Taper Turning on the Engine Lathe 240
Class Outline

Objectives
Overview of Taper Turning on the Lathe
Common Tapers
Common Methods for Turning Tapers
Calculating Taper per Foot
Taper Turning Using Tailstock Offset
Taper Turning Using The Compound Rest Method
Taper Measurement
Boring an Internal Taper
Summary
Lesson: 1/10

Objectives
- Describe the purpose of a tapered machine tool component.
- Describe common types of tapers.
- Describe common methods for turning tapers.
- Calculate taper per foot for a given example.
- Describe how to turn a taper using tailstock offset.
- Describe how to calculate and set up turning a steep taper using the compound rest.
- Describe how to measure and verify a taper after turning.
- Describe how to turn an internal taper.

![Figure 1. Tapered components are common in machine tools.](image1)

![Figure 2. Tailstock offset is one method of turning a tapered part.](image2)
Lesson: 2/10

Overview of Taper Turning on the Lathe
Manual lathes are used to create cylindrical parts from bar stock. The most complex turned parts often have a tapered form. A taper is a uniform change in the diameter of a workpiece when measured along its axis (Figure 1). While tapers created on a lathe are cylindrical, a taper created on a mill can be flat-sided or angular, like a wedge.

Tapers are common in machine tool components (Figure 2) because tapers give an accurate way to align parts and hold tools. For example, machine tool spindles have internal tapers that provide firm and reliable placement of toolholders and workholders. A number of standard tapers are used in machine tools, such as the Morse taper often found in lathe spindles and tailstocks.

Turning a taper on a lathe can be complicated, depending on the method chosen to perform the operation. Simply put, a taper is created by angling the workpiece and cutting tool relative to one another as the tool travels along the workpiece. As the tool travels along the workpiece, it gradually cuts deeper or shallower, creating a tapered surface, such as the tapered section in Figure 3.

This class covers taper turning on the engine lathe. You will also learn about different types of standard tapers and how to calculate taper angles.
Common Tapers
Many machine tools use components with a steep taper, sometimes referred to as an American Standard, NMTB or ISO taper. This is used to mate a toolholder adapter to a spindle. The term steep taper means that the angle of the taper is large enough that the spindle adapter will self-release easily. A threaded drawbar is commonly used to keep the adapter in place, while turning force is transmitted by slots on the flange. There are a number of different national standards for machine tool tapers, but most are compatible with the American Standard.

On the lathe it is more common to find a long taper, usually a Morse taper, in the tailstock, and likely in the spindle as well, which makes the mounting of centers much easier. The Morse taper is considered a self-holding taper, because it is held in place through friction rather than by a drawbar. It is more gradual than a steep taper. It is made in 9 sizes, numbered 0 through 7 and including a rarely-used 4-1/2 size. The Morse taper is also found extensively in drilling machines and grinding machines. Other common self-holding tapers are Brown & Sharpe, used mostly in milling machines and grinding machines, but also found in some lathes, and Jarno, used in lathes and grinding machines.

To calculate and set up a steep taper using the compound rest:

1. Calculate the taper per foot and taper angles. Several types of standard tapers exist, such as American Standard, Morse, and R8. “Long” tapers are used for short, steep tapers.

2. Measure and verify the taper after turning. The machinist can use a taper ring gage to check an internal taper.

To turn a taper using tailstock offset:

1. Offset the tailstock for turning the sample taper. The machinist must first loosen the front set screws and move the tailstock back so the work can be mounted on the cross slide.

2. To calculate taper per foot and taper angles, the machinist can use the trigonometric function on a scientific calculator. To find the angle in degrees, the machinist can use the trigonometric function on a scientific calculator.

Lesson: 3/10

Summary
Common Methods for Turning Tapers

Lesson: 3/10

Common Tapers
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Lesson: 4/10

Common Methods for Turning Tapers
Turning a taper on a lathe is done in one of three ways. The easiest is to use a taper attachment, although not every lathe is equipped with this option. Taper attachments are especially useful for long tapers without a steep angle, because the guide can be attached to the back of the lathe bed. The taper attachment has a taper bar, or guide bar, set on a sliding base. A guide shoe travels along the taper bar, which is set to the desired taper angle, measured in degrees of taper. The guide shoe is attached to the cross-slide and moves the cross-slide at an angle to create the taper as the carriage moves the toolholder. This method allows the lathe to machine the taper between centers for the full length of the center distance. The part could also be held in a chuck, if it is not too long.

Turning a steep taper with a shorter overall length can be accomplished by using the compound rest method. The work can be mounted between centers or in a chuck, and only the rest needs to be set for the operation. However, the scale on the rest is typically graduated in 1° increments, so accuracy is sometimes difficult to achieve.

Less common, and more difficult, is the tailstock offset method. This limits the taper, and does not allow for turning an internal taper, unlike the other two methods. In addition, this method puts a great deal of stress on the tailstock center. This can lead to damage in a live center, and requires thorough lubrication of a dead center. Before any other operation on the lathe, the tailstock must be realigned to the spindle centerline, which can be time-consuming.

Figure 1. A diagram showing a common taper attachment on the rear of the lathe.

Figure 2. A diagram of tailstock offset.
Lesson: 5/10

Calculating Taper per Foot
Almost every lathe, mill, drill press, and CNC machine uses a tapered component to hold workpieces and tooling. Tapers can be indicated with a ratio, such as 1:12, or more commonly as taper per foot \( tpf \), which is easily calculated by the formula in Figure 1. In the formula, \( D \) is the diameter of the large end of the work, \( d \) is the diameter of the smaller end of the work, and \( L_1 \) is the length of the tapered section.

Before turning a taper, the machinist must decide which method best meets the needs of the work. For a simple example, assume the blueprint calls for a workpiece of five and one-quarter inches to be machined into a self-holding taper that is 1.25 inches (31.75 millimeters) at its wide end tapered to 1.00 inches (25.4 millimeters) at the other end. Figure 2 illustrates such a taper.

Using the dimensions in Figure 2, the operator calculates the taper using the formula in Figure 1. Thus, the taper per foot \( tpf \) is .600 inches (15.24 millimeters). Since the taper for this workpiece is not a steep taper, and the workpiece is not especially long, any of the taper turning methods could be used. The easiest would be to use the taper attachment, or the guide bar, but not all lathes are so equipped.

\[
tpf = \frac{D - d}{L_1} \times 12
\]

Figure 1. A formula to calculate taper per foot.

Figure 2. A sample long taper.
Lesson: 6/10

Taper Turning Using Tailstock Offset
If a taper attachment is not available and the compound rest method is too imprecise, the operator can choose to mount the work between centers and use tailstock offset to machine the taper. In the example in Figure 1, the taper is relatively small. This operation requires another calculation to determine the amount of offset for the tailstock, so the machinist must use one of the formulas in Figure 2. The result is an offset of 0.13125 inches (3.33375 millimeters). The tailstock offset is not the easiest, nor is it the most common method for turning a taper, but it is suitable for a small taper such as this.

To offset the tailstock for turning the sample taper, the machinist must first loosen the front set screw at the bottom of the tailstock, and then the set screw at the rear, directly opposite. The tailstock can be moved the required distance, 0.13125 inches, along the X axis. The offset is checked easily by moving the tailstock toward the headstock, so that the centers can be compared by measuring the gap between the two.

Once the offset is verified, tighten the set screws and move the tailstock back so the work can be mounted. For this example, assume that the workpiece has already been machined to the correct large diameter, and center drilled for mounting. There may be some extra stock that will allow the piece to be held in a chuck later for the final parting procedure, but this is not necessary to turn the work between centers.

\[
\text{offset} = \frac{tpf \times L}{24}
\]

\[
\text{offset} = \frac{L \times (D - d)}{2 \times L_1}
\]

Figure 1. Diagram of a sample long taper.

Figure 2. Two formulas for calculating tailstock offset.

Figure 3. Tailstock offset is used for long tapers mounted between centers. One way to check offset is to use a machinist's rule to measure the offset of the centers. However, a machinist's rule is only accurate to 1/64 inch.
Lesson: 7/10

Taper Turning Using The Compound Rest Method
A part with a steep taper angle, like the one in Figure 1, may be more suited to the compound rest method of taper turning. To use the compound rest method, the machinist must calculate half the taper angle, the angle with the centerline ($\frac{1}{2} \alpha$). Using the tpf formula, the machinist determines that this part has 3.500 taper per foot. Dividing by 12, the taper per inch (tpi) is determined to be 0.2917 (7.409 millimeters).

To find the angle in degrees, the machinist can use the trigonometric function on a scientific calculator to find the tangent for $\frac{1}{2} \alpha$, or consult a trigonometric table to find the corresponding angle after solving the equation in Figure 2. Completing the formula, the machinist discovers that the tangent of the angle with the centerline is 0.1458, which translates to 8° 17’ 50” on a trigonometry table. The included angle is twice that, or 16° 35’ 39”. Due to the length of the part, the machinist will probably mount the work in a chuck, rather than between centers.

The compound rest method is particularly useful for turning short, steep tapers. To do so, the rest must be set at the angle with the centerline of the taper to be cut. This is difficult because the graduated dial on the compound rest is usually measured in 1 degree increments, not minutes and seconds. The machinist can set the rest at 8° and approximate 17 minutes (slightly more than ¼ degree), and make trial cuts, measure carefully, and readjust the rest until the desired taper is cut.

The compound rest in this example is set at approximately 8 ¼ degrees (8° 15’), slightly less than the required taper. The machinist sets the lathe speed appropriate to the material, and begins turning the piece, cutting from right to left and adjusting the depth of the cut at each pass. An experienced machinist may feed the tool by hand-turning the feed handle on the compound rest, until the taper is close to the required dimensions. At that point, careful measurements and adjustments begin.

\[
\tan \frac{1}{2} \alpha = \frac{D - d}{2L_1}
\]

Figure 1. A diagram of a sample steep taper.

Figure 2. The formula for calculating the tangent of the angle from the centerline, which leads to determining taper angle.

Figure 3. The compound rest method is the easiest way to cut a steep taper.
Lesson: 8/10

Taper Measurement
Several methods are available to verify the dimensions of the tapered piece. The machinist can scribe two lines exactly one inch apart on the taper. Using a micrometer to measure the diameter at each line yields the tpi of the taper when the smaller measurement is subtracted from the larger measurement. This is especially simple, as most micrometers have digital readouts that record to several decimal places.

A machinist may use a sine bar to measure the taper, but this requires removing the workpiece from the chuck. The sine bar method adds to the production time and effort. The taper micrometer consists of a small sine bar and an adjustable anvil, and can be used while the work is still mounted on the lathe. This device is adjusted using a micrometer thimble, and provides speedy, accurate measurements of tpi, which is easily converted to tpf.

The easiest and most precise measurements are made using a taper ring gage or a taper micrometer. Both of these can be used without removing the work from the chuck. To use a taper ring gage, the machinist places lines of machinist’s layout dye equally spaced on the taper before sliding the ring gage over the part. Giving the ring gage a half-turn over the taper and removing it reveals whether or not the taper is accurate. If the lines are rubbed only from one end, for example, the taper should be adjusted. If the lines are uniformly rubbed over the work, the taper is accurate.
Lesson: 9/10

Boring an Internal Taper
Turning an internal taper is similar to boring a hole in a workpiece, with the exception that it is done at an angle. Obviously, the tailstock offset method cannot be used because ID turning is impossible with the work mounted between centers. The work can be completed using a taper attachment. However, the machinist must account for any backlash, which can cause the tool to cut straight for a short distance before the tapering actually begins.

The taper calculations are the same as with an external taper. So if the internal and external tapers are matched, the same setting is used for both.

Using a boring tool with the compound rest method is useful for producing an internal taper. To begin, drill and bore a hole to the small diameter of the taper. Be sure to align the cutting tool to the centerline axis of the work, and set the compound rest to the angle from the centerline. The boring bar must be small enough to pass into the hole to be tapered without rubbing. Hand-feed the tool to ensure accuracy, and make small cuts as the taper is formed, until the correct size is cut.

It is important to ensure that all chips are cleared from the tool and the bore to avoid damaging both the part and the tool. When the desired taper is almost reached, standard size tapers can be finish-cut with a taper-reamer.

Figure 1. Boring an internal taper is similar to boring a straight hole. The only difference is the angle of the tool.

Figure 2. Using a taper plug gage is one way to check an internal taper.
Lesson: 10/10

Summary
Tapered components are common in machine tools and help align and hold the various workholders and tools. The angle of a taper is expressed by a ratio, such as 7:24, or by taper per foot. There are a number of formulas available to calculate taper per foot and taper angles. Several types of standard-sized tapers exist, such as American Standard, Morse, and R8. "Long" tapers are also referred to as "self-holding," and "steep" tapers are often referred to as "self-release."

Tapers can be turned on the lathe in three ways: by taper attachment, tailstock offset, and by using the compound rest. Of these, the tailstock offset is least common and most difficult, and is used for long tapers only. The compound rest method is best suited for steep tapers, but over a shorter length. The easiest method of taper turning is to use the taper attachment on a lathe, but not all lathes are so equipped. An internal taper can be turned much like an external taper, but not by using the tailstock offset.

Tapers can be measured and verified by using ring gages, micrometers, or sine bars for external tapers, or by using a taper plug gage or internal micrometer for internal tapers.

Figure 1. Tapered components are common in machine tools, and are known as "steep" (self releasing) or "long" (self holding).
Class Vocabulary

**American Standard**
A steep or long taper configuration that has been adopted by ANSI/ASME for use in machine tools. American Standard is used extensively in milling machines.

**Angle With The Centerline**
The 1/2 angle of a taper, degrees measured from the centerline axis of a cylindrical part.

**Backlash**
The amount of slack, or play, between a lead screw and nut that moves the cross-slide. Backlash grows over time and must be compensated for during turning.

**Brown & Sharpe**
A standard taper with a taper per foot of 0.5000 inches (12.7 mm), except for B & S # 10, which has a tpf of 0.5161 inches (13.11 mm). Used mostly in milling machines and grinding machines.

**Compound Rest**
A part of the cross-slide on a lathe that holds the toolpost, and can be rotated up to 90 degrees.

**Drawbar**
Usually, a threaded bar that fits through the spindle bore of a machine to hold and pull a collet or tapered toolholder tight against the spindle nose.

**Included Angle**
The full angle of a taper, or twice the angle from the centerline of a taper.

**Jarno**
A standard taper with a taper per foot of 0.6000 inches (15.24 mm). Used in some lathes, and many other machines.

**Long Taper**
Any of a series of self-holding tapers, typically with long shanks and a taper angle of 2 to 3°, or less than one inch per foot.

**Micrometer**
A measuring device used for measurements of machined parts typically to within 0.001 of an inch, and sometimes to 0.0001 of an inch.

**Morse Taper**
A standard taper with a taper per foot of approximately 5/8 inch (approx. 15.875 mm). Used in a wide variety of machines, especially lathes, but exclusively in twist drill shanks.

**Ratio**
An expression of taper in inches per foot, such as 1:12.

**Self-Holding**
Another term for a long taper, indicating that the taper is designed to be held in a spindle by friction.

**Sine Bar**
A measuring device used specifically to precision measure angles. Taper micrometers include small sine bars, and can be used to measure taper angles without removing work from the lathe.

**Steep Taper**
Any of a series of self-releasing tapers, typically with short shanks and a taper angle of 16° or 3.5 inches (88.9 mm) per foot.

**Tailstock Offset**
A method of turning long tapers between centers in which the lathe tailstock is set a small distance off the centerline.

**Tangent**
In a triangle, the ratio of the side opposite an angle to the side adjacent to the angle. Finding the tangent of an angle helps a machinist convert to degrees in order to set up a turning operation properly.

**Taper**
The uniform change in diameter of a cylindrical workpiece when measured along its axis.

**Taper Attachment**
A specialized lathe attachment that includes an angled guide bar and shoe used to machine a taper on a cylindrical part.

**Taper Micrometer**
A specialized measuring device that includes a small sine bar mounted on an anvil that can measure taper angles without removing work from a lathe.

**Taper Per Foot**
The change in diameter of a cylindrical part measured in terms of inches per foot of length.

**Taper Per Inch**
The change in diameter of a cylindrical part measured in terms of inches per inch of length.
Describe the purpose of a tapered machine tool component.

Describe common methods for turning tapers.

Today's businesses face the challenge of maintaining a trained workforce. Companies must locate apprenticeship programs, cover travel and lodging to calculate taper per foot and taper angles. Several types of standard finish both the part and the tool. When the desired taper is almost reached, standard size tapers can be used.

It is important to ensure that all chips are cleared from the tool and the bore to avoid damaging the tool. The taper calculations are the same as with an external taper. So if the internal and external tapers are identical, the taper per foot can be calculated using the following equation:

\[ \text{TPF} = \frac{d_1 - d_2}{L} \]

where:
- \( d_1 \) is the diameter of the large end of the work
- \( d_2 \) is the diameter of the smaller end of the work
- \( L \) is the length of the work

The taper calculations are similar to those used for calculating an external taper. So if the internal and external tapers are identical, the taper per foot can be calculated using the equation above.

The compound rest in this example is set at approximately 8 ¼ degrees (8° 15 seconds. The machinist can set the rest at 8° and approximate 17 minutes (slightly more than ¼ inch). The compound rest method is particularly useful for turning short, steep tapers.

Before turning a taper, the machinist must decide which method best meets the needs of the work. The easiest and most precise measurements are made using a micrometer from the chuck. The sine bar method adds to the production time and effort.

The Taper Ring Gage consists of a small sine bar and an adjustable anvil, and can be used while the work is mounted between centers. The work can be completed using a taper attachment.

Common Methods for Turning Tapers

- **Taper Ring Gage**: A measuring device with an internal taper used specifically to determine taper angle of a cylindrical part.

- **The easiest and most precise measurements are made using a micrometer from the chuck**.

- **The sine bar method** adds to the production time and effort.

- **To do so, the rest can be used with the work mounted between centers**.

- **The compound rest method** is particularly useful for turning short, steep tapers.

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