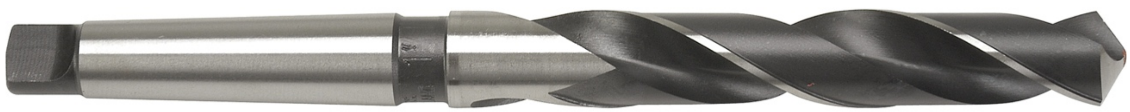
Introduction to Machine Tapers

A conical taper form is the most accurate way to bring two shafts together and know that when they mate, the centerline of both components are aligned. You will find conical tapers used to align tools to spindles universally throughout the machinery world. Where the taper standards differ is the diameter and angle of the taper, and the means by which twisting power is exchanged from the drive end (spindle) to the driven end (tool).

Morse tapers are an example of this. The tool (drill bit for instance) or the tool holder (drill chuck) has a male conical taper that fits precisely into a corresponding female conical taper of the same dimensions (typically in the spindle of the machine). The most common of these machine tapers is the Morse tapers – invented in the mid-1800 to secure a drill bit into the spindle of a drill press (this was before chucks existed). This is an example of a drill bit with a Morse taper end.



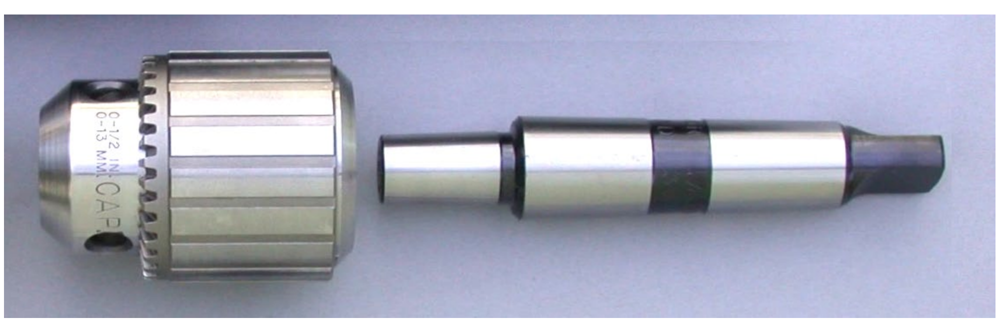
Several different sizes of Morse tapers are in use, and designated by a number from 0 to 7 (including a 4½) and all have a similar taper of approximately 3° included angle.

The specific dimension of the Morse taper standards are as follows.

Taper	Large End	Small End	Length	Taper/ Foot	Taper/ Inch	Angle From Center
#0	0.3561	0.2520	2.00	.6246	.0521	1.4908
#1	0.4750	0.3690	2.13	.5986	.0499	1.4287
#2	0.7000	0.5720	2.56	.5994	.0500	1.4307
#3	0.9380	0.7780	3.19	.6024	.0502	1.4377
#4	1.2310	1.0200	4.06	.6233	.0519	1.4876
#4-1/2	1.5000	1.2660	4.50	.6240	.0520	1.4894
#5	1.7480	1.4750	5.19	.6315	.0526	1.5073
#6	2.4940	2.1160	7.25	.6257	.0521	1.4933
#7	3.2700	2.7500	10.00	.6240	.0520	1.4894

But tapered conical interfaces such as this are used in countless machining applications where tool interchangeability is desirable.

The Jacobs taper is very similar in concept and is used to attach a drill chuck (which has a female taper at one end) to a drill chuck arbor (which has the identical male taper). This is an example of a drill chuck arbor with Morse taper #3 (MT3) at one end, and Jacobs taper #6 (JT6) at the opposite end.



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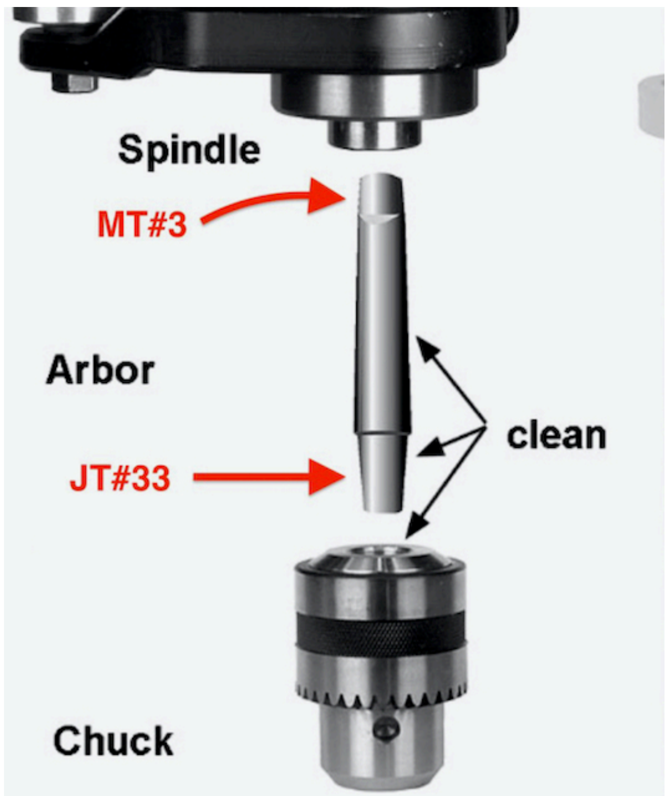
Several different sizes of Morse tapers are in use, and designated by a number from 0 to 7 (including a 4½) and all have a slightly different taper angles as shown below.

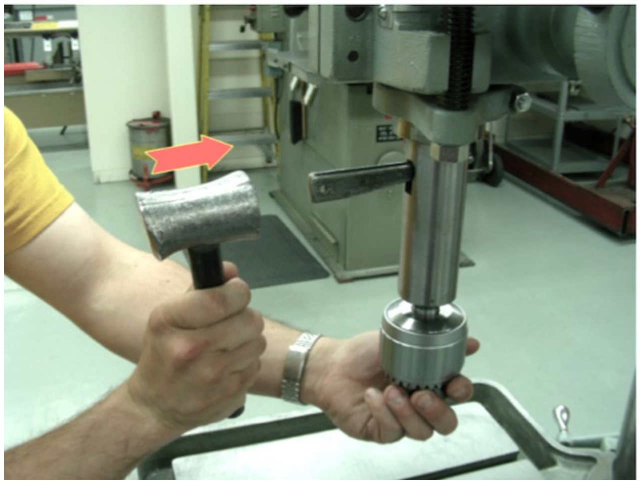
Taper	Large End	Small End	Length	Taper/ Foot	Taper/ Inch	Angle From Center
#0	0.2500	0.2284	0.44	.5915	.0493	1.4117
#1	0.3840	0.3334	0.66	.9251	.0771	2.2074
#2	0.5590	0.4876	0.88	.9786	.0816	2.3350
#2 Short	0.5488	0.4876	0.75	.9786	.0816	2.3350
#3	0.8110	0.7461	1.22	.6390	.0532	1.5251
#4	1.1240	1.0372	1.66	.6289	.0524	1.5009
#5	1.4130	1.3161	1.88	.6201	.0517	1.4801
#6	0.6760	0.6241	1.00	.6229	.0519	1.4868
#33	0.6240	0.5605	1.00	.7619	.0635	1.8184

Both Morse and Jacobs tapers rely on the precise fit and cleanliness of the mating surfaces to yield a friction fit so the spindle can transfer torque into the connected tool and remain seated in the spindle. To ensure a good friction fit, the taper is a low angle, and the surface area of contact is substantial – otherwise the tool may fall out of a spindle when mounted vertically.

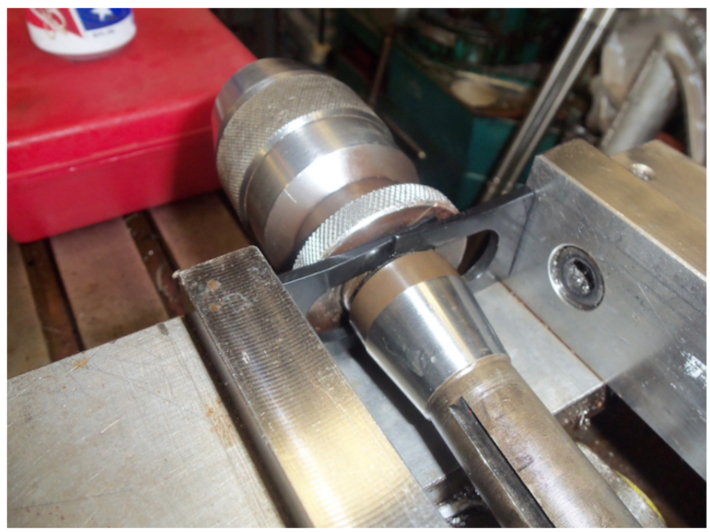


A tool or arbor with a Morse taper, may also have a flat section at the narrow end of the taper called a tang. When the tool or arbor is seated in the spindle of a machine, the taper secures the tool from falling out, while the tang will slot into a recess in the spindle to prevent the tool from slipping or twisting loose inside the spindle under extreme torque loads.

Morse and Jacobs tapers require a wedge of some sort to break the connection once the male and female elements are solidly joined. A Morse taper tool or arbor is typically released from the spindle by driving a wedge-shaped tool in from the side that forces the tool outward from the taper. This tools is commonly called a "drift punch" and is inserted into a slot in the side of the spindle and onward into a corresponding slot in the side of the Morse taper tool. When struck with a lead or soft-blow hammer, the drift will drive the Morse taper tool out of the tapered spindle.



A Jacobs taper is designed with a steep enough taper that a tang is not required to deliver full torque from the arbor to the drill chuck attached to it. Once seated, a drill chuck secured to a Jacobs taper arbor is nearly impossible to pull apart without the assistance of a matched-pair of wedges designed specifically for that purpose. These wedges are available in several sizes to fit the various Jacobs taper diameters. The wedges are forced together (typically in a vise) from opposing sides between the base of the drill chuck and the arbor, and will unseat the Jacobs taper connection.



The biggest issue in using a Morse taper on a mill is that removing the tool from the spindle requires driving a drift into the back end and side of the spindle forcing the tool outward. A better way was required to secure the tapered tool end into the tapered spindle socket and to facilitate removal.

Enter the drawbar. A drawbar is essentially a very long bolt that extends through the center of the spindle and threads into the end of the tool holder, and when the drawbar is tightened, it pulls the tool holder securely up into the spindle forcing the male/female parts of the taper to seat, thus ensuring alignment. To remove the tool, the drawbar is loosened, and a downward force/blow is applied to the top of the drawbar to force the tool out of the taper. Once free from the taper fit, the drawbar and continue to be unwound so that it is no longer threaded into the tool holder, then the tool holder can drop free.

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The next part in this evolution is adding some kind of mechanical means (other than fraction between the two tapered elements) to transfer twisting torque from the powered spindle to the tool holder. This is usually done by including some form of dog in the spindle mating with some kind of slot on the side of the tool holder.

Bridgeport was one of the first companies to recognize the need for something better than the friction fit of a Morse taper, and they invented the R8 taper standard. This is an R8 drill chuck arbor with a J0 taper at the working end for attachment to a drill chuck.

Shown below is an R8 arbor with the drawbar threaded into the end of the arbor. Note that the entire R8 section is quite long – about 120mm and that the taper only exists on the bottom 30 percent. Also note the slot along the side of the R8 section. That slot meshes with a dog-screw in the side of the spindle to transfer torque. Obviously, the R8 section has to be properly clocked to the spindle to get that dog-screw to align with the slot when inserting the tool holder into the spindle. The far end of the R8 taper has a 7/16-20 threaded hole for the drawbar to attach onto the tool holder.

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R8 became used throughout the machinist world in the first half of the 20th century and continues in use today on many manual milling machines. But R8 has a couple of disadvantages in high production environments.

First is s the drawbar having to be unwound at the top of the spindle and the tool hammered out of friction fit to the spindle. Enter the power drawbar. This is a pneumatic contraption that sits on the top of the mill head and will tighten or loosen the drawbar with what is essentially an impact driver. Most are adaptations of the handheld pneumatic impact drivers used to install lug nuts on automobile wheels. They are forceful enough to both loosen and force down the drawbar breaking the taper friction fit. A power drawbar helps make an R8 system behave more like a quick change tool system – easy in, easy out.

The only problem is that there is no easy way to convert an R8 tool holding system into something that can be automated with an automatic tool changer. In CNC production, you really need the machine to be able to change its own tools on command.

The other disadvantage with R8 is its ability to deliver torque above what you'd typically find on a Bridgeport-style mill with 3HP or smaller motor. If you want 5 or 10 or 50 horsepower behind the cutting tool, R8 isn't robust enough to handle that kind of load – the dog-screw would be quickly sheared off and the spindle damaged.

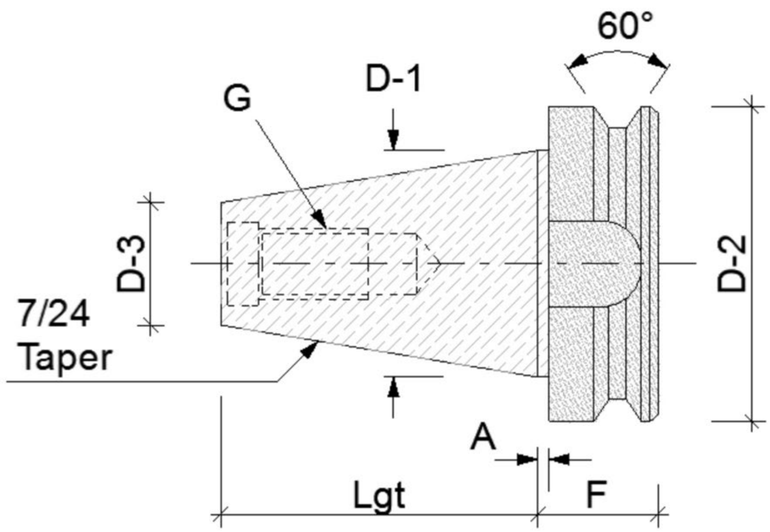
Enter the NMTB taper system, first patented by Kearney & Trecker for their horizontal mill in the 1920's.

This taper is significantly shorter than R8 – and is designed to go into socket at the end of the spindle, rather than going "into" the spindle in a significant way. It looks like this:

The taper is shorter, and the angle is more severe when compared to the R8, which makes this taper self-releasing when released from the spindle. The torque drive mechanism is via the two slots on the side of the tool holder – the spindle has two dogs that protrude outward to mesh with those slots and push the torque into the tool holder. The small end of this taper is a threaded hole, much like the R8.

The NMTB tapers differ in size (diameter), with 30, 40 and 50 being the most common on milling machines. The taper is 3.500 inches per foot and is also referred to as "7 in 24" or 7/24; the computed angle is 16.5943°. The NMTB taper has undergone several enhancements since originally introduced that are referred to as CAT, BT, ISO, etc.

Below is the BT taper drawing and corresponding dimensions.



Size	D1	D2	D3	L	F1	F2 min	A	G
30	1.250 (31.75)	1.812 (46.02)	1.250 (31.75)	1.875 (47.63)	0.750 (19.05)	1.375 (35.00)	0.125 (3.18)	1/2-13 thread
40	1.750 (44.45)	2.500 (63.05)	1.750 (44.45)	2.687 (68.25)	0.750 (19.05)	1.375 (35.00)	0.125 (3.18)	5/8-11 thread
45	2.250 (57.15)	3.250 (82.50)	2.250 (57.15)	3.250 (82.55)	0.750 (19.05)	1.375 (35.00)	0.125 (3.18)	3/4-10 thread
50	2.750 (69.85)	3.875 (98.41)	2.750 (69.85)	4.000 (101.60)	0.750 (19.05)	1.375 (35.00)	0.125 (3.18)	1-8 thread
60	4.250 (107.95)	5.500 (139.70)	4.250 (107.95)	6.375 (161.93)	0.750 (19.05)	1.500 (38.10)	0.125 (3.18)	1 1/4-7 thread

The “International” version of the NMTB standard is the same except the threaded drawbar hole is metric.

In most CNC situations, the threaded hole is filled with a “pull stud” – it looks like this:

The spindle of the machine is designed with a mechanism to latch onto the ball-end of the pull stud and retract it upward with a pneumatic or hydraulic actuator.

The NMTB system has its own limitations having to do with the thermal expansion of the spindle taper which alters the tool projection distance as the temperatures increase. To attain even higher tolerences with CNC equipment, an even more elaborate taper system was required, and this gave rise to the taper standard called HSK which emerged in the 1990’s. I will not go into that here.

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The BT or CAT 40 and 50 series are the most common in the milling industry simply because of their size. The BT30 is often employed on smaller machining centers up to about 5HP, and Tormach and Haas have introduced a BT30 options for the latest generation of their mills.

Tormach invented a tool holder system they call TTS which is a non-taper tool holder that has been adapted to the R8 spindle via a unique collet chuck. It works well on mills with 2HP or smaller motors. Under larger HP conditions or extreme milling situations, the tool holder can slip or pull out of the R8 collet chuck since there is no drawbar or drive-dog securing the tool holder.

This is the TTS adapter for the Tormach mills – it's an R8 tool holder with a specific (3/4") cylindrical hole at the end, and slits along the sides so that when the drawbar pulls up on the R8 end, the ¾" hole contracts as the tapered end is pulled into the R8 spindle taper.

The tool holders that fit this look like this, and are relatively inexpensive (this is an end mill holder):

While not a "taper" system per se, it has become widely popular as a quick change tool holding system and is adaptable to an R8 spindle. The power drawbar for the TTS system is also simpler than R8 systems since it only needs to push down on the drawbar rather than rotating the drawbar. Simply pushing down on the drawbar approximately 1/4" will release the tool holder.

The TTS tool holding system has one other advantage important on CNC machines: each time a tool is installed, the tool projection distance from the spindle remains consistent, thus the Z-axis is always calibrated to an established tool length from a library. Tormach also sells an option on their mills for an automatic tool changer.

The Royal Easychange system is similar to the Tormach TTS system in that it has an R8 compatible collet, and a proprietary tool holder for each tool. The advantage of the Easychange system is that you never have to mess with the drawbar to change tools. With TTS, you have to loosen the drawbar to remove and tighten to secure tool holders. The other advantage of Easychange over TTS is that the system incorporates a dog-slot drive system for transferring torque from spindle to tool, thus overcoming the torque limitations (tool pull-out) of the TTS. But Easychange is more expensive.

Here's an Easychange tool holder system in comparison – R8 collet on right, tool holder on left. It has a tapered fit giving more precise concentricity than TTS. Full torque is delivered through the two drive-dogs, and tool changes are twist-on/twist-off via the collar on the chuck (no drawbar action required).