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1.Lathe (metal)

Fig. Center lathe with DRO and chuck guard. Size is 460 mm swing x 1000 mm between centers

The principal part of a lathe are labeled below figures. Controls on the side of the head stock allow selection of any one of many speeds, which are arranged in logical geometric progression. A combination of electric chuck and brake is provided for starting, stopping, or jogging the work(1).

The machine has been greatly modified for various applications however a familiarity with the basics shows the similarities between types. These machines consist of, at the least, a headstock, bed, carriage and tailstock. The better machines are solidly constructed with broad bearing surfaces (slides or ways) for stability and manufactured with great precision. This helps ensure the components manufactured on the machines can meet the required tolerances and repeatability required.

1.1.Headstock
The headstock (H1) houses the main spindle (H4), speed change mechanism (H2,H3), and change gears (H10). The headstock is required to be made as robust as possible due to the cutting forces involved, which can distort a lightly built housing, and induce harmonic vibrations that will transfer through to the workpiece, reducing the quality of the finished workpiece.

The main spindle is generally hollow to allow long bars to extend through to the work area, this reduces preparation and waste of material. The spindle then runs in precision bearings and is fitted with some means of attaching work holding devices such as chucks or faceplates. This end of the spindle will also have an included taper, usually morse, to allow the insertion of tapers and centers. On older machines the spindle was directly driven by a flat belt pulley with the lower speeds available by manipulating the bull gear, later machines use a gear box driven by a dedicated electric motor. The fully geared head allows the speed selection to be done entirely through the gearbox and be a dogo

1.2. Bed

The bed is a robust base that connects to the headstock and permits the carriage and tailstock to be aligned parallel with the axis of the spindle. This is facilitated by hardened and ground ways which restrain the carriage and tailstock in a set track. The carriage travels by means of a rack and pinion system, leadscrew of accurate pitch, or feedscrew.

1.3. Feed and lead screws

The feedscrew (H8) is a long driveshaft that allows a series of gears to drive the carriage mechanisms. These gears are located in the apron of the carriage. Both the
feedscrew and leadscrew (H9) are driven by either the change gears (on the quadrant) and or an intermediate gearbox known as a quick change gearbox (H6) or norton gearbox. These intermediate gears allow the correct ratio and direction to be set for cutting threads or worm gears. Tumbler gears (operated by H5) are provided between the spindle and gear train along with a quadrant plate that enables a gear train of the correct ratio and direction to be introduced. This provides a constant relationship between the number of turns the spindle makes, to the number of turns the leadscrew makes. This ratio allows screwthreads to be cut on the workpiece without the aid of a die.

The leadscrew will be manufactured to either imperial or metric standards and will require a conversion ratio to be introduced to create thread forms from a different family. To accurately convert from one thread form to the other requires a 127-tooth gear, or on lathes not large enough to mount one, an approximation may be used. Multiples of 3 and 7 giving a ratio of 63:1 can be used to cut fairly loose threads. This conversion ratio is often built into the quick change gearboxes.

1.4. Carriage

![Carriage](image)

The carriage assembly includes the compound rest, tool saddle and apron. Because it supports and guides the cutting tool, it must be rigid and constructed with accuracy. Two-hand feeds are provided to guide the tool in a crosswise motion(1).

The operator moves the carriage manually via the handwheel (5a) or automatically by engaging the feedscrew with the carriage feed mechanism (5c), this provides some relief for the operator as the movement of the carriage becomes power assisted. The handwheels (2a, 3b, 5a) on the carriage and its related slides are usually calibrated, both for ease of use and to assist in making reproducible cuts.

1.4.1. Cross-slide

The cross-slide(3) sits atop the carriage and has a leadscrew that travels perpendicular to the main spindle axis, this permits facing operations to be performed. This leadscrew can be engaged with the feedscrew (mentioned
previously) to provide automated movement to the cross-slide, only one direction can be engaged at a time as an *interlock* mechanism will shut out the second gear train.

### 1.4.2. Compound Rest

It has been suggested that *slide rest* be merged into this article or section. (Discuss)

(2) The **Compound Rest** (or top slide) is the part of the machine where the tool post is mounted. It provides a smaller amount of movement along its axis via another leadscrew. The compound rest axis can be adjusted independently of the carriage or cross-slide. It is utilized when turning tapers, when screwcutting or to obtain finer feeds than the leadscrew normally permits.

### 1.4.3. Toolpost

(1) The tool bit is mounted in the toolpost which may be of the American *lantern* style, traditional 4 sided square style, or in a quick change style such as the multifix arrangement pictured. The advantage of a quick change set-up is to allow an unlimited number of tools to be used (up to the number of holders available) rather than being limited to 1 tool with the lantern style, or 3 to 4 tools with the 4 sided type. Interchangeable tool holders allow all the tools to be preset to a center height that will not change, even if the holder is removed from the machine.

### 1.5. Tailstock

![Fig. Tailstock with legend, numbers and text within the description refer to those in the image](image)

The **tailstock** is a toolholder directly mounted on the spindle axis, opposite the headstock. The spindle (T5) does not rotate but does travel longitudinally under the action of a leadscrew and handwheel (T1). The spindle includes a taper to hold drill bits, centers and other tooling. The tailstock can be positioned along the bed and clamped (T6) in position as required. There is also provision to offset the tailstock (T4) from the spindles axis, this is useful for turning small tapers.

The image shows a reduction gear box (T2) between the handwheel and spindle, this is a feature found only in the larger center lathes, where large drills may necessitate the extra leverage.
2. Types of metal lathes

There are many variants of lathes within the metalworking field. Some variations are not all that obvious, and others are more a niche area. For example, a centering lathe is a dual head machine where the work remains fixed and the heads move towards the workpiece and machine a center drill hole into each end. The resulting workpiece may then be used "between centers" in another operation. The usage of the term metal lathe may also be considered somewhat outdated these days, plastics and other composite materials are in wide use and with appropriate modifications, the same principles and techniques may be applied to their machining as that used for metal.

2.1. Center lathe

A center lathe or engine lathe may be considered the basis for the metal lathe and is the type most often used by the general machinist or hobbyist. The construction of a center lathe is detailed above, but depending on the year of manufacture, price range, or desired features, even these lathes can vary widely between models. For convenience, the center lathe may be considered a useful starting point.

2.2. Capstan (Ram-type) lathe

The modern name for a capstan lathe used in industry is a ram-style turret lathe. A capstan lathe is a production machine that combines the features of the basic lathe along with a capstan style tailstock. This tailstock has a short slide upon which sits the hexagonal capstan head and a set of depth stops, one for each turret face. The main body is fixed to the bed in the required position and all longitudinal movement is via the short slide. The stroke of the capstan is short but the sequence can be rapid as the tooling indexes automatically at the end of the stroke. This indexing and movement is performed by turning a large levered handwheel as required. This type of Lathe is ideal to perform multiple matching operations with high accuracy and superior surface finish. Modern capstan lathes are referred to as ram-style turret lathes. They have a short spindle-to-turret distance, usually in the range of twenty to thirty inches. It is rare to find a capstan lathe with a lead screw or a taper attachment, as lead screw threading is usually far too slow for production. A die head is used instead.
2.3. Turret (Saddle-type) lathe

A turret lathe is a production machine that to all appearances is the same as the capstan, however the turret slides directly on the bed rather than being fixed. Some turret Movement of the turret can therefore be anywhere along the bed.1 Because of this feature, saddle-type turret lathes are far longer than the ram-type turret lathe. It is common to find saddle lathes longer than 200" for sale. Oil country and hollow spindle lathes are often of the saddle turret type. The main advantage associated with this type of lathe is that different machining operations such as drilling, reaming, boring etc., can be performed in a single tool setting by using different tools in a hexagonal turret. This considerably reduces tool setting time.

2.4. Multispindle lathe

A multispindle lathe, commonly called a screw machine, is another production machine that is of high capacity. These machines may have up to 12 spindles that all operate simultaneously, each spindle will have its own tooling and the completion of one full cycle usually produces one part, although this depends on the number of operations required to produce the part. The sequence of events is programmed into the machine by adjusting stops, cams and levers and requires a highly skilled machine setter to perform the process efficiently. The setting and operation of the machine was quite often performed by different people. Two other machines fall into the screw machine category, chucking machines with a higher diameter capacity, and rotary transfer machines, capable of end-to-end parts production of both milled and turned parts.

2.5. Combination lathe

A combination lathe may introduce drilling or milling operations into the design of the lathe. These machines utilize the carriage and topslide as the x and y axis of the machine. These are exclusive to the home market, as the machines are not rigid, accurate, or large enough to be useful in a machine shop. They may be found in smaller, non-machine oriented businesses where the occasional part must be turned.

2.6. CNC lathe / CNC Turning Center
CNC lathes are rapidly replacing the older production lathes (multispindle, etc) due to their ease of setting and operation. They are designed to use modern carbide tooling and fully utilize modern processes. The part may be designed by the Computer-aided manufacturing (CAM) process, the resulting file uploaded to the machine, and once set and trialled the machine will continue to turn out parts under the occasional supervision of an operator. The machine is controlled electronically via a computer menu style interface, the program may be modified and displayed at the machine, along with a simulated view of the process. The setter/operator needs a high level of skill to perform the process, however the knowledge base is broader compared to the older production machines where intimate knowledge of each machine was considered essential. These machines are often set and operated by the same person, where the operator will supervise a small number of machines (cell).

The design of a CNC lathe has evolved yet again however the basic principles and parts are still recognisable, the turret holds the tools and indexes them as needed. The machines are totally enclosed, due in large part to Occupational health and safety (OH&S) issues.

2.7. Swiss Style Lathe / Swiss Turning Center

For work requiring extreme accuracy (sometimes holding tolerances as small as a few tenths of a thousandth of an inch), a Swiss style lathe is often used. A Swiss style lathe holds the workpiece with both a collet and a guide bushing. The collet sits behind the guide bushing, and the tools sit in front of the guide bushing, holding stationary on the Z axis. To cut lengthwise along the part, the tools will move in and the material itself will move back and forth along the Z axis. This allows all the work to be done on the material near the guide bushing where it's more rigid, making them
ideal for working on slender workpieces as the part is held firmly with little chance of deflection or vibration occurring.

This style of lathe is also available with CNC controllers to further increase its versatility.

Most CNC Swiss style lathes today utilize two spindles. The main spindle is used with the guide bushing for the main machining operations. The secondary spindle is located behind the part, aligned on the Z axis. In simple operation it picks up the part as it is cut off (or parted off) and ejects it into a bin, eliminating the need to have an operator manually change each part, as is often the case with standard CNC turning centers. This makes them very efficient, as these machines are capable of fast cycle times, producing simple parts in one operation (i. e. no need for a second machine to finish the part) in as little as 10-15 seconds. This makes them ideal for large production runs of small diameter parts.

Accessories

Unless a workpiece has a taper machined onto it which perfectly matches the internal taper in the spindle, or has threads which perfectly match the external threads on the spindle (two things which almost never happen), an accessory must be used to mount a workpiece to the spindle.

A workpiece may be bolted or screwed to a faceplate, a large flat disk that mounts to the spindle. Alternatively faceplate dogs may be used to secure the work to the faceplate.

A workpiece may be clamped in a three- or four-jaw chuck, which mounts directly to the spindle.

In precision work (and in some classes of repetition work), cylindrical workpieces are invariably held in a collet inserted into the spindle and secured either by a drawbar, or by a collet closing cap on the spindle. Suitable collets may also be used to mount square workpieces.

A soft workpiece (wooden) may be pinched between centers by using a spur drive at the headstock, which bites into the wood and imparts torque to it.

![Fig. Live center (top) Dead center (bottom)](image)

A soft dead center is used in the headstock spindle as the work rotates with the centre. Because the centre is soft it can be trued in place before use. The included angle is 60 degrees. Traditionally a hard dead center is used together with suitable lubricant in the tailstock to support the workpiece. In modern practice the dead center
is frequently replaced by a live center or (revolving center) as it turns freely with the workpiece usually on ball bearings, reducing the frictional heat, which is especially important at high RPM. A lathe carrier may also be employed when turning between two centers.

In woodturning, one subtype of a live center is a cup center, which is a cone of metal surrounded by an annular ring of metal that decreases the chances of the workpiece splitting.

A circular metal plate with even spaced holes around the periphery, mounted to the spindle, is called an "index plate". It can be used to rotate the spindle a precise number of degrees, then lock it in place, facilitating repeated auxiliary operations done to the workpiece.

**Modes of use**

When a workpiece is fixed between the headstock and the tailstock, it is said to be "between centers". When a workpiece is supported at both ends, it is more stable, and more force may be applied to the workpiece, via tools, at a right angle to the axis of rotation, without fear that the workpiece may break loose.

When a workpiece is fixed only to the spindle at the headstock end, the work is said to be "face work". When a workpiece is supported in this manner, less force may be applied to the workpiece, via tools, at a right angle to the axis of rotation, lest the workpiece rip free. Thus, most work must be done axially, towards the headstock, or at right angles, but gently.

When a workpiece is mounted with a certain axis of rotation, worked, then remounted with a new axis of rotation, this is referred to as "eccentric turning" or "multi axis turning". The result is that various cross sections of the workpiece are rotationally symmetric, but the workpiece as a whole is not rotationally symmetric. This technique is used for camshafts, various types of chair legs, etc.

**Chuck**

A *Chuck* is a specialised type of clamp used to hold rotating tools or materials.

**Collet**

A collet is a sleeve with a (normally) cylindrical inside and a conical outside. The collet has kerf cuts along its length to allow it to expand and contract. Depending on a particular collet's design, it can be either pulled (via a threaded section at the rear of the collet) or pushed (via a threaded cap with a second taper) into a matching conical socket to achieve the clamping action. As the collet is forced into the tapered socket, the collet will contract, gripping the contents of the inner cylinder.

Collets are most commonly found on milling machines, lathes, wood routers, and precision grinders. There are many different systems, common examples being the ER, 5C, and R8 systems. Collets can also be obtained to fit Morse or Brown and Sharpe taper sockets.
Typically collets offer higher levels of precision and accuracy than self-centering chucks, and have a shorter setting up time than independent-jaw chucks. The penalty is that most collets can only accommodate a single size of workpiece. An exception is the ER collet which typically has a working range of 1 mm (about 0.04 inches).

Collets usually are made to hold cylindrical work, but are available to hold square, hexagonal or octagonal workpieces. While most collets are hardened, "emergency" collets are available that can be machined to special sizes or shapes by the user. These collets can be obtained in steel, brass, or nylon. Step collets are available that are machinable to allow holding of short workpieces that are larger than the capacity of normal collets.

**Drill**

![Drill chuck](image)

**Fig. Keyless and keyed drill chucks**

A drill chuck is a specialised three-jaw chuck, usually with capacity of ≤0.5" (≤13 mm) and rarely >1" (>25 mm), used to hold drill bits or other rotary tools.

The image at right shows an assembled keyless chuck at the top. The tightening action of this chuck style is performed by twisting the body using firm hand pressure only.

The lower images show the traditional keyed style of drill chuck with its key. The arbor is shown separately to the right. These chucks require a key to provide the necessary torque to tighten and loosen the jaws. The rotary action of the key turns the outer body which acts on an internal screw; this in turn moves the threaded jaws in or out along a tapered surface. The taper allows the jaws to encompass various sizes of drill shanks. The end view shows the three small jaws that slide within the body.

Some high precision chucks use ball thrust bearings to reduce friction in the closing mechanism and maximizing drilling torque. These chucks are sometimes referred to as "super chucks".

**Special Direct System (SDS)**

Developed by Bosch in 1975 for hammer drills, the SDS uses a cylindrical shank on the tool, with indents to be held by the chuck. A tool is inserted into the chuck by
pressing in, and is locked in place until a separate lock release is used – no tightening required. The rotary force is supplied through wedges that fit into two or three open grooves. The hammer action actually moves the bit up and down within the chuck since the bit is free to move a short distance. Two sprung balls fit into closed grooves, allowing movement whilst retaining the bit. SDS relies on a tool having the same shank diameter as the chuck - there are three standard sizes:

- **SDS-Plus** – a 10 mm shank with two open grooves held by the driving wedges and two closed grooves held by locking balls. This is the most common size and takes a hammer up to 4 kg. The wedges grip an area of 75 mm² and the shank is inserted 40 mm into the chuck.\(^1\)
- **SDS-top** a 14 mm shank similar to SDS-plus, designed for hammers from 2 to 5 kg. The grip area is increased to 212 mm² and the shank is inserted 70 mm. This size is not common.\(^2\)
- **SDS-max** – an 18 mm shank with three open grooves and locking segments rather than balls. It is designed for hammers over 5 kg. The wedges grip an area of 389 mm² and the shank is inserted 90 mm.\(^3\)

Many SDS drills have a "rotation off" setting, which allows the drill to be used for chiselling. The name SDS comes from the German "Steck – Dreh – Sitz" (Insert – Twist – Stay). German-speaking countries may use "Spannen durch System" (Clamping System), though Bosch uses "Special Direct System" for international purposes.\(^4\)

### Three-jaw

A **three-jaw chuck** is a rotating clamp which uses three dogs or 'jaws', usually interconnected via a scroll gear (scroll plate), to hold onto a tool or work piece. Three-jaw chucks are usually self-centering (as a result of the jaws' meshing with the scroll plate) and are best suited to grip circular or hexagonal cross sections when very fast, reasonably accurate (±.005" TIR) centering is desired. Independent-jaw versions can be obtained.

The image shows a three-jaw chuck and key with one jaw removed and inverted showing the teeth that engage in the scroll plate. The scroll plate is rotated within the chuck body by the key, the scroll engages the teeth on the underside of the jaws which moves the three jaws in unison, to tighten or release the workpiece.

There are hybrid self-centering chucks that have adjustment screws that can be used to further improve the concentricity after the workpiece has been gripped by the scroll
jaws. This feature is meant to combine the speed and ease of the scroll plate’s self-centering with the runout-eliminating controlability of an independent-jaw chuck.

Three-jaw chucks can often be found on lathes and indexing heads.

**Four-jaw**

![Four-jaw chuck](image)

A **four-jaw chuck** is similar to a three-jaw chuck, but with four jaws, each of which can be moved independently. This makes them ideal for (a) gripping non-circular cross sections and (b) gripping circular cross sections with extreme precision (when the last few hundredths of a millimeter [or thousandths of an inch] of runout must be manually eliminated). The non-self-centering action of the independent jaws makes centering highly controllable (for an experienced user), but at the expense of speed and ease. Four-jaw chucks are almost never used for tool holding. Four-jaw chucks can be found on lathes and indexing heads.

The image shows a four-jaw chuck with the jaws independently set. The key is used to adjust each jaw separately.

**Multi jaw**

For special purposes, and also the holding of fragile materials, chucks are available with six or eight jaws. These are invariably of the self-centering design, and are built to very high standards of accuracy.

Two jaw chucks are available and can be used with soft jaws (typically an aluminum alloy) that can be machined to conform to a particular workpiece. Many chucks have removable jaws, which allows the user to replace them with new jaws, specialized jaws, or soft jaws.

**Self-centering four jaw**

A four jaw chuck with a mechanism for centering the work piece. Sometimes used to refer to chucks where the jaws are moved in interconnected pairs.

**Magnetic**

Used for holding ferromagnetic work pieces, a **magnetic chuck** consists of an accurately centered permanent magnet face. Electromagnets or permanent magnets are brought into contact with fixed ferrous plates, or ‘pole pieces’, contained within a housing. These pole pieces are usually flush with the housing surface. The part or
‘work piece’ to be held forms the closing of the magnetic loop or path, onto those fixed plates, providing a secure anchor for the work piece.

3. Tool bits

Fig. Various tool bits, carbide inserts and holders

The term **tool bit** generally refers to a non-rotary cutting tool used in metal lathes, shapers, and planers. Such cutters are also often referred to by the set-phrase name of **single-point cutting tool**. The cutting edge is ground to suit a particular machining operation and may be resharpened or reshaped as needed. The ground tool bit is held rigidly by a tool holder while it is cutting.

3.1. Materials

Originally, all tool bits were made of high carbon tool steels with the appropriate hardening and tempering. Since the introductions of high-speed steel (HSS) (early years of the 20th century), sintered carbide (1930s), and ceramic cutters, those materials have gradually replaced the earlier kinds of tool steel in almost all cutting applications. Most tool bits today are either HSS or carbide.

3.1.1. Carbides and ceramics

Carbide, ceramics (such as cubic boron nitride), and diamond, having higher hardness than HSS, all allow faster material removal than HSS in most cases. Because these materials are expensive and hard to work with, typically the body of the cutting tool is made of steel, and a small cutting edge made of the harder material is attached. The cutting edge is usually either screwed on (in this case it is called an insert), or brazed on to a steel shank (this is usually only done for carbide).

3.2. Tool holders

By confining the expensive hard cutting tip to the part doing the actual cutting, the cost of tooling is reduced. The supporting tool holder can then be made from a tougher steel, which besides being cheaper is also usually better suited to the task, being less brittle than the cutting-edge materials.
The tool holders may also be designed to introduce additional properties to the cutting action, such as:

- Angular approach - direction of tool travel.
- Spring loading - deflection of the tool bit away from the material when excessive load is applied.
- Variable overhang - the tool bit may be extended or retracted as the job requires.
- Rigidity - the tool holder can be sized according to the work to be performed.
- Direct cutting fluid or coolant to the work area.

Note that since stiffness (rather than strength) is usually the design driver of a tool holder, the steel used doesn't need to be particularly hard or strong as there is relatively little difference between the stiffnesses of most steel alloys.

3.3. Inserts

Almost all high-performance cutting tools use the insert method. There are several reasons for this. First of all, at the very high cutting speeds and feeds supported by these materials, the cutting tip can reach temperatures high enough to melt the brazing material holding it to the shank. Economics are also important; inserts are made symmetrically so that when the first cutting edge is dull they can be rotated, presenting a fresh cutting edge. Some inserts are even made so that they can be flipped over, giving as many as 8 cutting edges per insert. There are many types of inserts: some for roughing, some for finishing. Others are made for specialized jobs like cutting threads or grooves. The industry employs standardized nomenclature to describe inserts by shape, material, coating material, and size.

3.4. Form tools

This form tool is for a shift knob on a motorcycle. O-rings went into the grooves after machining from 6061-T6 Aluminum. This tool has an 8-degree rake from top to bottom for clearance. This tool was designed for a 2G Brown & Sharpe screw machine.

A form tool is precision-ground into a pattern that resembles the part to be formed. The form tool can be used as a single operation and therefore eliminate many other operations from the slides (front, rear and/or vertical) and the turret, such as box tools. A form tool turns one or more diameters while feeding into the work. Before the use of form tools, diameters were turned by multiple slide and turret operations, and thus more work to make the part. For example, a form tool can turn many
diameters and in addition can also cutoff the part in a single operation and eliminate indexing the turret.

For single-spindle machines, bypassing indexing the machine can dramatically increase hourly part production. On long-running jobs it is common to use a ‘roughing tool’ tool on a different slide, or from the turret to remove the bulk of material to reduce wear on the form tool. There are also different types of form tools. Insert tools are the most common for short- to medium-range jobs (50 to 20,000 pcs). Circular form tools are usually for longer jobs, since the tool wear can be ground off the tool tip many times as the tool is rotated in its holder. There is also a skiving tool that can be used for light finishing cuts. Form tools can be made of cobalt, carbide, or high-speed steel. Carbide requires additional care because it is very brittle and will chip if chatter occurs.

A drawback when using form tools is that the feed into the work is usually slow, .0005” to .0012” per revolution depending on the width of the tool. Wide form tools create more heat and usually are problematic for chatter. Heat and chatter reduces tool life. Also, form tools wider than 2.5 times the smaller diameter of the part being turned have a greater risk of the part breaking off. When turning longer lengths, a support from the turret can be used to increase turning length from 2.5 times to 5 times the smallest diameter of the part being turned, and this also can help reduce chatter. Despite the drawbacks, the elimination of extra operations often makes using form tools the most efficient option.

4. Metal Cutting Processes - Turning

4.1. Introduction

This training module is designed to give you ‘hands-on’ experience through which you can gain a good appreciation of this well-known type of machine tool. In particular your attention will be directed towards its operational uses and parameters, the general layout of controls, accessories, associated tooling, and the maintenance factors related to lathes.

In order that you can make the most use of the limited time available on lathes it is essential that you use every chance to consolidate what you observe. This type of work is largely self-motivated and the drive and desire to find out must come from you.

It takes a considerable time to become a skilled lathe operator and to possess all the skill of hand that goes with it. Therefore it is not expected that you will be manually skilled on completion of the module but you will have gained intellectually and without doubt, by practical involvement, some skill of hand will be achieved.

Turning is the machining operation that produces cylindrical parts. In its basic form, it can be defined as the machining of an external surface:

- with the workpiece rotating,
- with a single-point cutting tool, and
• with the cutting tool feeding parallel to the axis of the workpiece and at a
distance that will remove the outer surface of the work.

Taper turning is practically the same, except that the cutter path is at an angle to the
work axis. Similarly, in contour turning, the distance of the cutter from the work axis is
varied to produce the desired shape. Even though a single-point tool is specified, this
does not exclude multiple-tool setups, which are often employed in turning. In such
setups, each tool operates independently as a single-point cutter. View a typical
turning operation. This movie is from the MIT-NMIS Machine Shop Tutorial.

Cutting at Centre Lathe

The term Centre Lathe is derived from the fact that in its operation the lathe holds a
piece of material between two rigid supports called centres, or by some other device
such as a chuck or faceplate which revolves about the centre line of the lathe.

The lathe shown above is a typical example. This machine is usually used in a
jobbing (one off) situation or for small batch work where it would be too expensive to
specially 'tool up' for just a few items.

The lathe can also be used for the purposes shown in Fig 2c, 2d, 2e and 2f.
4.2. Cutting Tools

The tool used in a lathe is known as a single point cutting tool. It has one cutting edge or point whereas a drill has two cutting edges and a file has numerous points or teeth.

The lathe tool shears the metal rather than cuts as will be seen later and it can only do so if there is relative motion between the tool and the workpiece. For example, the work is rotating and the tool is moved into its path such that it forms an obstruction and shearing takes place. Of course the amount of movement is of paramount importance - too much at once could for instance result in breakage of the tool.

The type and design of the tools selected will depend on the job in hand, the machining operation selected and the material to be cut. The correct tool especially
the various face angles are essential if the operation is to be done in a cost-effective (i.e. productive) way. The tools used in a lathe are various, some of which are shown in figure 3.

The range of cutting tool types is extensive and a few examples only are shown in this handout. Nonetheless you should take every opportunity to look deeper into the types of tools available.

4.3. Basic Metal Cutting Theory

The usual conception of cutting suggests clearing the substance apart with a thin knife or wedge. When metal is cut the action is rather different and although the tool will always be wedge shaped in the cutting area and the cutting edge should always be sharp the wedge angle will be far too great for it to be considered knife shaped. Consequently a shearing action takes place when the work moves against the tool.

![Basic Metal Cutting Theory Diagram](image)

Figure 4. Basic Metal Cutting Theory

Figure 4 shows a tool being moved against a fixed work piece. When the cut is in progress the chip presses heavily on the top face of the tool and continuous shearing takes place across the shear plane AB. Although the Figure shows a tool working in the horizontal plane with the workpiece stationary, the same action takes place with the work piece revolving and the tool stationary.

4.4. Tool Angles
There are three important angles in the construction of a cutting tool rake angle, clearance angle and plan approach angle.

**Rake Angle**

Rake angle is the angle between the top face of the tool and the normal to the work surface at the cutting edge. In general, the larger the rake angle, the smaller the cutting force on the tool, since for a given depth of cut the shear plane AB, shown in Figure 4 decreases as rake angle increases. A large rake angle will improve cutting action, but would lead to early tool failure, since the tool wedge angle is relatively weak. A compromise must therefore be made between adequate strength and good cutting action.

![Figure 5. Main Features of a Single Point Cutting Tool](image)

**Clearance Angle**

Clearance angle is the angle between the flank or front face of the tool and a tangent to the work surface originating at the cutting edge. All cutting tools must have clearance to allow cutting to take place. Clearance should be kept to a minimum, as excessive clearance angle will not improve cutting efficiency and will merely weaken the tool. Typical value for front clearance angle is 6° in external turning.

<table>
<thead>
<tr>
<th>Metal Being Cut</th>
<th>Cast Iron</th>
<th>Hard Steel / Brass</th>
<th>Medium Carbon Steel</th>
<th>Mild Steel</th>
<th>Aluminium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top Rake Angle</td>
<td>0°</td>
<td>8°</td>
<td>14°</td>
<td>20°</td>
<td>40°</td>
</tr>
</tbody>
</table>

Table 1. Typical value for top rake angle

**Plan Profile of Tool**
The plan shape of the tool is often dictated by the shape of the work, but it also has an effect on the tool life and the cutting process. Figure 6 shows two tools, one where a square edge is desired and the other where the steps in the work end with a chamfer or angle. The diagram shows that, for the same depth of cut, the angled tool has a much greater length of cutting edge in contact with the work and thus the load per unit length of the edge is reduced. The angle at which the edge approaches the work should in theory be as large as possible, but if too large, chatter may occur. This angle, known as the Plan Approach Angle, should therefore be as large as possible without causing chatter.

![Plan Approach Angle](image)

Figure 6. Plan Approach Angle.

The trailing edge of the tool is ground backwards to give clearance and prevent rubbing and a good general guide is to grind the trailing edge at 90° to the cutting edge. Thus the Trail Angle or Relief Angle will depend upon the approach angle.

A small nose radius on the tool improves the cutting and reduces tool wear. If a sharp point is used it gives poor finish and wears rapidly.

### 4.5. Characteristics of Tool Material

For efficient cutting a tool must have the following properties:

**Hot Hardness**

This means the ability to retain its hardness at high temperatures. All cutting operations generate heat, which will affect the tool's hardness and eventually its ability to cut.

**Strength and Resistance to Shock**

At the start of a cut the first bite of the tool into the work results in considerable shock loading on the tool. It must obviously be strong enough to withstand it.

**Low Coefficient of Friction**

The tool rubbing against the workpiece and the chip rubbing on the top face of the tool produce heat which must be kept to a minimum.

### 4.6. Tool Materials in Common Use
High Carbon Steel Contains 1 - 1.4% carbon with some addition of chromium and tungsten to improve wear resistance. The steel begins to lose its hardness at about 250° C, and is not favoured for modern machining operations where high speeds and heavy cuts are usually employed.

**High Speed Steel (H.S.S.)**

Steel, which has a hot hardness value of about 600° C, possesses good strength and shock resistant properties. It is commonly used for single point lathe cutting tools and multi point cutting tools such as drills, reamers and milling cutters.

**Cemented Carbides**

An extremely hard material made from tungsten powder. Carbide tools are usually used in the form of brazed or clamped tips. High cutting speeds may be used and materials difficult to cut with HSS may be readily machined using carbide tipped tool.

### 4.7. Tool life

As a general rule the relationship between the tool life and cutting speed is

\[ V T^n = C \]

where;
- \( V \) = cutting speed in m/min
- \( T \) = tool life in min
- \( C \) = a constant

For high-speed steel tools the value of \( C \) ranges from 0.14 to 0.1 and for carbide tools the value would be 0.2.

### 4.8. Chip Formation & Chip Breaker

The type of chip produced depends on the material being machined and the cutting conditions at the time. These conditions include the type of tool used, tool rate of cutting condition of the machine and the use or absence of a cutting fluid.
Continuous Chip

This leaves the tool as a long ribbon and is common when cutting most ductile materials such as mild steel, copper and Aluminium. It is associated with good tool angles, correct speeds and feeds, and the use of cutting fluid.

Discontinuous Chip

The chip leaves the tool as small segments of metal resulted from cutting brittle metals such as cast iron and cast brass with tools having small rake angles. There is nothing wrong with this type of chip in these circumstances.

Continuous Chip with Builtup Edge

This is a chip to be avoided and is caused by small particles from the workpiece becoming welded to the tool face under high pressure and heat. The phenomenon results in a poor finish and damage to the tool. It can be minimised or prevented by using light cuts at higher speeds with an appropriate cutting lubricant.

Chip Breaker

A chip breaker is used to break the continuous chip into sections so that the chips cannot tangle around the cutting tool. The simplest form of chip breaker is made by grinding a groove on the tool face a few millimeters behind the cutting edge.

4.9. Cutting Speed & Feed
As you proceed to the process of metal cutting, the relative ‘speed’ of workpiece rotation and ‘feed’ rates of the cutting tool coupled to the material to be cut must be given your serious attention. This relationship is of paramount importance if items are to be manufactured in a cost-effective way in the minimum time, in accordance with the laid down specifications for quality of surface finish and accuracy. You, as a potential supervisory / management level engineer, must take particular note of these important parameters and ensure that you gain a fundamental understanding of factors involved.

**Cutting Speed**

All materials have an optimum Cutting Speed and it is defined as the speed at which a point on the surface of the work passes the cutting edge or point of the tool and is normally given in meters/min. To calculate the spindle Speed required,  

\[ N = \frac{CS \times 1000}{\pi d} \]

Where:
- \( N \) = Spindle Speed (RPM)
- \( CS \) = Cutting Speed of Metal (m/min)
- \( d \) = Diameter of Workpiece

Table 2 shows the cutting speed recommended for some common metals. It may be possible to exceed these speeds for light finishing cuts. For heavy cuts they should be reduced.

<table>
<thead>
<tr>
<th>Metal</th>
<th>meters /min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cast Iron</td>
<td>20-28</td>
</tr>
<tr>
<td>Mild Steel</td>
<td>18-25</td>
</tr>
<tr>
<td>High Speed Steel</td>
<td>12-18</td>
</tr>
<tr>
<td>Brass</td>
<td>45-90</td>
</tr>
<tr>
<td>Bronze</td>
<td>15-21</td>
</tr>
<tr>
<td>Aluminium</td>
<td>up to 300</td>
</tr>
</tbody>
</table>

Table 2. Cutting Speed

**Feed**

The term ‘feed’ is used to describe the distance the tool moves per revolution of the workpiece and depends largely on the surface finish required. For roughing out a soft material a feed of up to 0.25 mm per revolution may be used. With tougher materials this should be reduced to a maximum of 0.10 mm/rev. Finishing requires a finer feed than what is recommended.
4.10. Cutting Fluid & Lubricant

The aims in metal cutting are to retain accuracy, to get a good surface finish on the workpiece and at the same time to have a longer tool life.

However during the metal cutting process heat is generated due to:

- the deformation of the material ahead of the tool
- friction at the tool point

Heat generated due to friction can readily be reduced by using a lubricant. Heat caused by deformation cannot be reduced and yet it can be carried away by a fluid. Thus the use of a cutting fluid will serve to reduce the tool wear, give better surface finish and a tighter dimensional control.

The proper selection, mixing and application of cutting fluids is however often misunderstood and frequently neglected in machining practice. In order that the cutting fluid performs its functions properly it is necessary to ensure that the cutting fluid be applied directly to the cutting zone so that it can form a film at the sliding surfaces of the tool.

Cutting fluids in common use

**Water**

It has a high specific heat but is poor in lubrication and also encourages rusting. It is used as a cooling agent during tool grinding.

**Soluble Oils**

Oil will not dissolve in water but can be made to form an intimate mixture or emulsion by adding emulsifying agents. The oil is then suspended in the water in the form of tiny droplets. These fluids have average lubricating abilities and good cooling properties. Soluble oils are suitable for light cutting operations on general purpose machines where high rates of metal removal are often not of prime importance. There are many forms of soluble oil in the market and the suppliers instruction should be followed regarding the proportions of the ‘mix’.

**Mineral Oils**

They are used for heavier cutting operations because of their good lubricating properties and are commonly found in production machines where high rates of metal removal are employed. Mineral oils are very suitable for steels but should not be used on copper or its alloys since it has a corrosive effect.

**Vegetable Oils**

They are good lubricants but are of little used since they are liable to decompose and smell badly.
5. Screw Cutting

During this module you are required to explore the use of the lathe to cut, amongst other things, a metric screw thread on a bar. It is a slightly more difficult task than plain turning because it involves accurate setting up of the tool and exact setting of feed in relation to the work rotation. Once this is done however, and this you will be shown, the process of screw cutting becomes relatively simple. Fig 10 shows the arrangement in simplified form.

![Figure 10. Screw Cutting Set-up](image)

There are many different forms of screw thread, Fig 11 shows the 'sections' of three most common types.

More types and specifications of screw threads can be found in any Workshop Technology Hand Books and you must get used to finding such information and knowing how to apply it.

![Figure 11. Types of Screw Thread](image)

6. Safety

It is imperative that you fully understand that machine tools are potentially dangerous and that you must at all times:

Follow the laid down Section and IC Safety Rules.
7. References


