COLLEGE OF ENGINEERING AND APPLIED SCIENCE MACHINE SHOP
TOOLS AND PRACTICES

I. OBJECTIVE
To provide an overview and basic knowledge of the University of Wyoming, College of Engineering, Machine Shop equipment, tools, terminology, and practices.

II. MEASURING TOOLS
The University of Wyoming, College of Engineering, Machine Shop uses the English measurement system, i.e. the machine tools, the measuring tools, etc. are in inches. Conversions must be made when working with metric units.

A. RULERS AND SCALES are typically made of steel and are used to make rough measurements. Rulers and scales are typically graduated in 1/8, 1/16, 1/32, and/or 1/64 inch divisions.

B. SQUARES are used for laying out lines on work pieces, and for verifying two surfaces are perpendicular (squareness).

C. GAGES are made for a large variety of purposes: screw pitch, radius, center, wire and sheet metal, etc.

D. SLIDE CALIPERS and MICROMETERS are precision measuring tools generally used to measure to the thousandths or ten-thousandths of an inch.

   1. SLIDE CALIPERS are precision measuring tools that are typically accurate to 0.001 of an inch. Two types are available; vernier scale or dial scale. Six-inch range dial calipers are the most common, but longer sizes are also available. Vernier depth gages are another type of measuring instrument that are used to measure hole depths, slots, recesses, etc. They are available in 6 and 12-inch ranges.

   2. MICROMETERS are precision measuring tools. They are typically accurate to 0.001 of an inch, but some 1-inch vernier micrometers will give 4 place readings. Micrometers are either inside or an outside variety and in a variety of sizes up to 6-inches. The measuring range for any particular sized micrometer is limited to 1 inch.

E. DIAL INDICATORS are used to check correct alignment of one machine component with another and to correctly position work pieces in machine tools prior to machining. A dial indicator shows the amount of error, in alignment for a part being positioned in a machine tool. Most inch dial indicators are calibrated in either thousandths of an inch (0.001 inch) or ten-thousandths of an inch (0.0001 inch).

III. OPERATIONS

A. DRILLING, COUNTER SINKING, REAMING, AND COUNTER BORING

   1. DRILLS are used to cut holes through or into a material. The most common type of drill is the twist drill, which has either a straight or tapered shank (Morse taper). The straight shank is for fitting into a drill chuck, and the tapered shank fits into a tapered spindle. Drill sizes are designated one of three ways, fractional, number, or letter. Drilled holes may be slightly oversized and out-of-round.

   2. CENTER DRILLS are used for two main purposes: for providing a starting hole for drills or for providing a center hole for stock to be held in a lathe.
3. **COUNTER SINKS** are used to machine a coned shaped enlargement at the end of a hole. Many shapes and sizes are available, but most commonly used are 60 degree for lathe centers, and 82 degree for flat head machine screws. Countersinks are also used for deburring operations.

4. **REAMERS** are multiple edged cutting tools used to enlarge and finish a drilled hole to exact dimensions and smoothness. Reamers are typically made of H.S.S. There are many types of reamers: hand, machine, taper, etc. Machine reamers are designed for use on a drill press, lathe, or milling machine. Commonly used straight reamers are available in three sizes: standard, over and under. e.g. a ½-inch standard reamer is 0.500-inch diameter, the over reamer is 0.501-inch diameter, and the under reamer is 0.499-inch diameter.

5. **COUNTER BORES** are used to spot face or counter bore to enlarge a hole to receive the head of hex head cap screws or fillister head machine screws.

6. **DRILLING SPEEDS AND FEEDS** The use of proper cutting speeds and feeds promotes good tool life and machining efficiency. A cutting speed that is too high will cause overheating of the cutting tool and premature cutting edge failure. Too low of cutting speed will reduce productivity and increase tool wear. A table of cutting speeds for high speed steel (HSS) drills will show recommended cutting speed for various materials. Cutting speed (cs), spindle speed, revolutions per minute (rpm) are interrelated terms. Cutting speed is the distance a point on the tool circumference will travel in one minute expressed in terms of feet per minute (fpm). Spindle speed rpm can be calculated with the following formula.

   \[ RPM = \frac{(cs)(12)}{\pi D} \]

Example: A ¼ inch diameter drill with a cutting speed of 80 fpm has a spindle speed of 1222 rpm. A 1-inch diameter drill with the same cutting speed of 80 fpm has a spindle speed of 305 rpm.

Feed rate is the speed at which a tool is moved into or across the material expressed in terms of inches per minute. Speeds and feeds are adjusted up and down depending upon the conditions of the particular job setup and materials. Conditions may include such factors as kind of material, the cutter material, cutting fluids, size and rigidity of the machine, setup, quality of finish desired, etc.

7. **DRILL PRESSES** are principal used is to drill holes. Other operations include reaming, boring, counter-boring, counter sinking, and tapping. All drill presses are equipped with a hand feed lever or handle. Proper feed rate is controlled by the feel of the cutting action and by observing the chip. In soft steel a long stringy chip indicates the feed is too fast. With a proper feed the chip is a tightly rolled helix. The work is generally clamped to a table or held in a vice. Drill presses are variable speed which is adjusted in one of three ways; step pulleys, variable speed drive, or a gear drive system.
8. **SAFETY WITH DRILLING OPERATIONS**
   a) Always wear appropriate safety goggles or glasses.
   b) Never leave the chuck key in the drill chuck or the drill drift in the spindle.
   c) Mount the work securely before drilling. Do not hold thin or small pieces in the hands.
   d) Remove chips with a brush. Never use the hands.
   e) Ease up on the feed pressure as the drill begins to break through a hole. This will prevent the drill from catching or breaking, or pulling the work loose.
   f) Do not attempt to stop the spindle with the hands after turning the machine off.
   g) Never drill plastics, PVC, copper alloys, including brass and bronze, with a drill that is ground for steel. Request a drill ground for these materials. A drill ground for steel may dig in, break, ruin your work, and or cause injury.
   h) Keep long sleeves, other loose clothing, and especially long hair away from the revolving spindle or belts.

B. **THREADING, TAPPING, AND SINGLE POINTING**

1. **THREADING** is cutting external threads by hand and is done with a die. A die can be fixed or adjustable.

2. **TAPPING** is cutting internal threads and is done with a tap. Taps come in three styles: taper, plug, and bottoming. Tapping can be done on a drill press, milling machine, lathe, and by hand. Tap and tap drill selection: determine desired thread diameter and pitch, go to chart (fraction and machine screw tap drill sizes), and determine proper drill size. The chart will give recommended tap drill size for 75% full thread.

3. **SINGLE POINTING** is cutting threads on the work piece in a lathe. They may be external or internal, straight or tapered, and right or left hand. This method is slower but essential for cutting larger diameter threads (1 inch and greater), threads calling for a more accurate pitch or lead, or an unusual thread.

C. **SAWING**

1. **HORIZONTAL BAND SAWS** are probably the most commonly used piece of equipment in the shop. They have high cutting efficiency, variable blade speed (to select the best cutting speed for the material), and a variable feed rate. The work is held fixed in a vise and the blade is fed through the work.

2. **VERTICAL BAND SAWS** may be the handiest machine in the shop. They have high cutting efficiency, variable blade speed, and a wide variety of tooth styles and numbers of teeth/ inch. The worktable can be tilted and the work is fed through by hand, allowing various shapes and contours to be cut.
3. SAFETY PRECAUTIONS FOR BAND SAWs
   a) Always wear appropriate safety goggles or glasses.
   b) Always be sure that the saw guide is set to within 1/4 inch to 3/8 inch above the thickest portion of the work piece to be cut.
   c) Support protruding ends of long pieces so they will not fall and cause injury.
   d) Be sure that the saw blade is in good condition, and that the machine is set to the correct cutting speed.
   e) When starting the saw, stand to one side of the saw frame; then adjust the speed as desired.
   f) Avoid getting the hands too close to the blade.
   g) Use a stick to remove short pieces of work from the area close to the blade.
   h) Be careful in handling parts with sharp burrs on the ends.

D. TURNING

1. TURNING OPERATIONS In turning operations the work piece rotates against a fixed tool such as a turning tool, drill, reamer, tap, die, or tool post grinder. Turning operations are used to make cylindrical and conical parts. The principle turning machine is a lathe.

2. LATHES can be used, for drilling, tapping, reaming, counter-boring, plus threading (internal and external) and taper turning. The work piece is held in a chuck or collet and rotated. They have variable spindle speeds and the cutting tool is hand or power fed in the x (perpendicular to rotational axis) and z (parallel to rotational axis) directions. The turning operation (cutting) occurs when the fixed turning tool is fed into the rotating work piece. The tool may also be fed at an angle by using the compound screw. The tailstock is used to center and support work in the headstock, the tailstock can also be used for longitudinal drilling operations. Lathe accessories and attachments include taper attachments, steady rest, follow rest, face plates, three and four jaw chucks, collet holders, etc. A lathe is capable of producing work accurate to at least 0.001 of an inch.

3. TURNING SPEEDS AND FEEDS The rotating speed of the work held in the headstock is determined by the type of material, the diameter of the material, and the material of the turning tool. The feed rate is the rate at which the turning tool is fed past the work piece, and is determined by the work piece material, amount of material being removed and the desired surface finish. Spindle speeds are determined by referencing the chart on the Machine Shop wall for recommended cutting speeds. Spindle speeds are adjusted by either a step pulley system with a high and low range or by a variable speed motor and two or three speed gearbox selection. Powered tool feeds are gear drives from the spindle, so that the ratio of tool feed to spindle revolutions is constant. A wide selection of feed rates in ratio to the spindle revolutions is provided. Generally, 0.006-inch feed per spindle revolution is a good initial setting. A quick-change gearbox changes the feed ratio. This gearbox also controls the ratios of spindle revolution to feed for single point thread cutting. The ratio of the cross feed to the longitudinal feed will vary for different lathes, the cross feed may be equal to ½ times the longitudinal feed. The feed rate selection is a matter of operator judgment and experience. Factors to consider are tool shape and material, depth of cut, rigidity of the work piece and the machine, work piece material, finish desired, etc.
4. SAFETY PRECAUTIONS FOR LATHES
   a) Wear approved safety goggles or glasses.
   b) See that all guards are in place.
   c) Before starting the lathe, turn the spindle by hand to insure that it turns freely. If the spindle is
    locked in a stationary position with the back-gear lever as well as the bull gear pin, release
    one of these devices for the desired kind of drive and speed.
   d) Stop the machine for all measurements.
   e) Stop the machine to remove chips. Do not remove them with the hands – always use a brush
    do not use compressed air.
   f) Stop the machine to make adjustments.
   g) Always stop the machine when adjusting the tool in the tool post.
   h) Keep the machine clear of long chips, rags and unnecessary hand tools.
   i) Use the right type of cutting tool for the job.
   j) Adjust the feed, speed, and depth of cut according to the size and type of material.
   k) Be sure that the tailstock and the tailstock spindle are securely locked.
   l) Always cut toward the head stock whenever possible.
   m) Before starting the power feed, make certain that the carriage has sufficient free travel to
    complete the cut without running into the lathe.
   n) Be sure that the work is mounted tightly in the chuck.
   o) Always remove the chuck wrench or key from the chuck immediately after using it.
   p) Turn the chuck one complete revolution by hand after the work is mounted to see that it clears
    the carriage and the ways.
   q) Never allow the cutting tool or tool holder to come into contact with the revolving chuck
    jaws.

E. MILLING

1. MILLING OPERATIONS use a revolving cutter to shape the work piece, and the work piece is
generally moved in relation to the cutter, although drill press-like operations are possible. A
variety of milling operations can be performed depending on the type of machine, type of cutter,
accessories, and attachments. Milled features include flat surfaces (horizontal, vertical, and
angular), shoulders, grooves, slots, keyways, etc. CNC milling operations can produce complex
geometric surfaces. Milling operations include milling, drilling, boring, reaming, tapping, counter
boring, etc.

2. VERTICAL MILLING MACHINES have a vertical spindle that holds the revolving cutter. The
spindle (z axis) can be a hand feed or power feed operation (maximum of five inches travel). The
spindles have variable speeds and those with power feed have variable feed rates. The work piece
is held in a vise or clamped directly to the table that has three axis of travel (x, y, z). The table can
be a hand or power operated. The work piece is moved relative to the cutter by using the table feed
screws, which are equipped with collars graduated in thousandths of an inch. The accuracy of
milling operations is 0.001 ±0.0005 inch. Accessories and attachments include right angle heads,
rotary tables, dividing heads, etc.

3. MILLING CUTTERS are held in the spindle. Tooling used to hold the cutters in the spindle,
include collets, arbors, and adapters. Milling cutters are made in many shapes and sizes for milling
regular and irregular shapes. The most common type of cutter used in vertical milling machines is
end milling cutters. End milling cutters have teeth on the circumference and on the end and may
be used for horizontal, vertical, angular, or irregular surfaces. Common operations performed with
end milling cutters are milling slots, keyways, pockets, shoulders, flat surfaces, etc. Various end
milling cutters are:
a. **TWO FLUTE END MILLS** have only two teeth (flutes) on the circumference, the end teeth are designed so that they cut to the center, and therefore they can plunge cut. They are used on soft materials (aluminum, plastics, etc.) and are commonly made of H.S.S. Sizes range from 1/16 to 2 inches in diameter.

b. **FOUR FLUTE END MILLS** or multiple flute end mills have four or more teeth (flutes) on the circumference for cutting. Most are not center cutting, i.e. they will not plunge cut. They are used on steels and other tougher materials and are commonly made of H. S. S. Sizes range from 1/16 to 2 inches in diameter.

c. **BALL END MILLS** are again made of H. S. S. and come with two, three, or four flutes. They are used in milling fillets, slots with radius bottoms, rounding pockets, etc.

d. **SHELL END MILLS** have multiple flutes, a hole in the middle, for screw mounting to short arbors. They are used for surface milling, face milling, end milling, etc.

e. **FLY CUTTERS** are single pointed cutting tool mounted in a cylindrical holder and are used for planing surfaces.

f. **MISCELLANEOUS CUTTERS** include t-slot, woodruff key, corner rounding, concave, and convex cutters. These cutters are generally special purpose cutters for particular applications.

4. **MILLING MACHINE SPEEDS AND FEEDS** Cutter speeds (fpm) vary according to the diameter of the cutter, cutter material, the recommended cutting speed for the specific material, and the cutting fluid used. Feed rates vary by the type of cutter, number of cutter teeth, rigidity of the machine and setup, and rough or finish cut. The type of cut is the method in which the work is fed past the milling cutter, the two methods of milling are conventional and climb milling shown in Figures 80-10 and 80-11. Conventional milling is most often used, since climb milling can easily damage the equipment and the work piece.

```
RPM = \frac{cs \times 12}{\pi \times dia}
```

Recommended cutter speeds, cs, can be found in tables and on the charts in the Machine Shop. “dia” is the diameter of the cutter. Spindle speeds on a milling a milling machine are changed much the same as on a drill press using step-pulleys with a 2-speed box or a variable speed drive. The feed rate is the rate at which the work is moved past the cutter. When the feed rate is too high the cutter may fracture or the machine or work piece may be damaged. Too low of a feed rate will
dull the cutter rapidly and the metal removal will be inefficient. Suggested feed rates per tooth, per revolution are generally found in a table. Calculate the feed rate by using the following formula:

\[ F = \left( \frac{R}{T} \right) \times rpm \]

Where F is feed rate in inches per minute, R is feed per tooth per revolution in inches, T is the number of teeth, and rpm is the revolutions per minute of the cutter. Feed rates on a milling machine are controlled in one of three ways: manual feed uses a hand wheel or crank and the rate of feed is a matter of judgment. With small cutters the rate of feed per cutter tooth should be less than for larger coarser-toothed cutters. Most machines will have a gearbox to drive the spindle in the z direction with a ratio of 1.5, 3, 6, thousandths of an inch per spindle revolution. Older machines will have a mechanical gearbox for the direct selection of feed rates. Newer machines will have an electric servo motor drive for an infinite range of feed rates.

5. SAFETY PRECAUTIONS FOR MILLING MACHINE
   a) Wear approved safety goggles or glasses.
   b) See that the table is clean and dry before mounting holding devices for the work.
   c) Be sure that the bases of work-holding accessories or work pieces are wiped clean before they are fastened to the table.
   d) Check to see that the work piece is mounted securely.
   e) Select and mount the proper cutter, and see that it revolves in the proper direction.
   f) Be sure that the arbor, cutter, and collars are clean before mounting them on the machine. Use a rag to handle sharp cutters.
   g) Use only correct fitting wrenches on the machine.
   h) Select the proper spindle speed, feed, and depth of cut. Make these adjustments only while the machine is stopped.
   i) Use a lead or softheaded hammer to seat work pieces in the vise for setups.
   j) Make certain that the table, holding device, and work piece will clear all machine tool parts during the cut.
   k) Make sure that unauthorized persons are outside the safety zone of the machine when it is started.
   l) Keep clear of the revolving cutter.
   m) Use a brush for chip removal, do not use compressed air.
   n) When finished, remove and return all tools and accessories. Brush the machine free of chips and wipe up all excess oil.

F. GRINDING, SANDING, AND DEBURRING

1. GRINDING, SANDING, AND DEBURRING OPERATIONS remove material from a work piece by abrasive action. This process is relatively slow, but can be very precise and can produce a very smooth surface finish. Variations of these operations are: surface grinding, abrasive cutoff, lapping, honing, etc. The accuracy of these operations can be more than ±0.0001 inch.

2. SAFETY PRECAUTIONS FOR GRINDING, SANDING, AND DEBURRING
   a) Wear approved safety goggles or glasses.
   b) Check to see that the rest for hand held work pieces is adjusted correctly near the grinding wheel or sanding belt.
   c) Check to see that the grinding wheel or sanding belt is in good condition.
   d) Hold or clamp the work piece securely.
G. WELDING, BRAZING, AND SOLDERING

1. WELDING, BRAZING, AND SOLDERING join work pieces by filling the joint with melted material; material the same as the base material in the case of welding and a lower melting temperature alloy in the case of brazing and soldering. Since heat is used in these processes, distortion can be caused by thermal expansion and contraction as the work pieces are locally heated and then cool. Preheating the entire assembly can minimize thermal distortion. The accuracy of these operations is low, typically about 1/8 inch.

2. SAFETY PRECAUTIONS FOR WELDING
   a) Wear approved welding helmets or goggles.
   b) Check to see that flammable and combustible materials are not present in the welding area.
   c) Check to see that other personnel in the area will not be harmed by the UV emission from arc welding.
   d) Handle the work pieces carefully to prevent burns.

H. SHEARING, NOTCHING, PUNCHING

1. SHEARING, NOTCHING, PUNCHING join work pieces by filling the joint with melted material; material the same as the base material in the case of welding and a lower melting temperature alloy in the case of brazing and soldering. Since heat is used in these processes, distortion can be caused by thermal expansion and contraction as the work pieces are locally heated and then cool. Preheating the entire assembly can minimize thermal distortion. The accuracy of these operations is low, typically ranging about 1/8 inch.

2. SAFETY PRECAUTIONS FOR SHEARING, NOTCHING, PUNCHING
   a) Wear approved safety goggles or glasses.
   b) Check to see that the work area is clear and the tools are properly aligned and in good working condition.
   c) Keep hands, fingers and toes away from cutting edges and pinch points on the machines.

I. WATERJET MACHINING

1. WATERJET MACHINING uses a high-pressure jet of water and an abrasive to cut material into desired 2-D shapes. Most materials including, steel, aluminum, composites, wood can be cut with the waterjet, tempered glass and ceramics are notable exceptions. Many parts can be arranged so as to be cut out of a single plate of material. The machine is computer controlled so complex shapes can be easily cut. The width of cut is very small, 0.030 of an inch.

2. SAFETY PRECAUTIONS FOR WATERJETTING
   a) Wear approved safety goggles or glasses.
   b) Make sure that unauthorized persons are outside the safety zone of the machine when it is started.
   c) Check to see that the work piece is mounted securely.
   d) Keep hands and fingers away from the cutting nozzle.
   e) Be sure floor is dry when finished machining.