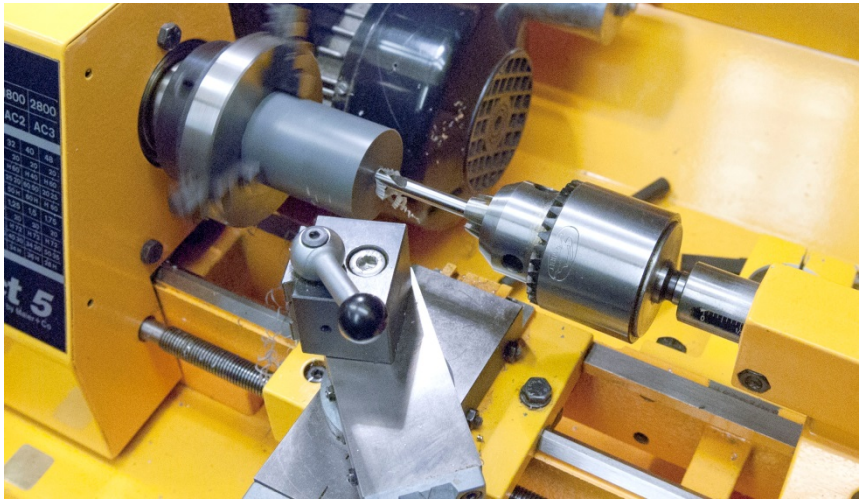
Finished Part...



Boring Operation

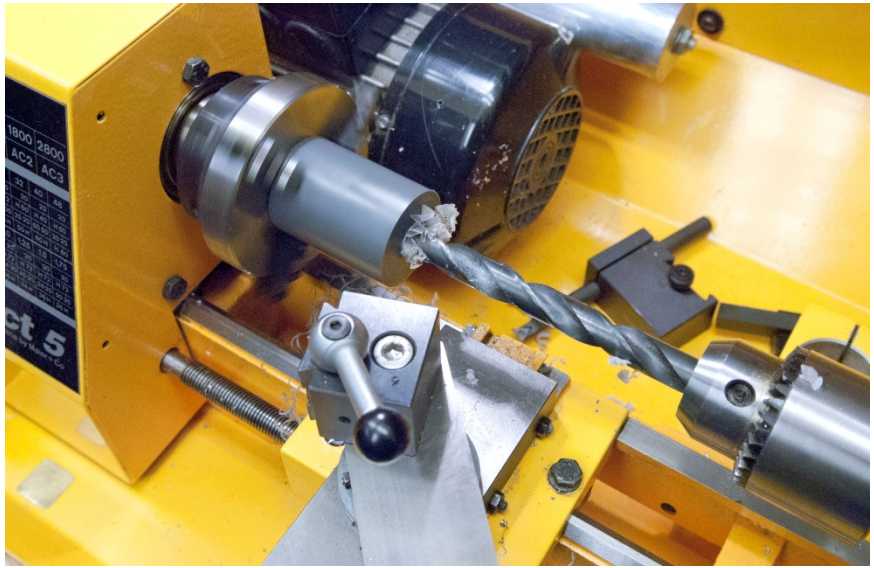


Face the stock.



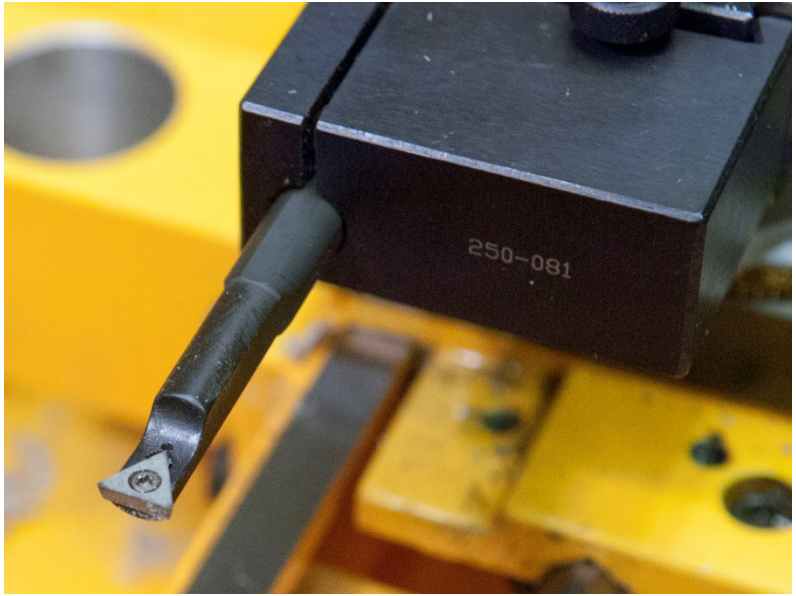
Center drill.

Drill a Starter Hole…

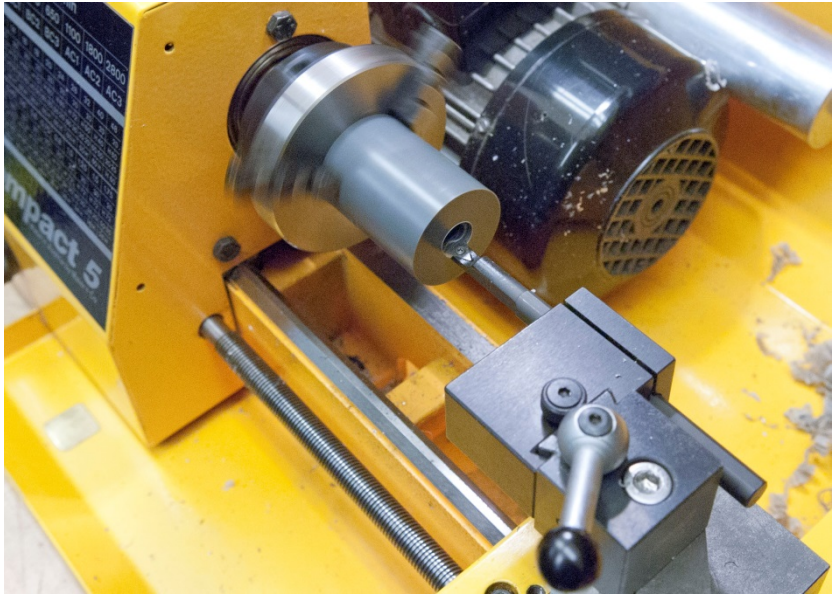


Drill a hole large enough for the boring tool. Step up drill bit sizes for larger diameter holes.

Using the Boring Tool…

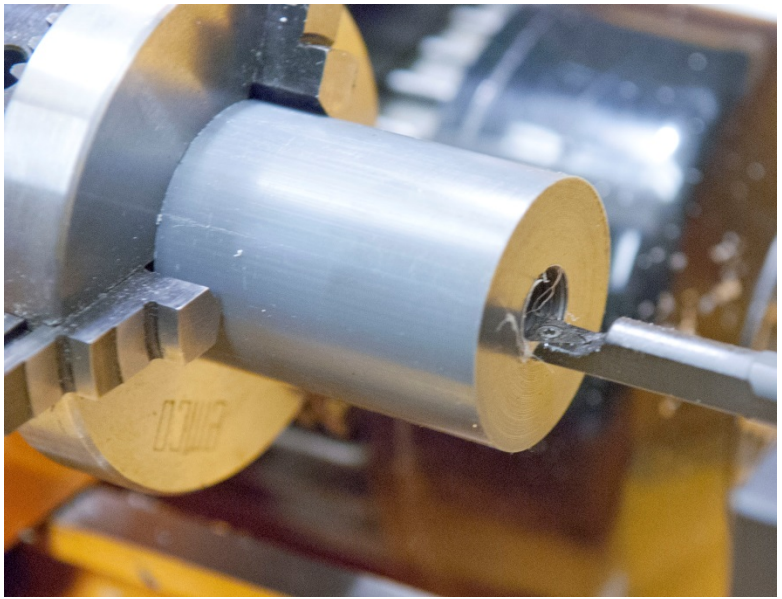


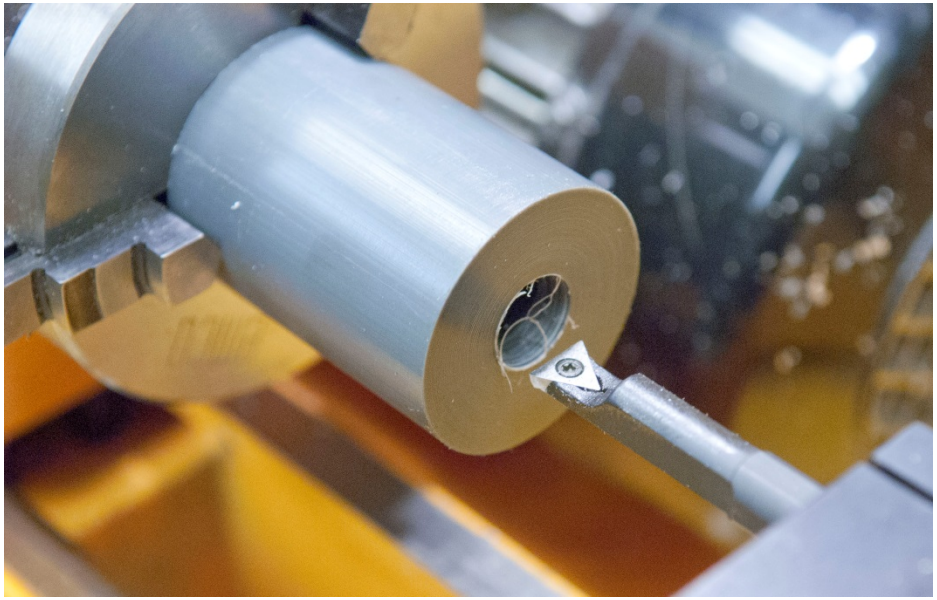
Align boring tool – here a HSS insert.



Check clearances, start at bottom or top of hole. Take off small amounts at a time.

Quality of the Boring…





Plastics can present a problem with melting and poor surface finish. Metals require a lubricant. Try experimenting with different speeds and tools/inserts.

Speed, Feed and Tapping Formulas

- IPR (inches per revolution)
- $S = Spindle\ Speed\ in\ RPM$
- $RPM = 3.82\ x \frac{SFM}{Cutter\ Diameter}$ (revolutions per minutes)
- $SFM = 0.262\ x\ Cuttter\ Diameter\ x\ RPM$ (surface feet per minute)
- $Feed = IPM = IPR\ x\ RPM$ (inches per minute)
- $IPR = specified,\ or\ if\ chip\ load\ per\ flute\ x\ number\ of\ flutes$
- For tap, $F(inch\ per\ min) = \frac{RPM}{TPI}$
- For twist drill, $F(inch\ per\ min) = F(inches\ per\ revolution) x\ RPM$
- F mills, $F(inches\ per\ min) = \left(\frac{Feed}{tooth}\ x\ n\right) x\ RPM$

Lathe Cutting Speeds…

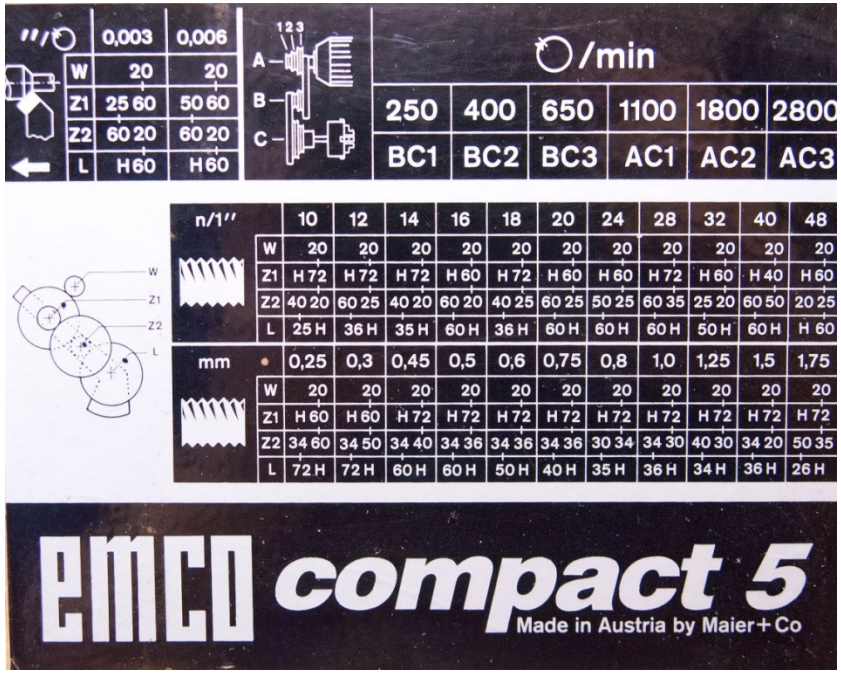
Table 2-1 Cutting Speeds

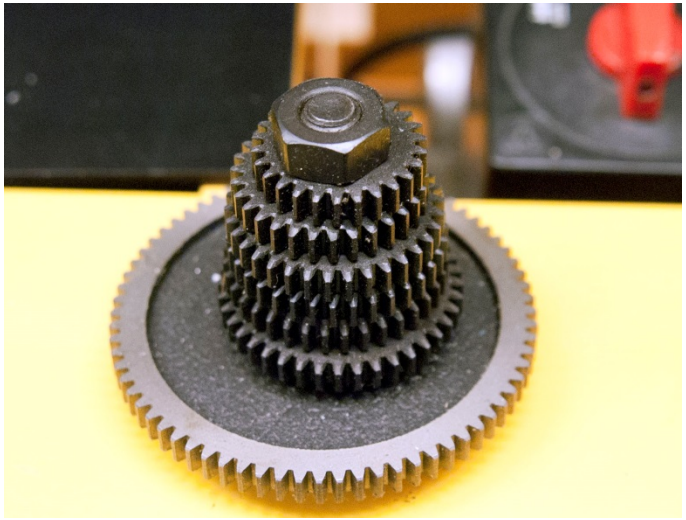
Workpiece Material		Cast iron	Mild Steel	Malleable iron	Cast iron	Bronze	Aluminium	Stainless steel	Brass
HSS tools	Rough cut (ft/min)	50-60	40-50	80-110	45-60	110-150	400	100-120	200-300
	Finish cut (ft/min)	80-110	65-90	110-130	70-90	150-180	700	100-120	200-300
Carbide tools	Rough cut (ft/min)	120-200	140-160	250-300	150-180	600	800	140-200	600-1000
	Finish cut (ft/min)	350-400	250-300	300-400	200-250	1000	1000	240-360	600-1000

See the reference chart for the particular lathe you are using.

http://www.cncspeedsandfeeds.com/index.html

Spindle Speed & Threading Gears





Change gear set.

Some lathes have electronic or gear-box speed controls.

Lubricants/Coolants

Most polymer materials will not need lubricant or coolant. Heavy-duty aluminum, brass and all steel machining should be lubricated/cooled. Wipe clean tools and oil as indicated.

Cleanup

- "Brush and sweep" is preferable when you are done.
- Careful "puffs" of air can be useful, but do not make chips fly carelessly into equipment and onto others.
- Solvent/oily rags should be disposed in an air tight receptacle to prevent spontaneous combustion.

Flammables

Store all flammable liquids in a designated cabinet.

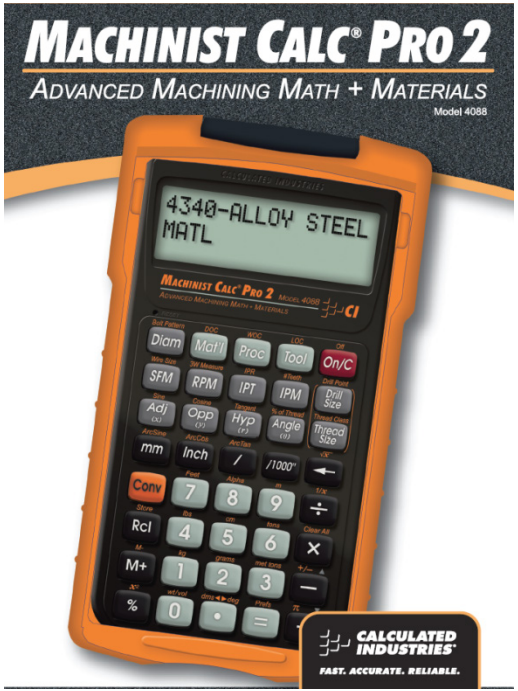
Summary

- Safety
- Lathe
  - Lathe features.
  - Chucks
  - Collets
  - Tools & tool holders
  - Tailstock
  - Steady and traveling rests
  - Lathe operations
  - Spindle and cutting speeds
  - Lubricants/coolants
- Cleanup
- Appendix
  - Formulas & Tables

Abbreviations and Units

- °C = Degrees Celsius
- DIA = Diameter
- d = Depth of Cut
- F = Feed in Inches or mm Per Minute (F)
- °F = Degrees Fahrenheit
- FPR = Feed Per Revolution (F)
- FPT = Feed Per Tooth
- IPM = Inches Per Minute
- IPR = Inches Per Revolution
- L = Length of Cut
- MRR = Metal Removal Rate (cubic in./min.)
- RPM = Revolutions Per Minute
- SFM = Surface Feed Per Minute
- SMPM = Surface Meters Per Minute
- MMPR = Millimeters Per Revolution
- T = Number of Teeth in a Cutter
- TCm = Time Cutting in Minutes
- TCs = Time Cutting in Seconds
- TPI = Threads Per Inch
- W = Width of Cut

Mill & Lathe Formulas



Cutting Speed (surface feet/min.)
SFM = 0.262 x DIA x RPM

Revolutions Per Minute
RPM = 3.82 x SFM ÷ DIA

Feed Rate (in/min.)
IPM = FPT x T x RPM

Feed Per Revolution
FPR = IPM ÷ RPM

Feed Per Tooth (in)
FPT = IPM ÷ (RPM x T)

Metal Removal Rate
MRR = W x d x F

Converting IPR to IPM
IPM = IPR x RPM

Converting IPM to IPR
IPR = IPM ÷ RPM

Converting SFM to SMPM
SMPM = SFM x .3048

Converting IPR to MMPR
MMPR = IPR x 25.40

Distance over Time (in minutes)
L = IPM x TCm

Time Cutting over Distance (Mill) (minutes)
TCm = L ÷ IPM

Time Cutting over Distance (Mill) (seconds)
TCs = L ÷ IPM x 60

Time Cutting over Distance (Lathe) (seconds)
TCs = L ÷ (IPR x RPM) x 60

Left: Calculated Industries
Right: HAAS Machinists CNC Reference Guide 2014

Inch Metric Conversion

INCH METRIC CONVERSION

mm x 0.03937 = in.	in. x 25.4 = mm
m x 39.37 = in.	in. x 0.0254 = m
m x 3.2808 = ft	ft x 0.3048 = m
m x 1.0936 = yd	yd x 0.9144 = m
km x 0.621 = mi	mi x 1.6093 = km
Celsius to Fahrenheit (°C x 1.8) + 32 = °F	Fahrenheit to Celsius (°F - 32) ÷ 1.8 = °C

Tapping & Threading Formula

INCH TAPS

Tap Drill Size (inch) = Thread Diameter $-\frac{0.01299 \times \%\text{ of Full Thread}}{\text{Number of TPI}}$

% of Full Thread (inch) = Number of TPI $\times \frac{\text{Major DIA of Thread} - \text{Drilled DIA}}{0.01299}$

IPM (Mill Tapping Feed Rate) = RPM ÷ TPI

IPR (Lathe Threading) = 1 ÷ TPI

Form Tap Drill Size = Basic Tap DIA $-\frac{0.0068 \times \%\text{ of Full Thread}}{\text{Number of TPI}}$

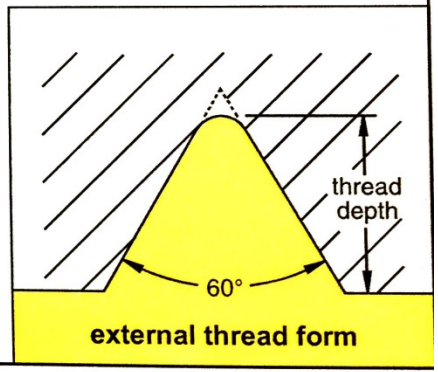
Recommended 65% form thread:

Form Tap Drill Size = Basic Tap DIA $-\frac{0.442}{\text{Number of TPI}}$

Infeed for External Threading

External UN Threads – Recommendations for Steel Workpieces (<300 BHN)

tpi	4	5	6	7	8*	9	10	11	12	13	14	16	18	20	24	28	32	36	40	44	48
thread depth	.1578	.1262	.1052	.0902	.0789	.0701	.0631	.0574	.0526	.0485	.0451	.0394	.0350	.0315	.0263	.0225	.0197	.0175	.0157	.0143	.0131
# passes 1	.0353	.0298	.0248	.0213	.0197	.0175	.0169	.0157	.0152	.0142	.0136	.0125	.0124	.0119	.0118	.0112	.0098	.0087	.0078	.0073	.0065
2	.0146	.0122	.0105	.0088	.0082	.0073	.0070	.0066	.0064	.0057	.0059	.0054	.0053	.0049	.0048	.0046	.0042	.0036	.0032	.0028	.0027
3	.0113	.0094	.0078	.0077	.0063	.0056	.0053	.0048	.0048	.0044	.0043	.0039	.0039	.0039	.0039	.0036	.0031	.0028	.0024	.0022	.0020
4	.0095	.0079	.0067	.0059	.0053	.0047	.0045	.0041	.0042	.0037	.0036	.0034	.0033	.0032	.0031	.0031	.0026	.0024	.0020	.0020	.0019
5	.0084	.0070	.0058	.0050	.0047	.0042	.0039	.0036	.0036	.0033	.0032	.0029	.0029	.0028	.0027						
6	.0076	.0063	.0052	.0045	.0043	.0037	.0036	.0031	.0032	.0030	.0029	.0026	.0026	.0025							
7	.0070	.0058	.0048	.0041	.0039	.0034	.0031	.0028	.0029	.0027	.0026	.0024	.0024	.0023							
8	.0065	.0054	.0045	.0038	.0036	.0032	.0030	.0026	.0027	.0025	.0024	.0022	.0022								
9	.0061	.0051	.0042	.0036	.0034	.0030	.0029	.0025	.0026	.0024	.0023	.0021									
10	.0057	.0048	.0040	.0034	.0032	.0028	.0028	.0024	.0025	.0023	.0022	.0020									
11	.0054	.0045	.0038	.0032	.0031	.0027	.0027	.0023	.0023	.0022	.0021										
12	.0052	.0043	.0036	.0031	.0029	.0026	.0026	.0022	.0022	.0021											
13	.0049	.0042	.0035	.0030	.0027	.0025	.0025	.0021													
14	.0048	.0041	.0034	.0029	.0026	.0024	.0024	.0020													
15	.0046	.0040	.0033	.0028	.0025	.0023															
16	.0044	.0039	.0032	.0027	.0025	.0022															
17	.0043	.0038	.0031	.0026																	
18	.0042	.0037	.0030	.0025																	
19	.0041																				
20	.0039																				



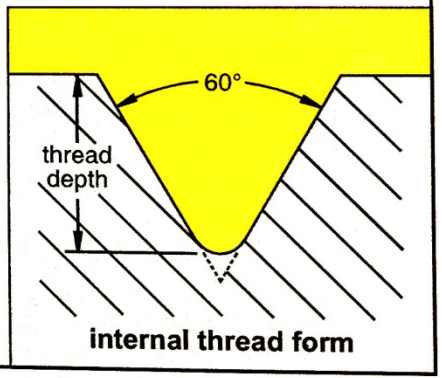
NOTE: These are nominal thread depths for full profile inserts. When using partial profile inserts, reduce the initial doc and increase the number of passes. When threading work-hardening materials, e.g. stainless austenitic steel, the infeed should not be less than .003 of an inch.

Image courtesy of Kennametal

Infeed for Internal Threading

Internal UN Threads – Recommendations for Steel Workpieces (<300 BHN)

tpi	4	5	6	7	8	9	10	11	12	13	14	16	18	20	24	28	32	36	40	44	48
thread depth	.1353	.1082	.0902	.0773	.0676	.0601	.0541	.0492	.0451	.0416	.0386	.0338	.0300	.0270	.0225	.0193	.0169	.0150	.0135	.0123	.0112
# passes 1	.0303	.0255	.0213	.0183	.0169	.0150	.0145	.0132	.0131	.0120	.0117	.0107	.0106	.0102	.0101	.0096	.0084	.0075	.0067	.0061	.0056
2	.0125	.0105	.0090	.0076	.0073	.0062	.0064	.0055	.0054	.0050	.0048	.0043	.0044	.0042	.0042	.0039	.0035	.0031	.0029	.0025	.0023
3	.0096	.0083	.0069	.0058	.0053	.0047	.0046	.0044	.0041	.0038	.0037	.0034	.0033	.0032	.0032	.0033	.0027	.0023	.0021	.0019	.0017
4	.0081	.0068	.0057	.0049	.0047	.0040	.0038	.0035	.0035	.0032	.0031	.0028	.0028	.0027	.0027	.0025	.0023	.0021	.0018	.0018	.0011
5	.0071	.0060	.0050	.0043	.0041	.0035	.0034	.0031	.0031	.0028	.0027	.0025	.0025	.0024	.0023						
6	.0064	.0054	.0045	.0039	.0036	.0032	.0031	.0028	.0028	.0025	.0025	.0029	.0023	.0022							
7	.0059	.0050	.0041	.0036	.0033	.0029	.0028	.0026	.0026	.0023	.0023	.0021	.0021	.0021							
8	.0055	.0046	.0038	.0033	.0030	.0027	.0026	.0024	.0024	.0022	.0021	.0020	.0029								
9	.0052	.0043	.0036	.0031	.0028	.0025	.0024	.0022	.0022	.0021	.0020	.0019									
10	.0049	.0041	.0034	.0029	.0027	.0024	.0023	.0021	.0021	.0020	.0019	.0018									
11	.0046	.0039	.0032	.0028	.0026	.0023	.0022	.0020	.0020	.0019	.0018										
12	.0044	.0037	.0031	.0027	.0025	.0022	.0021	.0019	.0019	.0018											
13	.0042	.0036	.0030	.0026	.0024	.0021	.0020	.0018													
14	.0041	.0035	.0029	.0025	.0023	.0020	.0019	.0017													
15	.0040	.0034	.0028	.0024	.0022	.0019															
16	.0039	.0033	.0027	.0023	.0021	.0019															
17	.0038	.0032	.0026	.0022																	
18	.0037	.0031	.0025	.0021																	
19	.0036																				
20	.0035																				



NOTE: These are nominal thread depths for full profile inserts. When using partial profile inserts, reduce the initial doc and increase the number of passes. When threading work-hardening materials, e.g. stainless austenitic steel, the infeed should not be less than .003 of an inch.

Image courtesy of Kennametal