Emergency Procedures

SEVERE INJURY
ACTIVATE SHOP E-STOP
CALL 9-1-1
CALL FIRST AID 604-822-4444

EYE INJURY
SUSPECT PARTICLE IN EYE – DO NOT ATTEMPT REMOVAL; HOLD EYELID OPEN AND REQUEST HELP, CALL FIRST AID
LIQUID SPLASH – USE EMERGENCY EYEWASH AT SINK
CALL FIRST AID 604-822-4444

FIRE, FLAMMABLE GAS LEAK, EXPLOSION, POLICE INCIDENT, HAZMAT
ACTIVATE SHOP E-STOP; EVACUATE BUILDING AND ACTIVATE PULL STATION AS YOU EXIT BUILDING
CALL 9-1-1

EARTHQUAKE
IF EASY TO DO ACTIVATE SHOP E-STOP
MOVE AWAY FROM MACHINERY, GET UNDER WORKBENCH AND HOLD ON UNTIL SHAKING STOPS.
WAIT 60 SECONDS AFTER SHAKING STOPS
ASSESS NEED FOR EVACUATION

EVACUATION ALARM RINGING (FIRE BELL RINGING, ANY PATTERN OF RINGS)
ACTIVATE SHOP E-STOP
EVACUATE FROM BUILDING, MOVE TO MUSTER LOCATION

FIRE SPRINKLER ACTIVATION OR MAJOR WATER LEAK
STAY OUT OF WATER
ACTIVATE SHOP E-STOP
EVACUATE KAISER 1190
PREVENT ENTRY INTO AREA
Purpose of the Student Machine Shop

The purpose of this Student Machine Shop facility is to facilitate graduate research assistants’ research work and to support education of mechanical and manufacturing engineering students by provision of instruction, tools and equipment for machining and fabrication of metal and plastic components. Students are provided with supervised access to cutting, shaping, forming and joining equipment such as milling machines, lathes, drilling machines as well as precision measurement tools.

User Qualifications

Shop users who are not formally qualified as machinists are considered to be “in-training” and are permitted supervised access during Student Shop Hours when a staff or faculty person is available to provide adequate supervision.

Use of the facility is generally free, so undergraduate and graduate students are encouraged to use it to build prototypes to support their development of engineering design skills.

Students with UBC WorkDay accounts (see your supervisor) also have the option to submit work to the Support Machining services described below.

MECH MakerSpace

The Kaiser 1180 MECH MakerSpace currently under development will have additional equipment such as abrasive water-jet cutter, 3D printers, sheet metal shearing, bending and punching equipment, wood-cutting equipment and tools for fitting, joining, finishing parts. Separate access qualifications will be in place when this facility is ready.

Support Machine Shop

The Department’s Support Machining Shop compliments the other facilities by providing professional machining services with state-of-the-art equipment operated by qualified machinists.
The shop accepts jobs on a fee-for-service basis from UBC WorkDay account holders. Please see our website at https://technicalservices.mech.ubc.ca/machine-shop/support-machining-services/ for details.

Access to the Student Shop

The facility is funded by the Department of Mechanical Engineering and is open to persons registered in or with appointments in the Department of Mechanical Engineering as detailed on the website.

Prior experience with tools and machinery is not required.

Orientation

Every person wishing to use the shop, regardless of prior training, must first successfully complete the shop orientation either by successfully completing the Mech 220/231 Machining Module or by attending a Basic Shop Orientation session which are held periodically throughout the year. The focus is primarily on risk and safety and is followed by completion of an online exam. Users must agree to conditions indicated on a legal agreement.

Persons wishing to use the shop for work on personal projects must also sign a waiver and indemnification agreement and must supply all of their own materials.

The orientation covers the following:
1. General shop operation
2. Overview of the Worker’s Compensation Act and WorkSafe BC Occupational Health and Safety Regulations
3. Emergency procedures
4. Special hazards
5. Lathe safety introduction
6. Milling machine safety introduction
7. Grinding and abrasive work safety introduction

Please Note: Completion of the orientation to the Student Machine Shop does not qualify the student for activities in any other shops and is not to be construed as a qualification to operate machinery independently or in any facility other than the Student Machine Shop.

Student Shop Hours and Capacity
Student Shop Hours
Due to COVID-19, the Student Shop is closed to non-staff users until further notice.

Shop Capacity
Constraints due to available supervision and minimum required safe work space limits the number of persons who can be in the shop at one-time. Capacity is currently under review due to changes in the arrangement of machinery needed to accommodate new CNC machinery for the Support Machine Shop.

On-line Reservation System
All shop use must be booked. Bookings can be made in advance using an on-line utility available through the website. Please be sure to read the instructions, particularly pertaining to information security.

Additional Rules for reservations:
1. Bookings may be adjusted to provide fair access to eligible students, however bookings will not be adjusted within 48 hours of the start time.
2. Your booking will only be held until 10 minutes past your start time, after which the booking is released to the first person who is waiting.

If you can’t make your booking, you must cancel it. If you fail to cancel your bookings you will be given lower priority for future bookings.

Tool Loans
Loaner tools are available for 24 hour loan for use outside the shop. There tools are located in the cabinet marked” Loaner tools”. Tools from the Student Shop toolboards are not available for loan. An online booking system is under development.

Restricted Areas and Equipment
Please do not touch the welding or cutting equipment, gas bottles or torches in the welding/grinding shop without direct permission. There are many hazards associated with this equipment depending on the situation in which it is to be used.

Please do not enter the Support Machine Shop (CNC machines and technician desk area) office or storage bay. These are “staff only” areas.
Materials and Supplies

MECH administration has arranged for ECE Purchasing, Stores and Receiving in CEME 1057 to support MECH and MANU students and researchers who need supplies and materials. See https://technicalservices.mech.ubc.ca/stores-purchasing-shipping-receiving/purchasing/

The machine shops have a limited selection of metal and plastic shapes on hand (primarily sheets and round bar stock) as our storage space is limited. This material is available to WorkDay accountholders only and any material used must be reported.

Local and on-line suppliers retail small quantities of metals and plastic at reasonable rates so you are encouraged to contact them directly (see list in Appendix[C]) or to consult ECE Stores.

The small off-cut material in the coloured plastic bins at the Kysor Johnson band saw is free for you to use for university-related projects and you can help yourself to it without a account code.

Rates for materials are posted on the second sheet of the Materials and Equipment Use Tracker spreadsheet. Please cut your rough stock and weigh it, then fill in the appropriate boxes on the online form.

A range of fasteners and other consumables are available at ECE Stores in CEME 1057.

All of our material stocks are for university purposes only and can only be acquired using a Department account code. Please note that as a public entity, we do not supply material for personal use nor do we sell material to persons without an account. Please contact your instructor or supervisor for your account code.
Clean-up Procedures and Equipment

1. Workbenches, manual equipment, machinery surfaces, chip trays and the shop floor must be left free of chips and coolant.

2. Brooms, dust pans, rags and absorbent are located on the north wall of the student shop.

3. All cutting tools are to be removed from machinery prior to cleaning unless the setup needs to be maintained.

4. Metals chips and scrap shall be placed in the blue recycling bins.

5. **Don’t use bare hands for handling chips.** Use paint brushes, corn whisks, brooms and dust pans for removing chips and coolant. There is a magnetic chip pick-up tool for handling steel chips. The vacuum in the wood shop is for cleaning of the wood shop only.

6. Blow-off guns may be used to clear chips off machines, however all persons in the vicinity must be made aware that the gun is going to be used and all persons must be appropriately protected. Blow-off guns are never to be directed at another person and care must be taken to ensure that the resulting spray is not directed at anyone.

7. Used coolant can be collected and re-used in the squirt bottles unless it is particularly dirty in which case it needs to be collected and stored in a 20 litre pail for proper disposal. Coolant and cutting fluids are not to be washed down the sink.

8. Please don’t forget to wash your hands. A citrus-based hand-cleaner is available at the sink.

You must plan your work accordingly to allow yourself time to clean up. It takes at least 15 minutes to properly break down a set-up and to clean a work area.
Safety Overview

Safety Regulations

The use of this facility must comply with safety regulations set by the Province of British Columbia and the Federal Government of Canada and must also comply with University policies on Health and Safety (i.e. Policy SC 1).

In Canada, the responsibility for regulating occupational health and safety is mandated to provincial and territorial governments.

In BC, occupational health and safety regulations are set by WorkSafe BC (formerly known as the Worker’s Compensation Board). These regulations specify safety requirements for equipment, facilities, employers and for workers and restrict how work is to be performed. Policy SC 1 makes these regulations applicable to all students, staff and faculty of UBC.

WorkSafe BC enforces workplace regulations through fines and prosecution and provides compensation to injured workers. Note that only insured workers (those for whom premiums are paid) are eligible for compensation.

Some of the other regulations applicable to activities at UBC include:

- BC Safety Standards Act
  - Electrical work
  - Boilers, Pressure Vessels and Refrigeration
  - Gas (natural gas, propane) systems
  - Elevating devices

- Hazardous Products Act (Canada)/ Controlled Products Regulations
- Transportation of Dangerous Goods Act
- Bylaws of Metro Vancouver (solid waste, air emissions, sewers)
- Environmental Protection Act

Workers Compensation Act of British Columbia (www.worksafebc.com)

The University is legally required to meet the requirements of the Act and is obligated to control activities according to the WCA in these areas. Anyone* wishing to enter or use the facilities must adhere to the regulations stipulated by the Act.

*Note: Anyone does mean anyone! Although only persons whose employers are paying WCB premiums are entitled to compensation under the WCA, the university is obligated...
to ensure that all persons entering the facilities adhere to regulations and requirements of the WCA.

**Personal Responsibilities and Liability**

The WCA indicates that workers have a duty to carry out their work in a responsible manner and could be personally liable for failure to do so.

*Students in engineering in particular should be aware that they are responsible for their actions and may be held personally liable for injury or damage that results from their actions. As mechanical engineering students you know about physics, electrical energy, failures and stability. It would be difficult to argue e.g. that you did not know that leaving the chuck wrench in the lathe chuck and starting the spindle would cause an injury, particularly if you received additional warning in an orientation.*

You must also keep in mind that the student next to you is most often not covered by extensive insurance* such as the compensation provided by the WorkSafe BC. If you injure the student, the student or the student’s estate might resort to suing you for compensation.

* Student Accident Insurance provides only minimal one-time compensation for an injury. It does not provide continuing benefits as may be required for a permanent disability.

The shop safety rules are based on the WorkSafe BC regulations.

**Requirement to Enforce Safety Rules**

The department is required to enforce safety rules that protect workers in the area. As such, the department is required to outline and also follow through with consequences. Penalties for students for violations range from temporary suspension of shop privileges to permanent suspension but may also include other actions by the university.

**Safety Incidents in the Machine Shop**

*How do accidents typically happen?*

Accidents in a machine shop like this one are most often caused by improper use of tools and equipment (hurrying and short-cutting), failure to properly use protective equipment and inattention. Failures in machine tools do occur but are comparatively rare.

*How do you avoid accidents?*
Don’t experiment with power tools. There are tools in this shop can cause severe injuries if used incorrectly.

You must be oriented on a machine tool before using it and you must ask for assistance if you are unclear about what to do next.

Learn to use tools and equipment properly following the safety rules and any manufacturer’s recommended practices and procedures. Each machine tool has a manufacturer’s operating manual provided in the associated tool cabinet or near the machine.

Use the appropriate safety gear. If you are not sure, ask shop personnel.

Work to minimize hazards. There are often several options for setting up a job on a machine. Choose the safest practical option.

Use your judgement: if something seems dangerous it probably is. This does not imply that something that seems safe is always safe!

Please report all incidents to Shop Personnel so that we can act promptly and appropriately on any safety issues. All injuries and near misses (incidents where someone could reasonably have been hurt) at UBC must be reported to the Campus Accident and Incident Reporting System (CAIRS).

Please read over this manual carefully and follow the rules described. If you have any questions about the operation of any machine or tool ask the area supervisor for instructions.
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Special Hazards, Fire and Explosion Prevention

- The welding room may at times contain compressed propane, acetylene and oxygen cylinders. Do not handle these cylinders unless trained to do so.
- Do not attempt to operate any of the welding, soldering or electric arc cutting equipment without proper training. Serious burns, explosions or electric shock could result if you use these improperly.
- Welding work may be performed by qualified individuals, however all activities must comply with CSA W117.2-12
- Keep combustibles out of the weld shop. Never weld, grind or otherwise work on any vessel that has contained a flammable liquid (fuel tanks) in this shop.
- Do not work with volatile substances (explosive fumes) in any part of the shop. This facility does not have an air-handling and extraction system designed for such substances. The welding shop ventilation system is for welding smoke removal and grinding dust collection only and may ignite flammable gases and vapours.
- Grinding, abrasive cutting and power-sanding of metals is restricted to steel, iron and their alloys. Serious fire, wheel fragmentation and dust hazards exist when power grinding soft metals such as aluminum, magnesium, titanium and their alloys, so this is not allowed in the shop.
- Most portable power tools create sparks internally at the motor brushes while at the same time drawing air through the tool, past the brushes. Be careful how and where you use them to avoid explosions from flammable gases and dusts.
- Grinding tools like the Dremel cut-off wheels eject a large amount of sparks which could ignite flammable or combustible materials such as sawdust, fuels, flammable gases and some types of synthetic clothing.
- Fires can also be started from excessive friction from cutting wood with dull bits or blades or power-sanding with too much pressure or worn out abrasive. It may ignite sawdust inside the machine or in the wood dust collector.
- Do not toss hot items into the garbage. Place hot items on the weld table in the welding room where they can cool down and mark the work as “hot”.
- Keep the heat down: use coolant when cutting milling and drilling to get the best finish, extend tool life and reduce the chances of burns.
- Never leave oily rags lying around as there is a possibility of spontaneous combustion, particularly if the oil is linseed based. Put rags in the red fireproof bucket behind the Triumph #3 lathe.
- Store flammables such as alcohol, solvent cements, etc. in the shop’s flammables cabinet when not in use.
W.H.M.I.S. and S.D.S.

Workplace Hazardous Material Information System and Safety Data Sheets

- The Workplace Hazardous Material Information System (W.H.M.I.S.) is a national system of standardized labels and symbols designed to inform workers of hazards associated with materials. The wall chart on the shop door provides a legend for symbols used in Canada. Refer to the chart to determine the meaning of symbols on SDS sheets in the binders containing the sheets.

- The Safety Data Sheet system is a standardized format for information on hazards associated with particular materials. Before working with any specialty materials, such as resins, glues, lubricants, coolants, etc. check the SDS for handling, storage, disposal, first aid and clean-up measures.

- If you intend to work with any materials that you are bringing into the shop, ensure that you get a copy of the SDS for that material and submit it to shop personnel for review before bringing the material into the shop. You are responsible for ensuring that you don’t create a hazardous waste problem and may be held accountable for clean-up costs if you do.

- The shops do not have facilities for machining or otherwise handling volatile, toxic or carcinogenic compounds such as may be produced when working with asbestos fibers, beryllium, cadmium, lead or similar metals or alloys containing significant amounts of these materials.

- Do not expect to be allowed to work with materials from outside the shop without a relevant SDS sheet.

- The provisions concerning a supplier label and SDS do not apply if the controlled product is product material or substance packaged as a consumer product and in quantities normally used by the consuming public is exempt from control, however, the labels and warnings on the package must be clearly visible. * WCA OHS Regulation 5.3 part 2 e

- SDS are also important for First Aid treatment information.

- Look at the UBC Safety and Risk Services website for information on finding SDS sheets.
Serious Hazards in the Shop

- Rotating machinery (lathe, grinder, buffer, sander, mill, drill press, portable angle grinder, abrasive saw)
  - ejection
  - entanglement
- Pinch points (existing and set-up generated)
  - Setting up close to moving parts
  - Automatic feed operation
  - Manual equipment linkages
  - Presses, clamps and rollers
- Toxins
  - coolants and lubricants
  - smoke from various operations
  - dusts and particulates
  - coatings
  - residues
- Electrical energy (shock hazards)
  - Welding equipment
  - Portable AC powered devices
- Pneumatic energy
  - Compressibility of air can make it dangerous because large amounts of energy can be stored, high forces can be easily generated and accidental releases are most often uncontrolled
  - Air jet can cause bodily injury (eye sockets, ear-drums, embolism)
- Sharp edges and points
  - saws, knives, razors
  - wood cutting tools
  - sheared metal edges
  - toolbits
  - scribes, music wire
GENERAL SHOP SAFETY RULES

1. If you are unsure about what you are doing, you must ask for help from shop personnel. Do not attempt to operate any equipment until you are clear on the risks and leading practices used to control those risks.


3. No operation of machinery without a supervisor present. Under no circumstances are you allowed to work alone in the shop or without shop personnel or a faculty supervisor present.

4. Don’t endanger other people. You have an obligation to keep others safe, too.

5. Act with due care to protect yourself and others, particularly with regards to head injuries. This includes immediately cleaning up slip, trip and collision hazards, properly routing extension and power cords, properly securing rotating components, protecting against ejection of items from machinery and tools such as presses, etc. where high force, high energy levels are present.

   The most frequent cause for ambulance calls to machine shop stems from individuals falling and hitting their heads. One of the chief causes of falls has been fainting brought on by discussions about injuries. Please refrain from graphically describing injuries.

6. As outlined in WorkSafe BC OHS Regulations, regarding Right of Refusal, you have the right to refuse to perform activities that are unsafe, i.e. without adequate supervision that you are not qualified to do or have not been trained to do safely.

7. Never run, push or indulge in horseplay and never throw objects.

8. No eating or drinking on the shop floor. If you need to take a break to eat or drink, do so, but not in the shop and be sure to wash your hands before handling food.

9. Approved eye and foot protection are required at all times when on the shop floor.

10. Hand protection in the form of suitable gloves should be used for handling hot objects, glass or other sharp-edged items, but must never be used to operate machinery.
11. Appropriate (protective) dress is required-cover from neckline to ankles with cotton, wool, synthetic blends; short sleeves ok.

12. Do not wear ties, scarves, open or loose clothing, jewellery such as rings, bracelets or necklaces, gloves, etc. around moving or rotating machinery. Long hair or anything that may dangle and get caught in machinery must be effectively constrained.

13. Do not come into the shop if your ability to safely operate machinery and tools is impaired in any way. Lack of sleep, drugs in your system and high levels of distraction should keep you out of the shop.

14. Report all injuries, accidents, near misses, spills and equipment problems to shop personnel.

15. Walkways and exits must be kept clear and free from obstructions, trip and slip hazards.
   a. Tripping hazards and spills must be addressed immediately. If you spill a liquid on the floor, wipe it up immediately with shop rags or paper towels (use the pelletized absorbent for oily liquids). Ensure that the slip hazard has eliminated before proceeding with other work.
   b. Large items such as bicycles, skateboards, backpacks, etc. are not allowed on the shop floor.

16. Do not attempt to enable tools that have been locked out or enable shop main power unless authorized to do so. Any attempt to bypass security lockouts or other protective devices, unauthorized reset of the shop emergency shutdown or power may result in damage and or injury.

17. Under no circumstances are you to bring unqualified individuals into the shop or to allow them to use tools from the shop.

18. During regular shop hours each user must be booked in on the shop reservation system and must carry the associated shop tag.

19. You must always leave machinery in a safe state for the next user with all cutters, chips and cutting fluid removed from the machine.

20. This shop is open only to persons actively registered in Mechanical Engineering or with appointments to the department of Mechanical Engineering.

21. All use of university-owned materials and use of the waterjet cutter must be reported prior to leaving the shop. Failing to report use or inappropriate use of university materials may result in additional charges and disciplinary measures.
22. Put tools back promptly for others to use and clean the machines after use to maintain your access to the shop.

23. Report damaged tools or equipment.

24. Use of the shop is for educational purposes and qualified research only. Use of the shop for commercial purposes is not allowed. Shop users who wish to develop ideas for potential future commercialization should review Policy #88 and contact the University Industry Liaison Office to clarify rights of ownership of intellectual property.
Learning Proper Tool Usage

Proper use of some tools may be intuitive, but it is generally a good idea to start by learning a bit about well-established techniques so that you aren’t blindly breaking rules of good practice.

You can greatly enhance your understanding of good shop practices by viewing videos (You-tube is a wonderful resource). See the website for links to some of our favourites.

You can also learn a lot by reading handbooks.

Free handbooks:

Worth paying some money for if you have to:
Mechanical and Metal Trades Handbook, Europa Lehrmittel, ISBN 978-3-8085-1913-4

Basic Metal Cutting

Cutting requires a tool with sharp edge and a hardness that exceeds the hardness of the material being cut.

For example, tools such as high speed steel milling cutters, saw blades and files are made from steels that contain additives and that have undergone heat treating and coating processes that increase hardness of the cutting edge. Once hardened, the tools can cut through other steels.

A common tool material for milling cutters and drill bits is High Speed Steel (HSS), which is really a range of alloys developed for use in cutting tools. These alloys contain additional compounds which help to enhance mechanical properties. High Speed Steel can be used to cut most common forms of metals (mild and alloy steel, stainless steels, aluminum, brass).

A common tool material for lathe work and for some milling operations is tungsten carbide. This material is extremely hard and has very high temperature resistance, so it can be used for higher cutting speeds than HSS. Carbide is more expensive, harder and somewhat more brittle than HSS, so tools often consist of a small piece of carbide attached to a steel shank. The steel shank is less costly and provides a tough support to offset the brittleness of the carbide.
One of the prime advantages of using carbide tools is that they are available as pre-sharpened inserts. Such inserts are screw mounted or clamped in place. Replaceable insert tooling is used both on turning and milling tools.

Improvements in production methods have made solid carbide milling cutters and drills much less costly, so they are now fairly common items in machine shops.

**Cutting Speeds and Feed Rates**

**Cutting Speed**: rate at which the tool’s cutting edge moves relative to the surface of the workpiece.

**Feed Rate**: rate at which the tool’s position is changed relative to the workpiece’s position.

Typically, cutting as fast as the operation will safely allow minimizes the amount of time required to finish an operation. Hence maximizing the cutting speed and feed rates is frequently desirable.

Cutting speeds are limited by several factors, the most important one being heat generated by the friction between the tool and the material being cut.

General ranges of cutting speeds and feed rates for cutting various materials are indicated by the carbide insert manufacturer.

Feed rates depend on the cutting tool edge geometry as well as the stiffness and strength of the workpiece and the stiffness, strength and available power of the cutting machine. In general terms, it is always desirable to use the stiffest set-up of the machine (i.e. largest tool held as short and workpiece supported as securely as practical)

Values for feed rates are also charted in handbooks such as the Machinery’s Handbook.
Measurement

*The Vernier Caliper*

One of the most important tools in the machine shop is a set of precision calipers. This will allow the machinist to check the actual size of features on parts being produced in the shop.
The simplest and most reliable style of caliper is the Vernier caliper. It has few moving parts, no need for batteries and is highly resistant to damage from particles and fluids typically found in the machine shop.

The Vernier caliper uses the Vernier scale for making precision measurements.\(^1\)

A Vernier scale uses a moveable expanded scale to magnify the effect of moving the expanded scale in small increments. In the diagram below, the lower scale is the main (fixed) scale and the upper scale (0-25) can be re-positioned relative to the lower scale.

![Vernier scale diagram]

Note that the expanded scale of 25 units represents a magnification of the smallest increment indicated in the lower scale.

The Vernier caliper has the moveable scale attached to the sliding jaw of the caliper. When the caliper is closed, the zeroes of the two scales coincide. As the caliper is opened, the expanded scale travels along the main scale. For example, if an object measuring 1” is placed between the jaws, the 0 on the expanded scale will be aligned with the 1 on the main scale. **The position of the zero of the expanded scale on the main scale indicates the gross measurement.**

![Vernier caliper diagram]

The expanded scale is used to refine the gross measurement indicated by the position of the 0 of the expanded scale. Consider the image below:

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The 0 is positioned between the marks indicating 2.450” and 2.475”. To find the actual position of the 0, look at the alignment of scale marks between the two scales and select the one on the expanded scale in closest alignment with any of the marks on the main scale. In this case, 13 on the expanded scale appears to have the best alignment. **To obtain the precision value, simply add the number from the expanded scale (13 representing 0.013”) to the gross value of the lower mark on the main scale (2.450”) to obtain 0.013”+2.450”=2.463”.

Calipers can be used to make various measurements as shown below

Common sources of measurement error:
1. “seeing” the desired value rather than reading the scale position correctly
2. Forcing the caliper to a desired position by applying high pressure to the jaws
3. Presence of foreign particles, chips and burrs under the caliper jaws increasing the apparent measurement
4. Caliper not held perpendicular to the feature being measured thereby increasing the apparent measurement. This is particularly problematic when measuring hole diameters.

**Good Practice:**
1. Take multiple measurements applying light pressure only.
2. Wiggle the calipers back and forth while applying pressure to feel when the jaws are squarely engaged with the surfaces of the part.
3. Check the zero position before making high precision measurements.
4. Inspect the tips of the calipers to see that they are in good condition. Deformed tips will offset your measurements.
5. Consider the effect of surface roughness on your ability to measure a feature particularly when adjusting a tool position to remove additional material. Consider creating a smooth interim measurement surface by using a finer feed rate for a portion of the cut.
Hand Tool Use

Hacksaw

The only hand saw in the shop designed for cutting metal is the hacksaw. Hacksaws with good quality blades and properly tensioned can cut most common metals easily if the workpiece is firmly held in e.g. a vise.

Hacksaw blades are installed to cut on the forward stroke. Two hands should be used to hold the saw; one on the handle and one on the front to guide the saw. Cuts should be made using long strokes. Short frenetic strokes will dull a portion of the blade very quickly, reducing the kerf in that region and causing the blade to jam.
Workpieces must be held very firmly because deflection or movement of the workpiece will jam the blade. The workpiece should be held so that the cut is as close as practical to the jaw of the vise.

Smaller bar stock and shafting (<20mm) can be cut easily using a hacksaw and much more safely than on the power saws.

Lubrication is rarely required for hacksaws, unless very thick sections are being cut.

Take care when cutting small pieces of harder materials such as steel as the cutting process will heat small pieces enough to cause skin burns.

**Files**

Files are simple tools with many tiny cutting edges. They are available in several shapes with cross sections that can be round rectangular, oval, square or triangular. They may have straight sides or taper. They are also available in many different sizes and with differing coarseness of cut.

Metal files are designed to cut on the push stroke only. Dragging the file backwards on a hard material can ruin the file because the sharp cutting edges are not well supported against loads in the backward direction. If the material is soft, some will argue that pulling the file back helps to clear chips.

Like hacksaws, they function best on a well supported workpiece, hence clamping pieces in a vise is best practice. It is possible to use a fine file to deburr workpieces that are hand-held as little material needs to be removed and cutting forces are low.

Softer materials such as aluminum tend to clog the teeth on a file and frequently cleaning with a wire brush or file card is required for efficient cutting. Failing to clean a file may also result in poor, irregular surface finishes as material embedded in the teeth is dragged across the surface.

Recently, diamond impregnated files have become readily available. These files can be used in both forward and backward directions as the diamond dust “teeth” are firmly embedded in the surface.
CUT ON FORWARD STROKE

LIFT FILE AWAY FROM WORKPIECE ON RETURN STROKE
HAND TOOL USE SAFETY RULES

1. Use hand tools for their intended purpose and do not overload the tool. (e.g. don’t use a knife blade for prying because the blades are sharp, hard and brittle and could easily slip or snap)

2. Be careful when handling sharp tools, such as knives, wood chisels, saws and scribers. Do not pile tools on top of each other.

3. Use sharp cutting tools only. Dull tools are difficult to control because they tend to stick and cut unevenly. Learn how to sharpen your tools.

4. Never work towards yourself or against yourself. Put your supporting hand out of the way of the cutting tool. Consider what might happen if you were to slip.

5. Never carry sharp tools in your pockets unless they are retracted or otherwise encased in a suitable protective sheath. Don’t carry items in your pockets if you are going to be working with moving machinery if there is a chance they could fall into the machine.

6. Be wary of filings, especially steel filings, when using the bench areas and when handling files. Clean up filings promptly to avoid spreading them around. Be proactive about reducing slivers by sanding, filing deburring or capping edges promptly.

7. Hand-cut sheet metal edges are often ragged and sharp. Wear gloves if necessary and remove burrs and cuttings promptly.

8. Use the vise or clamps to hold your workpiece when you work it. Don’t hold a workpiece by hand unless you can brace it firmly against the bench.

9. Don’t apply excessive force to a hand tool. If you have to push, pull or squeeze too hard, it is likely that there is something wrong. Never use “cheater” bars to extend the handles on a hand tool for more leverage because you are overloading the tool.

10. Never strike hardened surfaces or allow steel or other hard metal tools to hit hardened surfaces.

11. Be wary of pop-rivet and snap-ring tools. They sometimes eject pieces with enough force to damage your eyes.

12. Be aware of others around you when handling sharp or pointed items such as stiff wire so that others don’t walk into the object or are struck in the face.

Threaded Holes
Taps are cutting tools that are used to make internal threads in holes. Standard thread-cutting hand and machine taps need to be used only on predrilled holes of the appropriate size. Hole diameters and the drill required to make them for standard threads are charted.

Once the hole is drilled, the tap is lubricated with a cutting fluid and inserted into the hole. Cutting of the thread is achieved by turning the tap forward and back in $\frac{1}{2}$-1 and $\frac{1}{4}$ - 1/2 turn increments respectively. The reverse turn is required to break the chip raised by the cutting that occurred on the forward turn.

A tap wrench is used for hand taps. Small taps are held using a collet style holder. Larger taps are held in adjustable tap wrenches.
Care must be exercised when starting a tap to keep the tap in-line with the axis of the hole so that the thread is straight.

It is sometimes helpful to use a drill press (without turning on the motor!) as a guide for keeping the tap straight when starting. Unplug the machine for safety, hold the tap in the three jaw chuck and turn the chuck by hand. Alternately, a live centre may be installed in the drill press instead if the tap holder or the tap has a centring hole. The same processes can be performed on a lathe to tap axial holes in lathe work using the tailstock to hold the tap and by turning the lathe chuck by hand.

Be careful when tapping blind holes. The chips may fill the hole and bind the tap if the tap is not periodically removed for cleaning.
The drill press is a frequently used tool in a machine shop. It is relatively easy to set up for drilling holes in workpieces. A typical shop drill press has a 500-750 watt motor and can be used to drill holes ranging from Ø0.5mm to Ø50mm. Attachments such as hole saws can make holes as large as Ø150 mm in softer materials.

While a typical drill press can not be used to perform precise hole location as can be done on a milling machine, it can be used to quickly create precision holes using a combination of drilling and reaming.

Typical bits used in drill presses include straight shank twist drills, centre drills and straight shank reamers. These are held in a 3-jaw drill chuck mounted into the spindle. Larger drill bits and reamers (larger than Ø12mm) have taper shanks that can be fit directly into the spindle of the large drill press.
Workpieces are clamped to the table and the table clamp is tightened to lock the table into position. **Drilling forces for most operations in metal are generally too high to allow the operator to safely hold the part by hand. The drill may suddenly jam and spin the workpiece and it may also suddenly lift the workpiece, particularly as the drill breaks through the underside surface when drilling through-holes.**

Feed handles on the side of the drill press provide a large mechanical advantage which allows the operator to push the drill bit against the workpiece.

All of the shop drill presses are belt driven. The speed of the drill press is changed by altering the belt position on the stepped pulleys.
Preparation of the Workpiece for Drilling

Hole locations should be marked using a scribe, height gauge or with a template. Each location should be centre-punched to provide a guiding dimple for the tip of the drill.

![Figure 4: Double Ended Centre Drill](image)

Higher accuracy holes and holes on oblique or curved surfaces must be started using a centre drill as twist drills can easily deflect if one side of the tip contacts the surface before the other side. A centre drill is a short stiff drill bit that will make a hole with a conical entrance that will guide a standard drill bit.

Figure 4: Double Ended Centre Drill
Figure 5: Floor Standing Drill Press

Figure 6: Benchtop Drill Press
Speeds for Drilling

Approximate drilling speeds can be calculated based on charted values (see Appendix A), however these machines are designed for drilling metal and it is generally acceptable to use the higher speed ranges for small drill bits and low speeds for the larger bits. Generally, there is a need to keep heat build-up to a manageable level. Heat sensitive materials such as plastics can not be drilled too fast. If your bit is squealing, chattering or smoking as you use it, it is likely that the speed is too high. Once a bit has been overheated, the edges will be dull and will require grinding and re-sharpening.

Speed changes can be made by moving the drive belts to the correct pair of pulleys. Ensure the drill is turned off. Access the belt by raising the top cover. It will likely be necessary to slacken the belt tensioner and pull the motor forward in order to re-position the belt. It is typically easier to move the belt off the larger pulley first.

Cutting Fluid Use

Cutting oil or coolant should always be used when drilling steel with High Speed Steel bits. It is possible to drill most general grades of aluminum without coolant, however the drill bit may stick and break in deep holes. Deep holes should be drilled in stages with

Figure 7: Changing Speeds

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frequent backing out of the drill and re-application of lubricant. If workpiece material is sticking to the bit, stop drilling and clean the bit.

Drilling Hints:

1. Obtain the alignment of the drill bit with the punch mark before clamping down the workpiece by bringing the drill bit into the punch mark while twisting the drill chuck by hand.

2. Prevent long dangerous chips when feeding the drill into the workpiece by pausing or backing up the feed handles.

3. In emergencies drill presses with switches on the front can be turned off with a bump from your forehead if your hands are unable to reach otherwise.
**DRILL PRESS SAFETY RULES**

Critical

1. You must wear safety glasses.

2. Do not use it with loose clothing, long hair, rags or anything else that could get caught in the chuck or picked up by a spinning workpiece.

3. Remove all jewellery from hands and wrists

4. Check to see that the power switch is in the off position before connecting the power cord.

5. Always place workpieces so that they are unable to spin. Use a clamp or brace the workpiece against the left side of the drill press column.

6. Shield against cutting spray and chips and clean the tool and floor periodically if chips, coolant, etc. start to accumulate

7. If large chips form and start spinning, stop the machine, de-energize it and remove the chips. Swirling chips are an entanglement hazard.

8. Remove chips with a brush or a hook AND only when the drill has stopped. Never use your hand. Cuttings can have a high tensile strength and may be very sharp.

9. **Do not drill brass or other soft materials with regular drill bits**; it can be very dangerous because the drills may self-feed. Brass requires special bits. Ask the shop personnel.

10. Use only bits designed for use in a drill press. Do not use router bits or milling bits, grinding stones, cut-off saw blades or other such accessories that are not designed specifically for drilling.

11. Do not use a drill press for powered tapping! You may use a drill press only with the power disabled to hold a tap for starting a tapping operation and you must never use power for tapping unless the apparatus is specifically designed for this purpose.

12. Never place taper shank tools such as large diameter drills or tapered shank reamers in a 3 jaw chuck. Only straight shank tools such as standard drills can be clamped in chucks.

13. If the chuck drops out of the taper while you are drilling, do not retract the spindle until you have stopped the machine. This will help prevent the chuck from being ejected.
14. Never try to hold the chuck and apply power, tighten or loosen the drill chuck while the power is on or while the chuck is moving. Let the spindle stop of its own accord after turning the power off. Never try to stop the spindle with your hand.

15. Never clean or adjust the machine while it is in motion or plugged in. Always unplug it or lock off the power to protect against accidental activation.

16. Use spade bits for wood only. They are very dangerous if used on metal or fiber reinforced materials such as fiber reinforced plastics (fiberglass). Do not remove the wood cutting drill bits from the wood shop.

17. Consult manufacturer’s operating manual for more information.

Good Practice

1. Ensure that the drill will enter a clearance hole in the table if you are going to push the tip of the bit below the table surface.

2. Check the drill stop. It seems to be a common mistake not to do this.

3. Drill pressure is to be applied with one hand only. If you need more pressure than this, it is likely that the bit is not suitable for the drilling operation.

4. Use cutting fluid, particularly on steels.

5. Stop feeding momentarily to break chips before they become too large.

6. Keep the drill table clear of all unnecessary items.

7. Don't use a damaged, dull or cracked drill. Inspect the drill before using.

8. Ease up on drilling pressure as the drill starts to break through the bottom of the material.

9. When drilling holes larger than Ø3mm in metal or Ø12mm in wood, hold work in a vise or clamp to the drill table and lock the table in place. When reaming a free-floating workpiece, brace the work against a rotation stop such as a c-clamp on the table. A drill press pushes the point down on the workpiece and the flutes of the drill bit pull up on the workpiece. When the drill bit breaks through the bottom surface there is no more downward force from the drill press, only an upward force from the flutes. The workpiece must be held down against the table to prevent the bit from lifting, deflecting and jamming in the hole and possibly
spinning the workpiece. Ensure the workpiece is properly supported from the table and is not deflecting or rocking.

10. Avoid drilling sheet metal; use the Whitney-style hand punch or the Rotex turret punch and or hand reamer whenever possible.

11. Always double check that you have removed the chuck key and taper drift before starting the motor.

12. Check that the taper is tight before drilling, especially if you have just exchanged the chuck or a tapered bit.

13. Always clean drill shank and/or drill sleeve, and, spindle hole before mounting.

14. Don't drill with too much pressure. If you notice that the drill is deflecting or smoking, stop what you are doing and ask shop personnel for help.

15. Remove taper shank tools from spindle or sleeve with a drill drift and hammer.

16. If the drill binds in a hole, stop the machine, unplug the machine and turn the spindle backwards by hand to release the bit.

17. When drilling a deep hole withdraw the drill bit frequently to clear chips.

18. Run drill at correct RPM for diameter of drill bit and material. Slow for larger diameter bits; faster for smaller bits. Consult the Machinery’s Handbook.

19. Place a piece of wood on and lower the drill spindle close to the table when releasing the drill chuck or taper shank drill to reduce the chance of damage in the event they fall onto the table.
Band saws are relatively simple machines consisting of a ribbon-like sawblade made of flexible steel, looped around two or three wheels, one of which is driven by a motor. The blade passes perpendicular through a split table. Workpieces to be cut are rested on the table and pushed through the blade when the blade is moving.

The major advantages of the band saw are its speed and the ability to cut curved paths. It is sometimes most useful to remove bulk material with the saw before finishing a part on e.g. a milling machine.

Operators use special holders and push sticks to guide workpieces through the saw. Cuts are mostly done free-hand and cut surfaces often need refining using some other process. Even with a fence, the accuracy of the cuts is about 0.5 mm over 100mm. Holders and push sticks are stored on the machine.
Setting Up

Kysor Johnson Band saw

The large Kysor Johnson band saw in the Student Shop is designed for cutting metal and can handle thickness exceeding 150mm. The blade guard and guide roller assembly can be raised and lowered using the blade guard adjuster located on the right side of the saw. It is necessary to ensure that the adjuster is securely locked in the desired position using the adjuster lock knob.

Always adjust the guides and blade guard assembly to the minimum clearance required to cut your piece: this is safer and will also produce the most accurate cut.

Speed Selection
The speed chart on the front of the machine provides some guidance for speed selection. As a general rule, aluminum and other soft metals can be cut with the gearbox on the high range, while steels and iron should be cut at lower speeds using the low range of the gearbox. The gearbox lever should only be moved when the motor is turned off.

Intermediate adjustments are possible using the variable speed control which can only be adjusted with the motor running. Note that the variable speed control must be returned to minimum before attempting to change the high-low gearbox.

Wax lubrication of the blade is typically all that is required. The stick is usually kept on the front of the saw.

The stop and start buttons are located on the upper portion of the saw. Note that the saw may stop if the gearbox lever jumps out of position. It is very important to push the Stop button before attempting to do anything else or the saw may suddenly begin operating.

Don’t cut thin materials such as sheet metal on the Kysor band saw! The Jet 14” metal band saw is set up for materials from 1mm to 6 mm thick. Materials thinner than 1mm are to be cut on the shearing equipment or on the abrasive waterjet cutter. The minimum thickness of material that can be safely cut on a sawing machine depends on the tooth spacing of the blade. The material must be at least twice as thick as the blade pitch to avoid stripping teeth off the blade.
BAND SAW SAFETY RULES

1. Disable power and wait for the machine to come to a complete stop before attempting adjustment, changing blades, cleaning etc.

2. Keep guards in place. Do not use the machine if the guard is missing. The blade should not be accessible or exposed except in the cutting region between the table surface and the underside of the blade guide.

3. Adjust the upper blade guide and guard to within 5 mm of the workpiece, but never attempt to adjust or re-position guides, tables or guards when the saw is running.

4. Check that the blade guide clamp is tight before turning on the power.

5. Never start motor with the work piece touching the blade.

6. Do not use a kinked or damaged irregular blade because it can catch the workpiece and jam. It is dangerous because it will cut in an uncontrolled fashion. If you are unsure that the machine is operating correctly, stop the machine, lock it out and inform the shop personnel.

7. If the Kysor saw ever stops suddenly, be sure to press the STOP button before doing anything else. The high/low gearbox is worn and may disengage on its own. Attempting to re-engage the gearbox may cause the saw to start without warning.

8. No sheet metal (<6 mm thickness) is to be cut on the Kysor band saw. At least three teeth of the band saw blade must contact the workpiece at all times to prevent chatter and shearing off teeth due to tooth overload. For thin materials, including sheet metal, use the Jet band saw.

9. Hardened materials are not to be cut on any metal-bladed saw in the shop. Consider using the water-jet cutter for this.

10. Cut only work pieces that are supported against cutting forces. Overhanging features are subject to tipping or spinning when applied against the blade and they must be properly supported. Round metal stock must only be cut clamped in a fixture that prevents rotation. Consider using the Meba stock saw or manually using a hacksaw instead of the vertical band saw for such stock. The workpiece must lie flat on the table otherwise the blade may bind and break, or the workpiece may pinch or pull the operator’s hands towards the blade. Ensure the workpiece is properly supported from the table and is not deflecting or rocking.

11. You must use a push-stick, one of the saw’s workpiece holders or similar tool to feed pieces into the saw if there is the possibility of getting hands near the blade.
Using a handsaw and a bench vise rather than the band saw often results in a better-controlled cut.

12. The saw’s table must be kept clear of tools or other materials when the saw is in use.

13. Consult manufacturer’s operating manual for more information.

Good practice

1. Start the machine and let it run for a few seconds to see if the blade is tracking properly. If you notice that it has sections of teeth missing or runs irregularly, stop the machine and get shop personnel to look at it.

2. Use a brush to remove any particles off the table before placing the workpiece on it. Do not wipe the table with your hands because it likely contains fine steel slivers.

3. Keep proper footing and balance at all times.

4. Use cutting wax whenever cutting steel or when cutting aluminum thicker than 25mm. You will get better cutting results if you use wax for most cuts in steel.

5. Do not run the band saw at a higher speed than recommended for the material being cut. Blades are usually high speed steel, so cutting speed limits for this material apply.

6. Stop the machine and de-energize it to clean the table and floor periodically if debris starts to accumulate.

7. Use the right blade for the job. The blade must engage at least 3 teeth over the thickness of the material being cut, otherwise you risk tearing out teeth which results in uneven cutting and breaking of the blade. If the blade needs changing, ask the shop personnel.

8. Get assistance if you are handling larger pieces of material. Don’t try to feed them through the saw by yourself.

9. Don't feed the workpiece with too much pressure. A properly cutting blade should cut smoothly and evenly. If you notice that the blade is deflecting or smoking, stop what you are doing and ask shop personnel for help.

10. When cutting small radius curves use relief cuts to avoid twisting and fatiguing the blade.
11. Use the saw stick lubricant if you are cutting aluminum to prevent clogging of the teeth.

12. Avoid cutting sheet metal on the band saw; use the bench shear, hand shears, nibbler and notcher instead. Cutting sheet metal on a saw is noisy if the tooth pitch is larger than the material thickness because the teeth aren’t able to cut properly as the material is being fed into them. The thin material can strip teeth off the blade because it overloads the teeth. The quality of the cut edge is generally much poorer than an edge cut by shearing.

13. If the blade breaks or pops off the guide-wheels, shut off the power and stand clear until the machine has stopped moving. De-energize the machine and consult shop personnel.
MILLING MACHINES

Figure 1 Kondia FV-1 Vertical Mill

Milling Machines

Milling machines typically consist of a cutting tool spindle mounted fixed over a table that can be moved precisely in orthogonal directions. A workpiece is typically fixed to the table. The table is supported on three independent slides (XYZ), each of which has its own feed system. The feeds may be manually operated or powered. Coordinated motion of the slides may be possible if a computer controller and appropriate drive system is used (Computer Numerical Control).

Figure 2: Milling

In milling operations, the tool typically rotates at high speeds to generate the cutting velocity and the workpiece is fed into the cutter by moving the table left/right (X direction), fore and aft (Y-direction) and up/down (Z-direction).
The XYZ motion is produced using 3 orthogonally arranged precision slides. The slides are equipped with mechanical dials and digital encoders that allow positioning of the slide to an accuracy of 0.001”. Note that all of the machines in the Student Shop have dials with inch measurements.

The three large mills in the Student Shop are almost identical. This style off machine is known as a vertical knee mill due to the spindle orientation and the arrangement of slides supporting the table. The spindle is driven by an electric motor through a continuously variable speed drive and a 2 speed gearbox (HI-LOW RANGE) which provides a speed range from 90 to 4000 rpm. While it is possible to re-position and re-orient the spindle on these machines, it is usually placed in an upright position, normal to the surface of the table. Note that the variable speed drive must only be adjusted when the spindle is turning otherwise the drive may be damaged.
Milling Cutters
Milling cutters are available in various formats, shapes and sizes. Some are for generic uses and some are for very specific uses and all are made with hard materials that will cut most common steels and other metals. The lowest cost tool material is High Speed Steel (HSS) and harder materials such as cemented carbide, cobalt treated steel and ceramic are also used, typically in the form of replaceable inserts mounted on a steel holder.

One type of cutter used for many different operations is an end mill. This cutter appears similar to a twist drill bit because it has spiral cutting flutes, but unlike most drills, it is typically much shorter, has a flat tip, may have multiple pairs of cutting flutes and a much stiffer cross-section. End mills can be used to face surfaces as well as cutting sidewalls and slots. These cutters are available in standardized diameters in fractional inch or millimetre sizes.

![Figure 4: End Mill](image)

End mills are held in the spindle using a specific style of holder (collet chuck). The collets are expandable metal sleeves which grip the cutter shank when tightened in the collet holder. Collet chucks are specifically designed to withstand the cutting forces involved in milling operations and should not be confused with drill chucks which are designed to withstand high loads in the axial direction only.

Installation of the Collet Holder into the Spindle (Kondia #1, #2 Mills)

The collet holder must be mounted into the spindle in order to use end mill style cutters. The spindle on the mill has a standardized tapered bore and a long bolt (drawbar) that is used to pull and hold attachments securely and with a high degree of concentricity to the spindle. Two of the machines have manual drawbars and one machine has an automatic drawbar. (See Kondia #3 Notes).
Figure 5: Cutaway view of Manual Drawbar in Spindle (Kondia #1, #2)

1. Wipe the surface of the collet holder and the inside taper in the spindle to ensure that they are clean.
2. Slip the collet holder into the spindle, aligning the tabs (dogs) on the spindle with the slots on the holder and finger-tighten the drawbar.
3. Use the appropriate wrench to tighten the drawbar. Don’t over-tighten the drawbar as it has a large mechanical advantage on the collet holder taper and collet.
4. It is often necessary to put the hi-low speed range lever into the low range and to apply the spindle brake in order to keep the spindle from rotating as you use the wrench to tighten the drawbar.

Removal of the collet holder requires the following:

1. Ensure that the cutter has been removed.
2. Use the wrench to loosen the drawbar ½ turn. Don’t loosen any further than ½ turn to avoid damaging the drawbar in the next step.
3. Use a brass mallet and strike the top end of the drawbar sharply. This should separate the taper holding the collet holder to the spindle.
4. Check the collet holder. If you can shake it slightly, then it is loose.
5. Unscrew the drawbar while holding onto the collet holder.

Use of the Automatic Drawbar on Kondia #3

The drawbar on this machine is motor driven and operated via two push-buttons (see Figure Kondia #3). The green button activates the drawbar to mount the holder into the spindle and the red button is for ejecting the holder. Note that the mounting operation is activated by a momentary push of the green button and that it will continue to pull the drawbar into the spindle unless interrupted. It is important to keep your fingers clear of the holder flange as there is a potential pinch hazard as the holder is pulled into the spindle.

To load the holder:
1. Ensure that the quill (spindle extension) is in the fully retracted position.
2. Insert the holder into the spindle and rotate it to align the tabs on the spindle with the slots on the holder flange.
3. Push the green button momentarily.
4. Let go of the holder as soon as the tabs and slots are engaged.

To eject the holder:
1. Ensure that the cutter has been removed and that the table is lowered to provide adequate clearance.
2. Grasp the holder and push and hold the red button until the holder is free of the spindle. This function will operate only when the quill (spindle extension) is in the fully retracted position.

Installing the cutter:
The order of assembly of the collet into the holder is important for safe and proper use of end mills.

1. Select the cutter.
2. Select a the collet of the appropriate size. Note that you must use the collet that matches the shank size of the cutter. The expandable collet is designed to move only about 0.005” (0.02mm). Using undersized shanks may cause the collet to fail as will forcing an oversized tool into a collet.
3. Snap the collet into the collet ring.

4. Thread the collet ring loosely into the collet holder.
5. Install the cutter so that the full shank is held in the collet. The lower edge of the collet must be fully supported on the shank, so keep the relief cuts for the flutes below the collet.
6. Tighten the collet with the collet wrench. It is often necessary to put the hi-low speed range lever into the low range and to apply the spindle brake in order to keep the spindle from rotating as you use the collet wrench.

Removing the cutter:
1. Use the collet wrench to loosen the collet. Note that the collet ring will become loose as it is unscrewed but will become tight again when it starts to pull the collet out of its tapered seat in the collet holder. The collet wrench will be needed to continue to unscrew the collet ring and to extract the tool.
2. Be ready to catch the cutter as it may slip out of the loosened collet. Keep the cutter edges from hitting any metal surfaces by placing padding under the cutter.
3. The spindle will have to be held from rotating by switching to low range and by application of the spindle brake.
Work Holding

The forces exerted on the workpiece during milling operations can exceed 1000N so it is essential to hold workpieces securely. Larger workpieces can be clamped directly to the table surface using the tee-slots however it is more practical to mount a vise to the table when smaller pieces are being machined. Milling vises are usually set up with the rear jaw surface parallel to the X-axis direction of travel. Workpieces held in the jaws are supported with precision ground pairs of spacers (parallels).

![Diagram of a milling vise](image)

Figure 9: Side View of Vise Mounted on Table

Establishing Reference Points

There are several ways to use the dials or digital readouts on the milling machine to make accurate cuts. It is quick and relatively accurate (typically within +/-0.002”) to carefully bring the cutter into contact with the workpiece to establish X, Y and Z zero positions for the dials at each feed handle or for setting the digital readout zero positions. A more accurate method involves using an edgefinder (see Using and Edgefinder). Another option is to cut a new surface and to zero the axis at the cut.

Note that the scale on the feed handle dial contains a friction clutch and can be rotated relative to the handle position to adjust the zero.
Backlash in the feed screw must be considered when setting the dial zero.

1. Always ensure that the dial is rotated in the direction opposite to the handle rotation used to move the workpiece against the cutter. Any subsequent increments of the handle must be done in the same direction used to bring the cutter into contact if the dial is being used to measure workpiece movement.

2. It is o.k. to turn the handle backwards to move the workpiece away, but the dial will only show correct values if the handle is turned forward.

3. One useful trick is to overshoot the target point when travelling backwards in order to approach it from the positive direction.

Digital Readouts (Kondia #2, #3)

Digital readouts are very convenient to use and avoid the backlash problem associated with dials because the encoders are independent of the screw. Measurements can be displayed in inches or millimetres.

Moving the X, Y and Z Axes

Before attempting to move any axis, ensure that the table locks are loose.

All of the machines have handles that allow manual positioning of the axes. The X and Y feed handles on the machines equipped with power feeds have a free-wheel safety feature. In order to engage the handle, the handle must be pushed against the screw with the engagement pin aligned with the corresponding slot (see Figure 10).

It is advisable to favour raising the table towards the cutter using the Z-axis rather than using the quill feed lever to extend the spindle.
Speed Selection:

Check the Hi-Low Range lever position and ensure that it is fully engaged before turning on the motor. The lever is locked into one of 3 positions (Hi-neutral-Low) with a spring-loaded pin. To move the lever you must push the lever toward the machine to disengage the pin. It may also be necessary to grasp the spindle and to rock it back and forth in order to allow the gears to engage. The pin will only engage when the handle is in the correct position. **Do not turn on the spindle if the handle is not engaged as you will damage the gears.**

Low range covers 90 rpm – 500 rpm. High Range extends from 500 rpm to 4000 rpm. Please avoid running the machines at the high end of either range.

**Do not attempt to adjust the variable speed drive while the spindle is stationary! It must only be adjusted when the spindle is turning otherwise the drive may be damaged.**

Note that Refer to Appendix A for cutting speeds

Turning On the Spindle

1. Ensure the main power switch on the back of the machine is ON.

2. Ensure the spindle rotation is in the correct direction. All of the cutters in the shop are designed with a right hand helix and rotate as shown in Figure 2.

3. The design of the Kondia spindle drive provides a versatile range of speeds. One quirk of the gearbox design is that the direction of rotation of the spindle changes as the range lever is moved from high range to low range. To compensate for this quirk, the motor must be reversed.
   a. On Kondia #1 the motor switch has 2 ON positions.
   b. On Kondia #2 there are two green pushbuttons on the main control panel.
   c. On Kondia#3 there is a black rotary switch on the lower portion of the control panel

Speed Selection:

Refer to Appendix A for cutting speeds

Cutting
When practical, the feed direction for the workpiece should be opposing the cutter. This is known as conventional milling. The direction of motion of the cutting edges due to spindle rotation opposes the feed.

Pay attention to the direction of cutting forces: it is preferable to apply loads across the jaws of a vise rather than parallel to the jaw faces.

Always try to direct chips away from yourself.

Use chips shields.

Apply coolant using squirt bottles when cutting harder materials such as steel or when making heavy cuts or fine finishes in aluminum.

Figure 11: Front View of Kondia #2
Figure 12: Front View of Kondia #3
MILL SAFETY RULES

1. Constrain loose clothing, long hair or anything that could get caught in the spindle, picked up by the spinning bit or snagged by cuttings, or that could snag on the control levers on the machine.

2. Remove all jewellery from hands and wrists.

3. You must wear safety glasses.

4. You must wear safety shoes, particularly because workpieces, milling machine components and accessories like vises and dividing heads are heavy and often greasy and easily dropped.

5. You must wear appropriate clothing for protection from metal chips and coolant.

6. Enable power for operating the knee position only when necessary. Disable power otherwise during set-up. Be aware that on the green Kondia mill, the power to the knee is enabled when the breaker is on even with the STOP button depressed.

7. Do not bring chairs, stools or other similarly sized objects near the mill because the moving the knee (Z-axis) could present a sever pinch hazard. The powered feeds are capable of exerting high forces. You could easily crush a limb if you get it between a moving part of the table and a solid obstruction.

8. Before enabling the spindle check that the all screws, clamps or collars fastening the toolbit to the holder are tight (e.g. adjustable boring tool).

9. Remove chuck keys and collet tools from chucks and place them in the storage holder immediately after using.

10. Remove any loose items from the table or vise to avoid catching them with the spindle or jamming them between moving surfaces or knocking them on the floor.

11. Ensure the workpiece is held tightly in the vise or is clamped securely to the table and that all clamp fasteners are tight. Consider the direction of cutting loads.

12. Ensure that the feed levers are disengaged and the speed controls are set to a low value before applying power to the feeds.

13. Check the spindle speed setting. If the spindle speed is set >1500rpm, with the power off, set the high-low range lever to the low position so that you can adjust the speed safely once you start the spindle. **DO NOT ATTEMPT TO CHANGE THE SPEED CONTROL WITH THE POWER OFF!** You will damage the drive system.
14. If something does seem wrong, hit the STOP button and immediately alert shop personnel. If you must leave the machine unattended, you must first lock out the machine following the lock out procedure posted near the main power switch.

15. Test the brake function if equipped before proceeding with your cutting by stopping the spindle using the STOP button. The pneumatic brake should be activated automatically and should stop the spinning bit almost immediately. If the brake is dysfunctional, turn off and disconnect power. Wait until the chuck has stopped spinning and inform shop personnel. If you must leave the machine unattended, you must first lock out the machine following the lock out procedure posted near the main power switch.

16. Do not attempt to clear chips or turnings with your fingers. If chips accumulate stop the spindle and clear the chips using a brush or a chip hook. Never use a rag and do not attempt to remove chips when the spindle is rotating.

17. You must stop the machine and disable power before taking measurements, cleaning or oiling. If you do not disable power, you run the risk of accidentally activating the controls which could result in severe injury.

18. Never reach around a spinning chuck because of entanglement danger.

19. Never lean against the mill. The controls are dangerous to lean on! You may inadvertently jog a feed-wheel or actuate a lever that drives the vise into the tool.

20. Keep your eyes out of the plane of rotation of the toolbit where the tool meets the workpiece. If a piece is ejected, it tends to travel in this plane.

21. Stop immediately if the cutting tool appears to jumps or not cut smoothly. Consult shop personnel before continuing.

22. Never unclamp the workpiece when the chuck is spinning. All adjustments must be made with power disabled.

23. You must shield yourself and others against cutting spray and chips.

24. Keep your fingers below the flange on the taper when installing tool holders using the automatic drawbar or you may severely pinch your fingers.

25. Never try to touch or stop a moving spindle with your hand.

26. Do not use tool bits other than those designed for use on a milling machine because the forces generated by the mill are high and may fragment the tool.

27. Never leave the running machine unattended.
28. Never feed the workpiece without watching what you are doing. If someone
    distracts you, stop the feed, stop the machine and step away from it before dealing
    with the person.

29. Consult manufacturer’s operating manual for more information.

Good Practice

1. Don't run the machine faster than the proper cutting speed.

2. Avoid directing chips at yourself at all times.

3. Stand at the STOP button when first powering up to avoid having to reach to turn
    the machine off if you notice or suspect that something is wrong.

4. Always clean the collets and tool shank before assembling the chuck.

5. Always clamp the maximum clear shank length of the milling cutter in the holder
    to prevent it from breaking or chattering. Do not clamp the cutter on its flutes.

6. Always make sure that the toolbit is sharp and in good condition. Discolouration,
    uneven edges and rounded edges are often signs of a dull or damaged tool.
    Consult shop personnel if you are unsure.

7. Activate power for the electric drawbar only as necessary and disable it as soon as
    you have finished installing or replacing the tool holder.

8. Complete as much of your set-up and safety check as possible before enabling
    power.

9. Use one hand at a time only to activate controls for moving feed wheels or
    engaging feeds. It is very easy to become confused and to turn a hand-wheel or
    lever in the wrong direction if you are trying to use two hands at one time.

10. Clean the tool and floor periodically with the machine stopped and the power
    disabled if chips, coolant, etc. start to accumulate

11. Don't apply too much pressure or feed at too high a rate. If you notice that the
    machine is making excessive noise or the toolbit is deflecting or smoking, stop
    what you are doing and ask shop personnel for help.

12. Before cleaning the mill remove cutters from the chuck to prevent cutting yourself
    on the sharp bits.
13. Ensure that the table locks for the axes that you want to move are disengaged before attempting to move any axis.

14. Use power only when cutting. For all other activities, such as measurements, adjustments, tool changes or clearing of chips, stop the spindle using the locking emergency stop.

15. Always feed the cutter so that it’s surface velocity is in the direction opposing the feed direction. No climb milling!

16. Never make heavy cuts parallel to the vise jaws. Cut against the back edge of the vise whenever possible.

17. Get into the habit of moving the table so that the workpiece is far away from the toolbit whenever you need to get at it. Many injuries arise from dragging over the sharp tool while trying to access the workpiece.

18. Always move the table to provide generous clearance for handling when inserting or removing the workpiece or when exchanging toolbits.
LATHES

Figure 1: Manual Lathe

A lathe is a machine used to create precise cylindrical and conical parts and features by rotating a securely held piece of stock material and passing a well-supported tool across the surface.

Referring to figure 2 below: The grey cylinder is the stock material. Rough stock for use on a lathe is usually round but such stock is typically only nominally round and imperfections are large enough to prevent precise fits with e.g. bearings or gears. The (yellow) cutting tool removes a shallow shaving of material as it travels in the axial direction, leaving a very smooth and cylindrical surface. This is one typical mode of operation of a lathe. It can also be use with the tool moving in the radial direction or at some angle between purely radial and purely axial directions.

High precision components such as shafts, plain bearings, gear blanks, couplings and collars can be easily produced on a lathe. The spindle holding the material is supported on large, stiff, high precision bearings that rotate precisely about an axis. Round features are generated automatically as the material is spun. This process can easily produce highly accurate parts in most common metals and can also be used for other materials such as plastics.
Lathes are generally constructed with a motor-driven spindle (HEADSTOCK) mounted at one end of a heavy bed, with accurately ground metal rail (BED or WAYS). The workpiece is clamped in the spindle by a CHUCK. The cutting tool is mounted on a moveable platform (APRON or CARRIAGE) which slides along the WAYS. Adjustable slides (CROSS SLIDE and COMPOUND SLIDE) allow additional directions of motion of the tool to create various types of cuts as the workpiece spins.

The headstock contains the motor, clutch and drive-gears for powering the spindle and for driving the apron and cross slides automatically at controlled rates.
Figure 3: A Typical Engine Lathe (Front View)

The TAILSTOCK is a re-position able support that slides along the ways and is located on the opposite end of the lathe from the headstock. It can be used with a free-spinning support (live centre) to provide support for longer workpieces and can also be used to hold and feed tools such as drills to make holes in the centre of the workpiece.

The cutting tool mounts to the TOOLPOST on a repositionable set of slides, the largest of which is the carriage. The CARRIAGE can be moved either way in the axial direction via the handwheels or automatically using the powered FEED system.

The CROSS SLIDE is mounted on top of the carriage and allows the tool to move at 90° to the axis of rotation of the spindle. Movement of the cross slide can be controlled by hand or power activated, similar to the carriage.

The compound rest is yet another slide between the toolpost and the cross slide. Its orientation is adjustable so that it can be used to make angled cuts (conical features on the workpiece). The cutting tool and tool holder are secured in the tool post which is mounted directly to the compound rest.
General operations on the lathe include straight and shoulder turning, facing, grooving, parting, turning tapers, and cutting various screw threads.

The automatic CUTTING FEED systems on the lathes link the motion of the CARRIAGE or CROSS SLIDE with the rotation of the spindle. Feed rates are set by selecting the combination of FEED GEAR settings that provide the desired distance-of-travel of the cutting tool per rotation of the spindle. A chart on the gearbox indicates the feed rate for different gear combinations and allows the operator to select from coarse cuts for rapid removal of material to very fine cuts for a smooth surface finish. The finest cut is typically 0.001” (0.025mm) per revolution of the workpiece and the coarsest is typically around 0.040” (1.00 mm) per revolution.

Feed rates that the operator uses depends on the material being cut, cutting tool material and geometry and desired surface finish. Carbide insert manufacturers typically published ranges of feed rates and ideal depth of cut for their particular inserts.

Please note that use of the automatic feature must be handled carefully to ensure that the direction of feed is correct and that the feed is disengaged at the appropriate time. It is possible to run the carriage into the spinning chuck using the automatic feed. Doing so can have serious consequences for anyone near the machine (as well as severely damaging the machine). Please be sure that you understand how and are able to reliably stop the feed at the appropriate point.

The screw cutting system on the lathes uses some of the same gears as the automatic feed system and allows the operator to move the tool at a precisely controlled rate relative to the spindle so that accurate threads can be cut. Use of this system in the student shop is via special request and for safety reasons, the threading feed handles have been removed from the lathes. Please ask shop personnel for guidance if you need to use this feature and you must request the thread feed handle and ensure that you disengage the threading feed and remove the handle when you are finished. Accidental activation of the threading feed system can result in a serious accident.

The Student Shop is equipped with 2 models of Colchester lathes with the 2500 Master lathes being the oldest and the Triumph/2000 lathes being the newest. The machine functions are essentially the same, however, the position of controls and gearbox selection and some other features vary.

There are several important differences between the two machines. The newer Triumphs/2000 lathes have electric brakes that are interlocked to the chuck guard and can be activated three ways: turning off the clutch lever, opening the chuck guard (not recommended!) and pushing the emergency stop button.
The older 2500 Master lathes do not have electric brakes, however they do have a foot-activated brake. Stepping on the foot brake automatically disengages the clutch lever, but the operator must continue to apply a load onto the pedal to slow the spindle to a stop.

Neither of the braking systems have any effect on the automatic feed systems. The feed motion will continue as long as the spindle is turning and will continue if the spindle is re-engaged without disengagement of the feed handle.

The diagram below shows the older 2500 model. Manuals for the machines are available upon request.

Figure 4: COLCHESTER 2500

Mounting the workpiece:
The workpiece will be held by the 3-jaw chuck. A three jaw chuck of this style (scroll chuck) will automatically centre the workpiece as it is tightened.

1. A chuck key must be used to open and close the chuck.
2. Once you tighten the chuck, spin the chuck by hand to see how well your workpiece is centred (you may need to temporarily disengage the gearbox by moving a gear select lever into a neutral position). Visible wobble may indicate that only two of the three jaws are engaging the workpiece. This is potentially dangerous. Loosen the chuck, re-centre the workpiece and retighten the chuck and repeat the check until you are sure that the workpiece is securely held and centred.

3. Ensure that all gearbox speed selection levers are returned to fully engaged positions.

Preparing and Installing the cutter

1. Inspect the cutter’s edge for damage before you install it on the toolpost. Report any damaged cutters so that you avoid wasting your time and ruining your material as well as reduce the chances of experiencing a shattered cutter.

2. Minimize the cutter extension from the holder. Minimising the extension of the cutter from the holder will allow more accurate and safer cuts. Reducing the extension by 50% reduces the associated deflection by a factor of ~8 (recall beam deflection equation for a transverse load applied to a cantilver-supported beam of regular cross section is based on the cube of the length©). If necessary, use the special t-shaped socket wrench on your toolboard to loosen the setscrews on the holder and reposition the cutter. Ensure that the setscrews are tight before you continue.

3. The quick release toolpost is operated with a removable handle. Note that the toolpost can be tightened in 2 directions and that the handle must be brought to a neutral (central) position to allow removal and installation of the tool holder.

4. Check the height of the cutting tip. It should be in-line with the centre of rotation of the spindle. An easy way to check this is to temporarily install the live centre in the tailstock and to carefully bring the tool point to the tip of the live centre. Use the adjustment screw on the toolholder to raise or lower the tool as needed (the toolpost clamp must be loosened temporarily to allow the adjustment to work).

5. Ensure that the cutter is at an angle that allows you to make the cut you need and ensure all fasteners are tight.
Selecting the spindle speed

In all cases:

Speed changes must be made with no power in the drivetrain! Do not attempt to change gears when the spindle is in motion. Turn the motor off as a precaution when possible.

It may be necessary to rock the chuck back and forth to enable the gears to engage (see below for details).

Colchester Triumph and 2500

1. Select and adjust the range first and ensure that the colour band on the range selector is aligned with the corresponding fixed colour band above the selector.

2. Rotate the speed select lever such that the appropriate arrow is aligned with the desired speed (you may need to be able to rock the chuck back and forth to engage the gears, see below). The colour of the arrow must match the colour of the desired speed and both of these must match the corresponding colour on the fixed colour band.

Figure 6: Spindle Speed Selectors
3. Rocking the chuck- this must only be done with no power to the spindle. On the Triumph/2000 lathes you must first unlock the spindle brake. The brake is passively applied and power must be enabled to release and hold the brake open. To apply power, unlock the emergency pushbutton and depress the white (brake release) button. The white button will flash, indicating that the brake has been disabled. Turning on the motor power or disabling power via the emergency stop will reset the brake.

**Turning on the motor**
In all cases ensure that the clutch engagement lever is in the neutral position

Colchester Triumph/2000
   1. Unlock the emergency stop, close the chuck guard and press the green button.
Colchester 2500
   1. twist the motor start switch as indicated. Note that this is a spring-loaded momentary contact switch.

Turning on the coolant pump
Ensure that the coolant outlet valve is closed and point the nozzle into the chip tray to avoid getting splattered.

Colchester Triumph/2000
   1. twist the pump switch from 0 to 1.
   2. Open the valve on the coolant arm.

Colchester 2500
   3. twist the motor start switch opposite to the direction indicated to start the motor.
       Note that this is a latching contact switch.
   4. Open the valve on the coolant arm.

If the pump is on and the valve is open but no coolant is flowing pour up to 1 litre of cool water into the chip tray. The machines use a water based coolant and the water tends to evaporate over time.

**Engaging the spindle clutch**
Check that both the carriage and the cross-feed hand wheels are free to move (if they move freely then automatic feed and thread cutting are both disengaged)

Colchester Triumph/2000 and 2500
   1. pull the handle slightly towards the tailstock to disengage the detent and push the handle down allowing the clutch to slip to apply power gradually to the spindle. The chuck should rotate counterclockwise. Note that pulling up on the handle
from the off position will engage the reverse direction, spinning the chuck clockwise.
2. disengage the clutch on the 2500 by stepping firmly onto the footbrake rather than pulling up on the lever. You may accidentally reverse the spindle and damage the machine if you pull up on the lever while the spindle is turning in the forward direction.

**Tailstock Use**

The tailstock on all of the lathes can be used to hold drill chucks for straight-shanked drills and reamers and also for holding taper-shanked tools (e.g. larger drills).

There are two lock handles on the tailstock. The larger handle locks the tailstock to the ways. The smaller handle locks the tailstock spindle in position (this is typically used when a live centre is mounted).

Tools and holders with Morse taper shanks can be fitted directly into the spindle. Ensure that all surfaces are clean and that the spindle is extended such that the zero mark engraved on the spindle is at or beyond the reference. Push the taper into the spindle until it is firmly seated. Note that tapers such as this rely solely on friction for engagement, hence the contacting surfaces must be in good condition.

To extract a taper from the spindle, simply turn the feed handle backwards until the taper “bottoms out” and disengages.

![Figure 7: Tailstock and Accessories](image-url)
Cutting Tools and Holders

Cutting tools come in a variety of shapes. Some are for very specific operations (e.g., parting tools) and others can be used for many different operations.

![Insert Style Cutting Tools](image)

**Figure 8: Insert Style Cutting Tools (Top Views)**

Insert cutting tools such as the 55° and the triangular tools can be used for turning (cuts fed parallel to the axis of rotation) and facing (cuts made across the axis of rotation using the cross slide).

![Turning and Facing Operations](image)

**Figure 9: Turning and Facing Operations**
Figure 9: Tool Holder and Tool Post Arrangement

Tools should be set into the tool holder with the minimum extension to maximise stiffness.

Both the triangle insert and 55 degree insert tools can be used for turning and facing and the tool holder can be placed at appropriate angles in the toolpost. The tools are designed to withstand side and frontal loads from turning and facing.

Parting tools are designed to cut through the workpiece to release it from the raw stock held in the chuck. The tool simply plunges through the material creating a narrow slot until it separates the workpiece from the stock. Parting cuts should be made at relatively low speeds to reduce the chance of throwing the workpiece and the workpiece must be allowed to drop freely onto the bed (perhaps onto a piece of wood but never onto a rag or anything else that can potentially become entangled in the rotating elements).
Figure 10: Parting Tool Mounting

The parting tool must always be set perpendicular to the axis of rotation of the workpiece and must be used only to make perpendicular cuts. Never attempt to use an insert parting tool to cut sideways. The tip of the parting tool must not be subjected to a side load as this will cause the insert to move and jam in the slot which results in ejected material and will severely damage the tool and the workpiece.

Using Dials and Digital Readouts

The cross slide and compound slide are equipped with 0.001” increment dials. The carriage feeds do not have precise dials, however the larger lathes have digital encoders that indicate the carriage position.

The dials and the DROs can be set to zero at any point. The dials have built-in friction clutches to hold the position of the scale.
Backlash (free play) in the feed screw must be considered when setting the dial zero.

4. Always approach the zero setting in the positive direction. Any subsequent increments of the handle must be done approaching the desired setting from the same direction.

5. It is o.k. to turn the handle backwards to move the cutter away, but the dial will only show true position of the cutter if the handle is turned forward and all of the backlash is removed.

6. Generously overshoot the target point when travelling backwards in order to ensure no backlash when approaching it in the positive direction.

Carriage travel can be indicated precisely using a magnetic base dial indicator.

Cutting

It is usually necessary to cut a smooth region onto the surface of the raw stock to allow for precise measurement and setting of zero references using the dials or the digital encoders.

The typical procedure is as follows:

1. Cut a clean surface
2. Without retracting the cutter, set the dial or DRO for the axis to zero
3. Measure and record the diameter
4. Calculate the total depth of cut required to achieve the final dimension
5. Take intermediate cuts and verify that the part is at the expected dimensions. Take care to prepare a clean, smooth measuring surface or your measurements will appear larger than the true dimension.

Drilling with the Tailstock

1. Use a centre drill to start all holes
2. Mount the drill bit securely and check that the taper is seated
3. Use a steady flow of coolant to flood the drill.
4. Back out of deep holes frequently to clear chips and to cool the drill.
5. If the taper separates as you are drilling, don’t retract the tailstock spindle. Stop the machine and re-seat the taper before continuing.

Tapping with the Tailstock

1. All tapping must be done without power!
2. Mount the tap in the drill chuck or use a live centre to support the back of the tap/tap wrench (see Tapping notes)
3. Set the gearbox to a neutral position so that the chuck can be turned by hand
4. Apply cutting fluid to the tap
5. Allow the tailstock to slide
6. Use the tailstock feed to push the tap forward as you rotate the chuck by hand.
7. Back up ¼ turn for every ½ turn forward to break the chips.
8. Back out of blind holes frequently to clear chips.
9. The lathe can also be used this way simply to start the tap. The workpiece can be moved to a vise for easier access if needed.
LATHE SAFETY RULES

1. **Never experiment on this machine.** If you don’t know exactly what to do, you must ask shop personnel. The lathe is one of the more versatile yet also significantly more dangerous pieces of machinery in the shop. The power involved in cutting (typically 3 to 8 kW on the larger lathes) the kinetic energy in the system and the open architecture make it more likely that an accident, if it happens, will be severe.

2. **BEFORE YOU DO ANYTHING ELSE ON THE LATHE,** ensure that the main control lever and the feeds are disengaged and the spindle speed is set on a low speed range.

3. Comply with all General Safety Rules, particularly with regard to appropriate clothing, removal of jewellery, constraining of long hair and use of PPE.

4. Check that the chuck is securely tightened onto the lathe spindle by checking the Cam-lock key position (Colchester 2500, Triumph 2000). Consult the manufacturer’s manual for details and get shop personnel to double-check your set-up before starting the lathe.

5. Ensure that all screws fastening the toolbit to the holder are tight and that the toolbit is at the correct height.

6. You must shield yourself and others against ejected chips and coolant. Use the portable chip guards.

7. Remove chuck keys from chucks and place them in the storage holder immediately after using. An ejected chuck key is unfortunately a frequent yet very dangerous accident.

8. Ensure the workpiece is held tightly with sufficient engagement and securely in the chuck and is in contact with all chuck jaws. It is possible and dangerous to pinch a workpiece between only two of the jaws of a three jaw chuck. The workpiece is likely to fly out of the chuck because of forces due to its eccentric rotation and because the two jaws cannot hold the piece securely. Insufficient depth of engagement is a frequent cause of workpiece ejection.

9. You must support workpieces protruding more than 3 diameters from the chuck with a live centre in the tailstock or similar to prevent excessive and potentially dangerous lateral deflection.
10. Do not attempt to chuck or turn a workpiece that is asymmetric or more than 15 diameters long or protruding from the rear of the spindle by more than 3 diameters without first consulting shop personnel. Long, slender workpieces can easily become unstable when rotating and are potentially lethal.

11. Adjust speed settings only with the power disabled. Rock or rotate the chuck by hand to aid engagement when moving the gear select levers. Start with lower speeds and adjust to higher speeds as necessary as it is far safer to go too slowly than too fast. Note that cutting speed calculations define the fastest allowable rate of tool movement based on the tool and workpiece materials. Most materials will also cut well at far less than the charted cutting speeds and that, unlike production machinists, your need to optimize cutting speeds is not critical. Start by cutting slowly and only if necessary, increase your speed keeping in mind the squared relationship between speed and kinetic energy in the system.

12. Test the brake function once before proceeding with your cutting by stopping the lathe with the brake. If the brake is dysfunctional, disengage the drive and hit the STOP button. Turn off and disconnect power. Wait until the lathe has stopped spinning before leaving the lathe. Lock-out the lathe (follow the instructions on the back of the machine) and immediately inform shop personnel.

13. Beware of pinch points and entrapment areas and keep fingers well away from these areas (think ‘meat pump’ when viewing such areas to remind yourself of what the machinery is easily capable of doing).

14. If any filing is done on work revolving in the lathe, use the file left handed to prevent slipping into the chuck. Use only lathe files (they are marked). Never use a file without a handle. Never use a file that is shorter than 12”.

15. Sanding or polishing the workpiece by holding emery paper or a rag or similar device against the workpiece with your hand is not allowed. See WorkSafe BC Regulation 12.39. Make a sanding stick of at least 12” in length instead, fix the abrasive to it and use it in the same fashion as a lathe file.

16. Clear chips only with the power off and do not attempt to clear chips or turnings with your fingers. Use a brush or chip hook. Do not allow long strings of turnings to accumulate as they can easily catch fingers and may bunch up and catch on and break the tool. Stop the lathe and clear the chips and turnings regularly.

17. You must stop the machine fully before taking measurements or cleaning the lathe. If you do not disable power, you run the risk of accidentally activating the controls.
18. Avoid reaching across a spinning chuck because of entanglement risk (e.g. extended chuck jaws become less visible at higher speeds) and because you are entering the plane in which most ejected particles tend to fly.

19. Never lean against the lathe in operation. The spinning shafts and the controls are dangerous to lean on! You may also inadvertently jog a feed wheel or actuate a lever that drives the tool post into the workpiece or chuck.

20. Keep yourself out of the plane perpendicular to the axis of rotation of the lathe where the tool contacts the workpiece. Particles ejected from the lathe tend to stay in this plane and the risk of being hit is much higher in this zone.

21. Stop immediately if the cutting tool appears to jumps or not cut smoothly. It is likely that the cutting edge is damaged. Look closely at the tool edge. If it is damaged, you need a new tool. Consult shop personnel before continuing.

22. Avoid moving the tailstock along the bed towards the chuck when the lathe is moving. The tailstocks are heavy and it is difficult to control their sliding along the bed.

23. Do not store items on or against the lathe bed, carriage or tailstock as these items can fall into the rotating workpiece, contact the rotating shafts or jam the saddle or control levers.

24. Never try to stop the spindle with your hand, even when it is coasting freely. Use the brake.

25. Never leave the running machine unattended, particularly if you are using automatic feeds.

26. Never feed the tool into the workpiece without watching what you are doing. If someone distracts you, stop the feed, stop the machine and step away from it before dealing with the person.

27. Don’t walk behind other operators and don’t allow other people to walk behind you when you are operating the lathe. The operator’s space is never to be occupied by more than one person when the machine is in operation.

28. Do not drill brass or other soft materials with regular drill bits as the cutting edge geometry can pull the drill bit into the workpiece in a dangerous fashion. Brass drilling requires special cutting geometry to prevent ‘corkscrewing’ of the drill into the workpiece. Ask the shop personnel for assistance.

29. Consult manufacturer’s operating manual for more information.
Good Practice

1. Plan the sequence of cuts before you start or run the risk of finding yourself stuck a scrap part. Cartoon sketch of each step will help you think about which tool needs to be used and how material is removed in a way that permits safe removal of the remaining material.

2. Before enabling power complete your set-up, double-check speed settings, critical clamps, fasteners, clearances and control lever settings.

3. Always make sure that the toolbit is sharp, is set to the correct height and has the proper clearance for the operation. Failure to do this is one of the most common causes of problems on the lathes in the student shop. Don't use damaged, dull or cracked bits. They will perform poorly and may break because higher loads will be required to get them to cut and they will create poor surfaces. Inspect all tools before using. Ask for assistance making adjustments.

4. Remove all wrenches from the chuck, toolpost and slides. If you develop the habit of never releasing a hand tool unless it is to replace it on its storage hook (grab it, use it, replace it on the hook), you will rarely have a problem with a tool falling into the moving machinery or causing a collision.

5. Use one hand at a time only to activate controls for engaging drives or moving the tool to avoid becoming confused and turning a hand-wheel or lever in the wrong direction.

6. Refrain from using the top of the headstock to store tools or other items. Remove any loose items from on top of the headstock that may fall into the chuck.

7. If you are using a drill chuck in the tailstock, remember to start with a centre drill, ensure that the drill bit is tight in the chuck and that the chuck is properly seated in the tailstock taper.

8. If possible, place the toolbit so that it will hit the chuck first in the event of a collision between the chuck and the compound slide. Toolbits are much cheaper to replace than compound slides.

9. Turn the chuck through by hand before turning on the power to be sure there is no binding or clearance problem.

10. Stand out of the plane of rotation of the chuck when first turning on the motor.

11. Stand to the tailstock side of the lathe when activating the control lever to avoid parts that are ejected out of the chuck. If you notice or suspect that something is wrong, stop the lathe, turn off and disable the power and get shop personnel to inspect the machine.
12. Always clamp the toolbit as short as possible in the tool holder to prevent it from breaking or chattering.

13. Get into the habit of removing the toolbit whenever it is practical to do so. Many injuries arise from dragging over the sharp tool. Always remove the tool holder from the tool post as soon as you are done to avoid catching or cutting yourself on the exposed tool.

14. Always move the cross slides and tail stock to provide generous clearance for handling when inserting or removing the workpiece.

15. Don't run the machine faster than the proper cutting speed.

16. Stop and clean the floor around the machine periodically if chips or ejected coolant start to accumulate.

17. Position chip guards so that they deflect coolant and chips into the chip bed.

18. Before cleaning the lathe remove tools from the tool post and tailstock to prevent cutting yourself on the sharp edges.

19. Use coolant for the operation to extend tool life and enhance finish.

20. Use the brake! It removes energy from the system quickly and safely and reduces the chance of accidental activation.

21. Don't drill with too much pressure and retract the drill frequently to clear chips and allow coolant to enter the hole. If you notice that the drill is deflecting laterally, squealing or smoking, stop what you are doing and ask shop personnel for help.

22. Never place taper shank tools such as large diameter drills or tapered shank reamers in a drill chuck. Only straight shank tools such as standard drills can be clamped in chucks. Use the taper adapters to match the bit with the tailstock taper.

23. Always clean drill shank and/or drill sleeve and taper bore before mounting.

24. Remove taper shank tools from the tailstock by winding the feed handle backwards until the spindle must be fully-retracted and the tool is ejected.

25. Always remove the drill chuck key immediately after using it.

26. Drill at the correct RPM for diameter of drill bit and material. Consult the cutting speed calculations.
27. Use the proper cutting fluid for the material being turned or drilled. Ask the shop staff about the appropriate fluid for the material you are machining.

28. Do not use spade or other drill bits designed for wood on the lathe.
Maxiem 1515 Abrasive Water-jet Cutter

A water-jet cutter uses a narrow, highly pressurized stream of water and abrasive to cut through materials. It can be easily programmed to cut very complex 2D profiles in almost any material.

The Maxiem 1515 can cut sheet and plate (e.g. steel, aluminum) up to 50 mm thick with acceptable results, however it is best used for thicknesses below 15 mm.

Material to be cut is secured over a large open water bath and is flooded with 1-2 cm of water. The water greatly reduces noise and also disperses the jet once the material has been pierced.

You need to come to the shop with your cut files ready to go (use a USB stick). Software for creating cutting paths and for calculating cutting time and cost and licenses to run the software can be obtained via the shop’s website (search for “Intellimax”). Learning how to create toolpaths is easy but not obvious. It will be very worthwhile to watch the posted videos as there is a significant amount of very helpful automatic toolpath feature generation in the software.

Please create your toolpaths outside the shop so that you are using the water-jet interface for running cuts only. The water-jet cutter is a very popular tool and we don’t want it tied up with editing.

The width of the cut is typically 0.8mm. Where possible, radius corners on the profile as much as practical as it greatly speeds up cutting which will save you cost. Guidelines for designing parts are in Dan Gelbart’s notes on Fast Prototyping that are also posted on the website.

All materials normally stocked in the machine shop are ok for water-jet cutting. If you are bringing other materials, please ensure that you are not cutting materials containing significant quantities of toxic, poisonous or otherwise harmful substances or you may face a very expensive hazardous waste disposal problem (no lead, cadmium, asbestos, etc.).

Some materials are problematic to pierce. Laminates and layered materials such as fiberglass can delaminate due to the pressure in the cut. Brittle, crack-sensitive materials such as glass and acrylic have a tendency to crack during piercing. Always use the cutting settings for brittle materials when loading profiles.

Operation:

Basic operation of the machine is best described in the videos posted on the shop website.
The Maxiem should generally be left powered up with water, air and AC power enabled, but with the charge pump turned off (enabled only when cutting as it is somewhat noisy).

PPE: Safety glasses and protective footwear are required as the machine can eject an abrasive-laden stream of water and because the materials and hold-down weights you are moving are heavy; hearing protection (foam earplugs or ear muffs) is required if cutting is not submerged.

1. In Make, load your file and check the settings
2. Retract the Z axis and clear obstacles from the clamping area.
3. While it isn’t always necessary, it is a good idea to set your workpiece so that it nests in the corner of the L-shaped plate in the nearest corner of the machine.
4. Add weights to hold down your part. Consider using speed clamps braced against the inside of the tank to keep the workpiece from shaking.
5. Move the nozzle to the starting point on your workpiece and set the Part Home origin.
6. Set the nozzle offset height using the stacked quarter method.
7. Check the abrasive hose for wet sand. If there is any trace of moisture, disconnect it and blow it dry with compressed air.
8. Push the end the abrasive hose into the hole in the side of the nozzle and also into the feed control valve under the hopper. The hose is retained by friction at each end.
9. Check that there is sufficient abrasive loaded in the hopper (a full hopper is good for ~ 25 minutes of cutting). Additional abrasive is in the black pail. Ensure that the abrasive is kept absolutely dry otherwise the abrasive will not feed properly. The white pad is for wet abrasive.
10. Check for wet abrasively in the feed control valve under the hopper. Clear away any moist sand; disassembly maybe required.
11. Turn on the charge pump
12. Start the job
13. When finished, retract the z-axis and move it out of the way prior to removing workpieces.
14. Use the spray hose to wash sand off your parts and keep sludge inside the tank
15. Remove your clamp set-up
16. Open Internet Explorer on the Maxiem workstation and record job particulars as prompted by the usage reporting form.
17. In Make, re-set any default settings that you have changed.
18. Wipe down the rails on the machine and remove any water puddles that are potential slip hazards.

Steps to power up the machine:

1. Plug in 115 VAC supply for controller
2. Ensure all three E-stops have been released by popping each red button in and out
3. Turn on in the following order:
4. Pump power (large red throw switch on the east wall behind WJ cutter)
5. Water supply (yellow handled valve in southeast corner behind WJ cutter)
6. Pump unit (press the square green button)
7. Controller (press the green start button)

8. Wait for the computer to boot
9. Have shop personnel log in to the machine o provide access
10. Start the Intelli-Max Make software
11. Skip past the Add Notes screen
12. Fully retract the Z axis using the Page Up arrow (to clear any obstacles)
13. Ensure that there are no obstructions to X-Y movement of the nozzle
14. Move the machine within 50mm of the Absolute Home hard stops
15. Reset the Absolute Home
16. Move to the User Home

The machine is now ready to use following the steps listed in the previous section.
PRESS BRAKE

The Atek press brake is a 24-ton machine capable of bending sheet and plate. Most of the tooling is for bends up to 90 degrees.

Gooseneck tooling permits return bends on parts.

Currently, there is one punch and die combination that facilitates bends to 30 degrees and there are also flattening dies.

Gooseneck punches and matching ¾” dies segmented in 20 mm increments from 60mm to 160 mm are also available.

Hazards:

This is a very high force mechanism. It can load parts with up to 24 tons of compressive force.

The machine has moving parts and presents pinch and amputation hazards.

Free ends of parts move during forming (45 degree rotation for 90 degree bend).

Parts are loaded with high compressive and bending loads- use of brittle work-pieces or tooling may result in ejected particles with bullet-like velocities.

Compressed air is used to power the machine.

Tooling can be heavy weighing in excess of 30 kg.
ATEK PRESS BRAKE SAFETY RULES

1. Wear eye protection.
2. Ensure that the air switch is in the off position before making any adjustments that require reaching into the working area of the press. The air supply switch is to remain in the off position during set-up. Turn the air supply on only after completing set-up of tooling and any work supports.
3. Only bend ductile, sheet or plate materials. Hard materials may shatter dangerously due to the high loads, potentially resulting in bullet-like velocities in ejected particles.
4. Use only tooling designed for this machine. Any custom tooling has to be approved by shop personnel. Never use hardened tools on the machine.
5. Never prop, block or modify the safety guard on the foot switch.
6. Use the table whenever possible.
7. Only the person operating the foot pedal is permitted to have their hands on the workpiece.
8. Beware that the operation of the machine causes the free ends of the stock to move upwards (45 degrees for 90 degree bends) and may strike or pinch the operator if the operator’s hands or face are above the workpiece.
9. Ensure tooling is secure before attempting to bend.
10. Observe all warning stickers on the machine.
11. Consult the posted information for more details.

Good Practice:
1. Check for adequate clearance of the finished shape: it is possible to bend and “lock” a workpiece into the machine. Consider using a cardboard back-up of your part to check your bend sequences.
2. Keep the throttle valve at the minimum speed setting so that the punch moves slowly and gives you adequate time to stop.
3. Press and hold the foot pedal until all movement of the machine stops.
4. No bending of shafts, wire or other shapes that apply point loads to the punch or die. Such material shapes will permanently damage the tooling.
SIP SPOT WELDER

This machine can be used to easily join steel and stainless steel pieces up to 6 mm total thickness.

Hazards:

The machine does not provide any significant feedback indicating that it is energized. A red LED was added to the machine to help users see when it is in the “ON” state. Activation of the foot pedal without weld material or with excessive current can result in an arc flash and expulsion of molten copper metal.

Ejection of sparks is very common.

Temperatures exceeding 1600 °C occur at the weld during operation.

The electrodes and support arms are un-insulated and are “live” when the machine is energized. Accidental bridging of the live components with conductive objects can result in severe burns and arc flash.

PPE: safety glasses, non-combustible clothing and insulated gloves required. Check posted guideline from Miller for additional information.

SPOTWELDER SAFETY RULES

1. This machine is for steel and stainless steel only. Do not attempt to use it for welding any other metals.
2. Workpieces must be clean in the weld region. Do not weld galvanized, painted or plated metals as toxic fumes will be released and weld quality will be poor.
3. Turn off the breaker feeding the outlet and ensure that the machine is turned off prior to removing or inserting any plugs, changing or adjusting tooling.
4. Ensure that the electrodes are adjusted and align and contact your workpieces only where the weld is intended to occur.
5. Never allow workpieces to contact the electrodes at locations other than the tips otherwise a large arc may occur and electrodes may be damaged.
6. Ensure that workpieces are securely clamped with independent clamps(don’t rely on the clamping action of the electrodes to hold the workpieces in position). The spring clamps in the plastic bucket are for spotwelding.
7. Ensure that all screws and clamps for electrodes are tight. This is especially important when using the 90 degree adapter.
8. Don’t use power settings higher than necessary. Starting with too much current can result in expulsion of molten metal, arc flash and damage to the machine. If you don’t already know settings for your materials, start with very short duration and moderate current settings for the thicknesses of material being welded. Gradually increase the current until a satisfactory weld is achieved.
9. Never use an assistant to operate the machine or to hold workpieces.
10. Ensure that anyone within 5 metres of the machine is wearing PPE and is aware that you are going to operate the machine.
11. Never operate the machine in wet conditions. If necessary, move the machine to a dry location.
12. Coolant is required if the electrodes become hot. Consult shop personnel for operation of the chiller.
13. Follow any posted precautions for spot-welding.

MISCELLANEOUS EQUIPMENT

SAFETY RULES FOR BROWN AND BOGGS 249BL SHEAR

Critical

1. Watch where you place your fingers! Never reach under the clamp or in the cutting plane of the blades. If you need to retrieve something from this area, use a tool.

2. Never attempt to cut any hard, brittle or high strength materials or any stock shape other than sheet.

3. Never let someone else operate the treadle when your hands are at the clamp or blade.

4. You must wear safety glasses.

5. Consult the manufacturer’s instructions for more information.

Good practice

1. Cut edges on sheet metal are sharp and may have burrs; use gloves when handling if necessary.

2. Clean up cuttings immediately using a brush, dustpan and gloves.
3. Do not attempt to cut material other than sheet metal with the following maximum thickness restrictions:
   a. Aluminum 10 gauge (3.2mm)
   b. Mild Steel 16 gauge, (1.6mm)
   c. Stainless Steel 20 gauge (1.0mm)

4. Get assistance if you are handling larger pieces of material. Don’t try to balance them by yourself.

5. Don’t overreach. Keep proper footing and balance at all times.

6. Do not leave the lever in the down position. If the lever jams in this position, you must shield and mark it to keep other people from running into it.

**SAFETY RULES FOR BURNETT CONNECTICUT BRAKE**

**Critical**

1. Watch where you place your fingers! Never reach under the clamp or put your hands near the workpiece when activating the brake; put them on the handles.

2. Never attempt to bend any hard, brittle or high strength materials or any stock shape other than sheet.

3. Never let someone else operate the brake when your hands are at the clamp or on the workpiece.

4. Stand out of the way of the workpiece because it swings upward as the brake is activated

5. You must wear safety glasses.

6. Consult the manufacturer’s instructions for more information.

**Good practice**

1. Cut edges on sheet metal are sharp and may have burrs; use gloves when handling if necessary and deburr before bending.

2. Do not attempt to bend material other than sheet metal with the following maximum thickness restrictions:
a. Aluminum 10 gauge (3.2mm)
b. Mild Steel 16 gauge, (1.6mm)
c. Stainless Steel 20 gauge (1.0mm)

3. Get assistance if you are handling larger pieces of material. Don’t try to balance them by yourself.

4. Don’t overreach. Keep proper footing and balance at all times.
SAFETY RULES FOR MANUAL ARBOR PRESS

1. Keep your face away from the parts being pressed when applying a load.

2. You must wear safety glasses and keep your face out of the region where parts may be ejected.

3. Ensure that your work pieces are supported against buckling.

4. Watch where you put your fingers! Don’t use your fingers to support loads when pressing. The press is designed to exert a high compressive force with a relatively small force applied to the lever. Don’t place your fingers under the arbor as the weight of the lever given the mechanical advantage of the rack is enough to break your finger.

5. Don’t balance the lever in mid-air. Flip the lever back so that it holds the press open. Do not leave the press with the lever protruding. Place the lever in a safe position where no one will run into it and it won’t suddenly fall.

6. You must support your workpieces with supports that are in a stable arrangement and that can withstand the loads.

7. Do not attempt to press hardened, brittle materials as they are likely to shatter, sending pieces flying through the air.

8. Do not overload the press. Don’t extend the handle e.g. by slipping hollow stock over the bar. The manual arbor press is rated for 2 Tons.

Good practice

1. Use a series of press and release steps instead of one long push. This will allow parts that have compressed to realign and will reduce eccentric loads that can lead to buckling.

2. Make press tooling such as rings and cylinders using a lathe. Faces are much more likely to be flat and parallel.

3. Use lubrication and the material’s coefficient of thermal expansion to your advantage to reduce pressing forces and get parts to seat accurately. High forces due to large interference can raise burrs that interfere with proper seating of parts. Warm up rings and cool down cylinders.

4. If you are producing parts on a mill, lathe or drill press, you might use your setup to lightly press mating parts together while they are still concentrically aligned with a drill chuck before taking them to the arbor press to finish them off.
5. Get assistance if you are handling larger pieces of material. Don’t try to balance them by yourself, however never let someone else control the lever when your hands are near the anvil.
ROTARY TOOL SAFETY RULES

1. You must wear safety glasses.

2. Check the cord or plug for damage.

3. Check that the speed control is in the off position before connecting the power cord.

4. Unplug the tool when you are changing bits, cleaning or adjusting.

5. Do not attempt to hold small work pieces by hand when using the tool for drilling or cutting. You can not hold them safely. You must hold them in a suitable clamp or vise.

6. Don’t direct the tool or cuttings towards yourself (especially your eyes) or anyone else. Ensure that the bit will not hit anything or anyone if it were to suddenly grab the workpiece.

7. Do not use bits that are not designed for use in the tool or dull or broken bits. It turns at speeds of up to 35,000 rpm and the centrifugal forces are sufficient to cause tool bits to disintegrate.

8. When using cutting disks or stones, use only the edge of the disk or stone. Using the sides could cause the bit to fly apart.

9. It is easy to burn toolbits due to friction. Be careful not to use the tool if heating is dangerous (e.g. if doing so could ignite a fire).

10. Periodically verify that the toolbit is securely held in the chuck. Vibrations from use may cause tool shanks to slowly slip out of the collets, so check that the length of the exposed shank is not changing.

11. If the tool vibrates excessively or if you are unsure that the tool is operating correctly, stop the tool, unplug it and inform the shop personnel.

12. Keep the area clear of tools or other materials that may interfere with the operation.

13. When using the 3-jaw chuck, check to see that you have centred the bit properly. It is not uncommon to jam the bit between only 2 of the jaws on a 3-jaw chuck.

14. When working with the tool, apply only light pressure or you will shatter the toolbit and/or burn out the motor.
15. The rotary tool, like most portable electric motor driven devices, create sparks at the motor brushes and at the bit and therefore must not be used when volatile or explosive substances are present. Care must be taken to ensure that the sparks emitted from the grinding and cut-off accessories do not ignite fires.

16. Consult manufacturer’s operating manual for more information.
PORTABLE DRILL GENERAL SAFETY RULES

Critical

1. You must wear safety glasses.

2. Check to see that any trigger locks or controls are in the off position before connecting the power cord.

3. You must not use the tool if the cord or plug is damaged or if the battery is cracked or leaking.

4. Always unplug corded drills when you are changing bits, cleaning or adjusting.

5. Hold and support workpieces securely. Do not attempt to hold small pieces by hand when drilling as you can not hold them safely. You must hold them in a suitable clamp or vise. Always support your workpiece against a solid surface. Don’t hold it in the air.

6. Don’t drill or eject particles towards yourself or anyone else. Ensure that the bit will not hit anything or anyone as you drill into the workpiece.

7. Do not use bits that are not designed for use in the drill. Never use router bits, milling cutters or rotary saw blades. Use only straight-shank or hexagonal shank drill bits and driver bits designed for use in a 3 jaw chuck.

8. Spade bits, hole-saws and similar tools must not be used to enlarge existing holes because they rely on the central tip for guidance. Never start the motor with the outer circumference of the tool touching the workpiece without support at the centering tip.

9. Drills, like most portable electric motor driven devices, create sparks at the motor brushes and occasionally at the bit and therefore must not be used when volatile or explosive substances are present.

10. If you are unsure that the tool is operating correctly, stop the tool, unplug it and inform the shop personnel. Get a plug lock and warning tag from the lockout cabinet and put it on the tool.

Good Practice

1. Whenever possible, brace yourself well and use both hands to steady and guide the drill. This is particularly important when using the large high torque drills with larger bits. Using the larger drill requires good hand and arm strength. Avoid using it in confined areas because the drill body may spin if the bit jams and this could injure you.
2. Don’t overreach when using the tool. Keep proper footing and balance at all times. You must anticipate what may happen if the bit jams suddenly or breaks through the material.

3. Keep the area clear of tools or other materials that may interfere with the drilling operation.

4. No sudden movements! Be slow and deliberate in everything you do with power tools.

5. Always feed work gradually and deliberately.

6. Never attempt to stop a workpiece that is spinning because it has been caught by the bit. ALWAYS turn the power off, unplug the cord and wait for the drill to stop moving before attempting any removal. Secure the workpiece before applying power to back the drill out.

7. When you first start the drill, check to see that you have centered the bit properly. It is not uncommon to jam the bit between only 2 of the jaws on a 3-jaw chuck

8. If your work is creating a lot of debris, stop the periodically and sweep up.

9. Don't drill with too much pressure. A sharp drill with proper coolant should work smoothly and evenly. If you notice that the workpiece is smoking, stop what you are doing and ask shop personnel for help.

10. Do not drill with dull or broken bits. They will not drill straight, will generate excessive amounts of heat and may disintegrate.

11. Consult manufacturer’s operating manual for more information.
DISC SANDER SAFETY RULES

Critical

1. The disc sander is for wood and plastics only!

2. Constrain loose clothing, long hair or anything that could get caught in the moving components. Remove rings and jewelry from your hands and wrists.

3. You must wear safety glasses AND a face shield.

4. Check to see that the power switch is in the off position before connecting the power cord.

5. Do not use gloves when operating the sander. Gloves are easily sucked into the machine.

6. Check the condition of the abrasive sheet. Do not turn on the machine if the sheet is damaged or not fully adhered to the disk. Request assistance from the shop personnel.

7. Check that the table and stop are tightly fastened before turning on the power.

8. Use a brush to remove any sawdust or chips off the table before placing the workpiece on it.

9. Never start motor with the work piece touching the disc.

10. Do not sand small pieces unless you are using a holder of some kind (locking pliers, etc.) which keeps your hands away from the disk.

11. Do not operate sander without the guards or rests in place and always place your workpiece against the table or rest where it will be pulled against the rest AND before touching it to the abrasive.

12. Never try to adjust the table or stop when the power is on or while the device is moving. You must unplug the machine to perform any adjustments.

13. The sander must not be operated without the dust collector system on and the gate valve on the duct open.

14. Always check that the clearance between the rest and the abrasive surface is minimal. The gap should never be more than about 2 mm.
15. Use only the side of the disc that will pull the workpiece down against the table. Never sand using the upward motion side as this will lift the workpiece possibly throwing it upwards.

16. Do not operate machines with torn or ripped discs. These are dangerous because they will catch the workpiece or your hands. Ask shop personnel to replace them.

17. Sand only wood on this machine. Never power sand any material that will give off a dangerous dust such as aluminum, magnesium, titanium, beryllium or beryllium copper, zinc coated metals, cadmium, chromium or composites containing glass, carbon or boron fibers or asbestos. Check the MSDS for precautions required if you are not sure. The dust extractor on this unit is designed for wood particles only. It is not a fume filter.

18. Never attempt to brush or clear debris when the machine is running.

19. If you are unsure that the machine is operating correctly, stop the machine, unplug it and inform the shop personnel.

20. If the disc tears, immediately shut off the power and stand clear until the machine has stopped moving. Remove the key, unplug the machine and consult shop personnel.

21. Never attempt to move the sander when it is running.

22. At all times while the sander is on, keep your hands clear of the disc. Never attempt to “rescue” a workpiece or cutting that is jammed in the gap between the moving disc and the table/stop. ALWAYS turn the power off, unplug the machine and wait for the machine to stop moving before attempting any removal.

23. Keep out of the plane of the rotating disc at all times. Abrasive particles and objects caught by the disk are ejected in this plane at high speeds.

24. The sander is free-standing and it is possible to tip it if you push with enough force.

25. Never clean the machine while it is in motion or plugged in. Always unplug it to protect against accidental activation.

26. Consult manufacturer’s operating manual for more information.

Good Practice
1. Don't feed the workpiece with too much pressure. A properly abrasive should work smoothly and evenly. If you notice that the workpiece is smoking, stop what you are doing because you may start a fire in the machine or dust collector.

2. Pay attention to what is happening at the disc and note where your hands are! If you are interrupted or distracted in your work, stop feeding the workpiece and turn off the machine and deal with the distraction while well away from the machine.

3. Don’t overreach. Keep proper footing and balance at all times.

4. Keep the table clear of tools or other materials. Only your workpiece and possibly the guide should be on the table.

5. No sudden movements! Be slow and deliberate in everything you do around power tools.

6. Stop the machine and unplug it to clean the table and floor periodically if debris starts to accumulate.

7. Get assistance if you are handling larger pieces of material. Don’t try to balance them by yourself.

8. Always feed work gradually and deliberately against the abrasive. Use the abrasive cleaner stick to unclog the abrasive.

9. Do not reach over the disc when it is moving.

10. Let the disc stop of its own accord after turning the power off. Never try to stop it by holding something against the moving surface.

11. Always use both hands together to hold the workpiece.

12. When reaching to hit the power switch, keep your other hand stationary.
**Bench Grinder Safety Rules**

1. **Grind iron, steel and stainless steel only.** Soft metals clog the grinding surface and can overheat the wheel surface causing failure (shattered wheel). In particular do not grind aluminum, lead, magnesium, titanium, chromium or any fiber composites (glass, graphite, boron, etc.) or coated or galvanized metals as these may ignite or produce explosive and/or highly toxic dusts.

2. You must wear safety glasses and a face shield.

3. Do not use it with loose clothing, long hair, rags or anything else that could get caught in the spinning wheel.

4. Remove all jewelry from hands and wrists.

5. Abrasive wheel machinery must not be operated without the appropriate guards in place.

6. Tool rests must be set no more than 3mm from the wheel and must be secured.

7. The water bath must be filled before starting the grinder. Water is necessary to cool the work piece.

8. The grinding process ejects a lot of particles and sparks. The local exhaust ventilation and the room exhaust must be turned on.

9. Work pieces should be held with bare hands, however if there is a risk of contact with the wheel, use a holder such as a pair of locking pliers. Never attempt to hold and grind very small work pieces by hand. You cannot hold them securely and they heat up rapidly.

10. Never use a wheel that is chipped, has been dropped or has received a heavy blow, even though there may be no apparent damage. Such wheels may be weakened or unbalanced enough to fly apart.

11. Ensure that everyone is well out of the plane of the grinding wheels when using the grinder in case one of the wheels shatters. Immediately shut off the grinder if it starts to vibrate unusually, lock it out and inform shop personnel.

12. Never use the side of the wheel for grinding as this weakens the wheel and may cause it to fly apart.

13. Report to shop personnel immediately any signs of misuse, cracked, broken or otherwise defective wheels or other malfunctions or suspected safety issues, lock out the grinder and inform shop personnel.
14. Hold work securely while grinding, always using the tool rest to support the work.

15. Consult manufacturer’s operating manual for more information.

Good Practice

1. Keep out of the plane of the wheel as much as practical.

2. Do not use excessive pressure while grinding.

3. Move the work piece across the wheel such that the wheel wears evenly.

4. Do not allow heat to build up. Cool the work piece frequently and watch for telltale discolouration (light tan going to bluish). This is particularly important when grinding tool steel as excess heat can destroy the condition of the steel.

5. Use the rougher wheel for as much of the initial shaping and material removal as practical. This will reduce time and potential heat build-up.
Appendices

Appendix A  Cutting Speed Guide
Appendix B  Common Inch Size Screw Threads
Appendix C  Local Retail Sources for Parts, Materials and Tools
Appendix D  Using an Edge-finder
Appendix E  Tool and Equipment List and Locations
**Cutting Speed Guide**

The optimal cutting speed of a material is determined by the machine-ability of the material. Usually, it is desirable to remove as much material as quickly as possible (minimize machining time), however the cutter’s ability to withstand loads, the available power, the strength of the material, tool and machine, the management of heat from the cutting process and the required surface finish all affect the rate of cutting. Charted values provide a starting point however it is up to the machinist to observe the cut and to make adjustments.

**Important**: Work piece stability and safety considerations often limit the cutting speed. In general, most materials can be cut effectively at very slow speeds. If it is safer and effective to limit speed, you are encouraged to do so.

Speed is expressed in surface feet per minute

<table>
<thead>
<tr>
<th></th>
<th>High Speed Steel</th>
<th>Carbide</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cutter (SFPM)</td>
<td>90</td>
<td>360</td>
</tr>
<tr>
<td>Machine Steel</td>
<td>50</td>
<td>200</td>
</tr>
<tr>
<td>Tool Steel</td>
<td>40</td>
<td>160</td>
</tr>
<tr>
<td>Stainless Steel</td>
<td>200</td>
<td>800</td>
</tr>
<tr>
<td>Aluminum</td>
<td>150</td>
<td>600</td>
</tr>
</tbody>
</table>

To determine RPM use

\[
RPM = K \times CS \times \frac{4}{D}
\]

- **RPM** = (cutter for milling/drilling or workpiece for turning)
- **K** = cutting speed modifier (see below)
- **CS** = cutting speed in SFPM
- **D** = diameter of cutting tool or workpiece (inches)

**K values**

<p>| | |</p>
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Turning</td>
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<td>Milling</td>
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<tr>
<td>Drilling</td>
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</tr>
<tr>
<td>Reaming</td>
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</tbody>
</table>

More detailed information is available in the Machinery’s Handbook. Recommended speeds, feed rates and depth of cut are also provided by tool manufacturers. The following page shows these data for the most commonly used inserts in the Student Shop.
Carbide Insert Lathe Tooling: Recommended Depths of Cut, Feeds and Speeds

<table>
<thead>
<tr>
<th>INSERT STYLE</th>
<th>PARTING TOOL</th>
<th>RIGHT HAND 55° INSERT TOOL</th>
<th>RIGHT HAND TRIANGLE INSERT TOOL</th>
<th>INSERT STYLE PARTING TOOL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandvik Coromat 55° (Diamond) Inserts for medium machining of steel (gold)</td>
<td>Depth of Cut</td>
<td>Feed Rate</td>
<td>Cutting Speed</td>
<td></td>
</tr>
<tr>
<td>DCMT 3(2.5)3-PM 4035</td>
<td>.024”-.118”</td>
<td>.005”-.014”/r</td>
<td>890-605</td>
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</tr>
<tr>
<td>Sandvik Coromat 55° (Diamond) Inserts for medium machining of aluminum (silver)</td>
<td>Depth of Cut</td>
<td>Feed Rate</td>
<td>Cutting Speed</td>
<td></td>
</tr>
<tr>
<td>DCGX 3(2.5)1-AL H10</td>
<td>.012”-.157”</td>
<td>.002”-.006”/r</td>
<td>8205-820</td>
<td></td>
</tr>
<tr>
<td>Korloy Triumph 55° (Diamond) Inserts for machining of aluminum (silver)</td>
<td>Depth of Cut</td>
<td>Feed Rate</td>
<td>Cutting Speed</td>
<td></td>
</tr>
<tr>
<td>DCGT 32.501-AK H01</td>
<td>.004”-.200”</td>
<td>.0012”-.020”/r</td>
<td>8205-820</td>
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</tr>
<tr>
<td>Korloy Triumph 60° (Triangular) Inserts for machining of aluminum (silver)</td>
<td>Depth of Cut</td>
<td>Feed Rate</td>
<td>Cutting Speed</td>
<td></td>
</tr>
<tr>
<td>TCGT 32.50.5-AK H01</td>
<td>.004”-.200”</td>
<td>.0012”-.020”/r</td>
<td>8205-820</td>
<td></td>
</tr>
<tr>
<td>Sandvik Coromat Parting Inserts (gold)</td>
<td>Depth of Cut</td>
<td>Feed Rate</td>
<td>Cutting Speed</td>
<td></td>
</tr>
<tr>
<td>N151.2-300-4E 4125 Steel</td>
<td>N/A</td>
<td>.002”-.010”/r</td>
<td>670-255</td>
<td></td>
</tr>
<tr>
<td>Heat resistant Alloys</td>
<td>N/A</td>
<td>.002”-.010”/r</td>
<td>130-50</td>
<td></td>
</tr>
</tbody>
</table>

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### Common Inch Size Screw Threads (North America)

**Bold type indicates most common sizes.**

<table>
<thead>
<tr>
<th>Designation</th>
<th>T.P.I.</th>
<th>Major Diameter</th>
<th>Minor Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>#00</td>
<td>80 UNF</td>
<td>0.060</td>
<td>0.0438</td>
</tr>
<tr>
<td>#1</td>
<td>64 UNF</td>
<td>0.073</td>
<td>0.0527</td>
</tr>
<tr>
<td></td>
<td>72 UNF</td>
<td>0.073</td>
<td>0.0550</td>
</tr>
<tr>
<td>#2</td>
<td>56 UNC</td>
<td>0.086</td>
<td>0.0628</td>
</tr>
<tr>
<td></td>
<td>64 UNF</td>
<td>0.086</td>
<td>0.0657</td>
</tr>
<tr>
<td>#3</td>
<td>48 UNC</td>
<td>0.099</td>
<td>0.0779</td>
</tr>
<tr>
<td></td>
<td>58 UNF</td>
<td>0.099</td>
<td>0.0758</td>
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<tr>
<td>#4</td>
<td>40 UNC</td>
<td>0.112</td>
<td>0.0795</td>
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<tr>
<td></td>
<td>48 UNF</td>
<td>0.112</td>
<td>0.0849</td>
</tr>
<tr>
<td>#5</td>
<td>40 UNC</td>
<td>0.125</td>
<td>0.0925</td>
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<tr>
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<td>44 UNF</td>
<td>0.125</td>
<td>0.0955</td>
</tr>
<tr>
<td>#6</td>
<td>32 UNC</td>
<td>0.138</td>
<td>0.0975</td>
</tr>
<tr>
<td></td>
<td>40 UNF</td>
<td>0.138</td>
<td>0.1055</td>
</tr>
<tr>
<td>#8</td>
<td>32 UNC</td>
<td>0.164</td>
<td>0.1234</td>
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<tr>
<td></td>
<td>36 UNF</td>
<td>0.164</td>
<td>0.1279</td>
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<tr>
<td>#10</td>
<td>24 UNC</td>
<td>0.190</td>
<td>0.1359</td>
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<tr>
<td></td>
<td>32 UNF</td>
<td>0.190</td>
<td>0.1494</td>
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<tr>
<td>#12</td>
<td>24 UNC</td>
<td>0.216</td>
<td>0.1619</td>
</tr>
<tr>
<td></td>
<td>28 UNF</td>
<td>0.216</td>
<td>0.1696</td>
</tr>
<tr>
<td>¼”</td>
<td>20 UNC</td>
<td>0.250</td>
<td>0.1850</td>
</tr>
<tr>
<td></td>
<td>28 UNF</td>
<td>0.250</td>
<td>0.2036</td>
</tr>
<tr>
<td>5/16”</td>
<td>18 UNC</td>
<td>0.313</td>
<td>0.2403</td>
</tr>
<tr>
<td></td>
<td>24 UNF</td>
<td>0.313</td>
<td>0.2584</td>
</tr>
<tr>
<td>3/8”</td>
<td>16 UNC</td>
<td>0.375</td>
<td>0.2938</td>
</tr>
<tr>
<td></td>
<td>24 UNF</td>
<td>0.375</td>
<td>0.3209</td>
</tr>
<tr>
<td>7/16”</td>
<td>14 UNC</td>
<td>0.438</td>
<td>0.3447</td>
</tr>
<tr>
<td></td>
<td>20 UNF</td>
<td>0.438</td>
<td>0.3726</td>
</tr>
<tr>
<td>½”</td>
<td>13 UNC</td>
<td>0.500</td>
<td>0.4001</td>
</tr>
<tr>
<td></td>
<td>20 UNF</td>
<td>0.500</td>
<td>0.4351</td>
</tr>
</tbody>
</table>
**Local retail sources for parts, materials and tools:**

Dunbar Lumber
COE Timber Mart
Home Hardware
The Home Depot
Canadian Tire
Lowes
Industrial Plastics and Paints
Summit Tools
Lee Valley Tools
Princess Auto
Lordco Auto Parts
Metal Supermarkets

**Other Resources**

McMaster Carr [www.mcmastercarr.com](http://www.mcmastercarr.com)
Stock Drive Products [www.sdpsi.com](http://www.sdpsi.com)
Jameco Electronics [www.jameco.com](http://www.jameco.com)
Edmund Scientific [www.edsci.com](http://www.edsci.com)
Using an Edge-finder

The Edgefinder

The edgefinder is held in place of the milling cutter and rotated under power at about 500 rpm. The side of the tip is brought up against the surface of interest. The X or Y stage of the mill is moved slowly into position, until the edge and the edgefinder begin to make contact. Moving the stage will cause the wobble in the tip to diminish until the eccentricity is no longer apparent. Once the exact edge position is reached, the tip displaces noticeably to the side.

Select the 0.375” collet from the collet set and snap the collet into the collet collar.
Thread the collar loosely onto the chuck holder

Insert the edgefinder into the collet
Tighten the collet with the wrench Don’t over-tighten the collar; a single tug with one hand on the wrench should be sufficient.

To find the rear jaw of the vise:

Turn on the machine and adjust the spindle speed to about 500 rpm. Bring the edgefinder close to the rear jaw, until it just touches the surface.
At a certain point, the tip should suddenly be displaced to one side.
Reset the zero for the Y axis. Back the vise away from the edge finder and repeat the procedure to refine the position. It is easiest to watch the digital display. Move the Y-axis until the display reads one or two units away from zero and check the edge finder position. Reset the zero as necessary.

Measure the diameter of the edge finder tip (usually 0.200”). The centre of the collet chuck is offset from the edge by half of this value (i.e. 0.100”). It is usually convenient to re-zero the Y axis by moving to 0.100” and re-setting zero.

The edge-finder can be used to find edges on fixtures as well as parts. It will only work properly on flat surfaces or edges and can not be used to accurately locate curved surfaces.
Guidelines for designing parts to be made in the shop

- Consider designing parts out of bent sheet metal. It can be much cheaper and faster to do so. Flat patterns are easily cut on the waterjet cutter, bends can be performed readily, parts can be easily joined with spot welding or through other means and with a little attention, strong and stiff parts with precise features can be made.

- Be clear on where precision is required and how much. This makes a huge difference in the amount of set-up required to make parts.

- When machining, for highest precision, avoid ever letting go of the stock as it is being machined – this means that you have to plan the sequence of your cuts.

- Stock materials from local suppliers are generally available only in imperial dimensions.

- Consider how the material will be held while it is machined. Adding a bit of extra material to make a part easier to hold can make for a big reduction in the amount of time required for setup.

- Parts that can be cut without having to re-orient the part will be faster to cut and it will be easier to control position, size and orientation of features.

- Stock material surfaces are rarely flat, round or straight enough for precision fits. Anticipate the need for machining of all surfaces intended to fit against adjoining surfaces.

- Think about tool reach. Common sizes of cutters have aspect ratios of less than 1:6.

- Milling cutters are in fractional imperial sizes. Design slots, corner and groove radii accordingly. We do have metric drills and reamers for metric holes. Holes larger than 25mm are cut by interpolation or if needed, via boring set-up so an infinite range of sizes is possible.

- Holes that are to be drilled should be sized to common sizes
Tool and Equipment List and Locations

Layout and Marking (at layout table and in brown rolling cabinet)
- Height gauges
- Rules
- Squares
- Scribers
- Centre punches

Measuring and Inspecting (at layout table and in cabinets by office)
- Dial indicator and magnetic base
- Calipers
- Micrometers
- Granite blocks
- Height gauges
- Bore Gauge Set

Hand Tools for Cutting, Shaping and Filing (on toolboards, blue shelves and in brown tool cabinet)
- Hacksaw
- Miniature hacksaw
- Carpenter’s Saw (wood, plastic)
- Coping Saw (wood, plastic)
- Japanese Pull Saw (wood, plastic)
- Files
- Chisels

Clamping and Work Holding (blue shelves, toolboards, welding shop)
- Bench vises
- c-clamps
- vise-grip pliers
- speed clamps
- spring clamps

Sheet Metal Tools (shop floor, brown cabinet, toolboard)
- Bench shear
- Notcher
- Hand punch
- Nibbler
- Wire and Stock Bender

Drilling, Reaming Tapping
- Drills (number, letter, fractional, metric)
- Taps and dies
• Reamers

Assembly Tools (toolboards)

• Screwdrivers
• Wrenches
• Pliers
• Socket Set
• Allen Keys
• Drifts
• Snap Ring Pliers

Portable Power Tools Available for Use by Students
Dremel Tool
Cordless Drill
Hammer Drill
Jigsaw

Stationary Power Tools Available for Supervised Use by Students
Maxiem 1515 Abrasive Waterjet Cutter

Milling Machines

1. Clausing Kondia FV-1 #1 manual feed, no DRO
2. Clausing Kondia FV-1 #2, #3 power feeds, DROs on 3 or 4 axes
3. King Mill Drills #1 and #2

Milling Accessories
• Each machine has its own parallels and toolholder/collet set. Please do not mix these sets.
• Shared milling accessories (dividing heads, angle plates, boring heads) are located on the blue shelves

Lathes
1. Colchester 2500 Lathe #1, #2
2. Colchester Triumph 2000 (restricted use)

Lathe Accessories
• Each lathe has its own toolboard with three cutters (right hand, left hand and parting tool), setscrew wrench, chuck key, corn whisk and toolpost wrench
• Other accessories, such as boring bars, high speed steel tool bits, 4 jaw and collet chucks, faceplates, steady rests, etc. are available upon request.
If you need special tooling, consult with shop personnel.

Metal Saws

1. Kysor Johnson Vertical Band saw
2. Meba Horizontal Band saw
3. Jet 14” metal band saw (for sheet metal sawing)

Drill-presses for metal

The shop has 5 drill presses for metal; two floor-standing models and 3 smaller, bench-mounted models. Note that only the King Mills and the Jet and the KBC drills have removeable chucks for using taper shank drills and reamers.

Wood Room

1. Jet Drill Press
2. King 14” Band saw (wood and plastics)
3. Disc Sander
4. Sandblaster
5. Wood dust extractor
6. Lapping and polishing station

Sheet Metal Equipment

1. Brown and Boggs 48” Shear
2. Brown Boggs 48” Pan Brake
4. Brown Boggs 48” Slip Rolls
5. 6” Corner Notcher
6. Diacro 4” Bench Shear
7. Rotex 18-A Manual Turret Punch
8. Atek 48” 24-Ton Pneumatic/hydraulic Press Brake

50 Ton Manual Hydraulic Press
Stock Bender

Fadal 88 CNC Milling Centre (dedicated technician supervision required)

Welding Equipment

1. SIP 15KVA foot-operated spotwelder
2. Miller 2.5KVA manual spotwelder
3. Hobart Stick and TIG Welder
4. Miller MIG welder
5. Spotwelder
6. Plasma Torch
7. Oxy-Acetylene Torch
8. Acetylene Brazing Torch
9. Welding tables
10. Firebrick area
11. Bench Grinder
12. Buffer/Polisher
13. Ventilation Hood
14. Local Exhaust Fan
15. Portable Fume extractor

Waterjet license
Waterjet operation
3D printer operation
Finishing: coating, painting, texturing, polishing

Materials

Steels
Aluminum
Brass and Bronze
Plastics

Often has a blackened appearance if hot rolled. Cold rolled generally has a shinier surface. Magnetic. 3 times more dense and 3 times stiffer than aluminum.

Shiny reflective or matte grey surface

Light grey to silver. Recently cut edges silvery. Easily scratched with screwdriver