PART IA MACHINE TOOLS

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A day or two before your timetabled session:

- Read *all* of this handout and the accompanying risk assessment.
- Sign and date the risk assessment.
- Watch the two short videos referred to in this handout.

On the day of your timetabled session:

- Bring along the signed risk assessments, which will be collected in.
- Do not bring the rest of the handout, you will be guided by a demonstrator throughout.
- Come to the student machine tools area (below) at the south end of the Dyson Centre.

- Be prepared to answer some basic questions about the exercise and the risk assessment.
- If it is clear that you have not read this handout and the risk assessment, you will not be allowed to continue and it may not be possible to reschedule your participation for another time.

1 Introduction

Manufacturing engineering is concerned with the processes by which raw materials are transformed into finished products. Thousands of years of technical innovation have made possible a dazzling array of products manufactured from a wide variety of raw materials (metals, plastics, ceramics, composites, textiles) using an ever expanding range of processes. For example, solid objects may be *cast* in metal or *moulded* in plastic. Or they might be *formed* by extrusion, rolling, forging, pressing, bending or shearing. Parts might be *joined* by welding, brazing, soldering, adhesive bonding or fastening. The recent development of *additive manufacturing* (3D printing) has made possible the construction of solid objects through the controlled deposition of material. If the surface finish is critical or the dimensional tolerances are tight, objects might require *machining* or *subtractive manufacturing*, umbrella terms that describe the controlled removal of material from a workpiece to form a finished product. Machining is performed on a number of different machines using a number of different processes. For example, holes might be drilled, bored or reamed on drill presses, milling machines or lathes.

In this laboratory, you will be introduced to the lathe and the milling machine, two of the most common machine tools. You will manufacture a small aluminium wheel (below, left) on the lathe and a small aluminium beam (below, centre) on the milling machine. Technical drawings for these parts can be found in Appendix A. You will need to manufacture them within the prescribed tolerances so that they can be combined with Lego parts to build a three-wheeled buggy (below, right)[1]. Although you will operate the lathe and the milling machine manually, you should aim to take away from this laboratory an idea of how the machines could be computer numerically controlled (CNC) for greater accuracy and higher throughput.



Aims and objectives

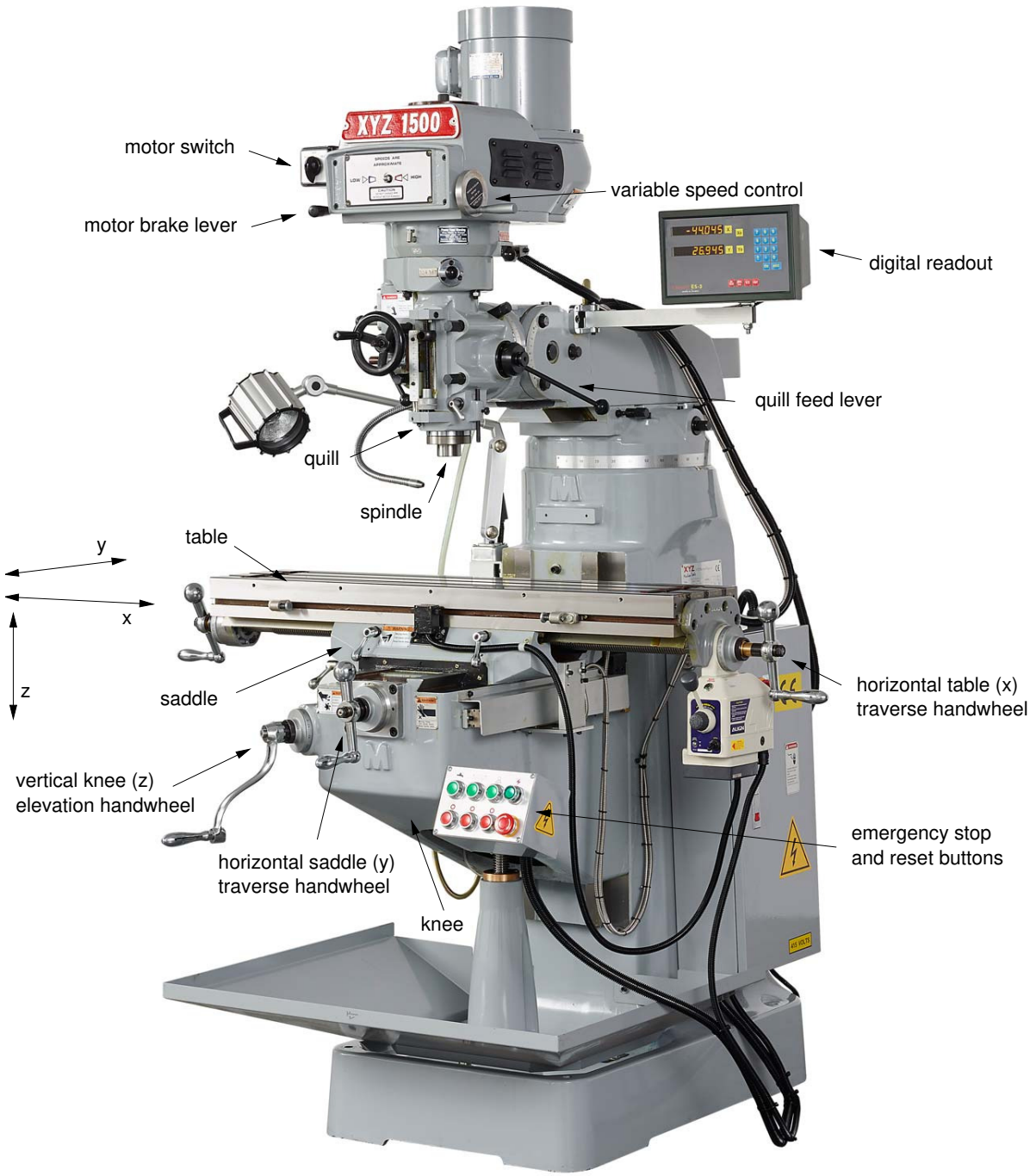
- To understand the basic principles of manufacturing using lathes and milling machines.
- To appreciate the Health and Safety implications of working with machine tools.
- To manufacture some simple parts on a manual lathe and a manual milling machine.
- To understand what is meant by *accuracy* and *tolerance*.

2 Making a beam on a milling machine

Watch https://www.youtube.com/watch?v=U99asuDT97I now

Milling machines like the XYZ 1500 are versatile tools for subtractive manufacturing. The workpiece is mounted on the *table* and a variety of cutting tools can be attached to the spinning *spindle*. The relative (x, y, z) positions of the cutting tool and the workpiece can be controlled accurately using the various handwheels and levers, allowing material to be removed from the workpiece in a highly controlled manner. The *digital readout* displays x and y displacements to a precision of $5\,\mu\mathrm{m}$. There is no digital z readout: vertical displacements must instead be read from the analogue gauges on the quill and the knee handwheel.

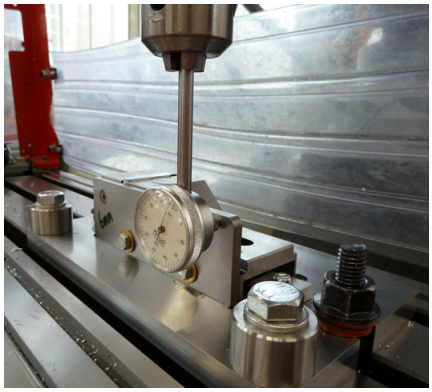
[1] Be aware of other parties' copyright! The parts you will make are not Lego clones and are only partially compatible with Lego.



When using a milling machine, considerable effort goes into mounting the workpiece in an appropriate manner and establishing the position of the cutting tool with respect to landmarks on the workpiece. For example, in this exercise you will be provided with an aluminium blank with finished outer dimensions but lacking the five holes and the slot rebates[2]. Once you have mounted the workpiece with its major axis parallel to the machine's y-axis, and located the spindle so it is sitting precisely above the location of the first hole, it is just a matter of drilling the first hole, traversing the right distance in the y direction, drilling the second hole, and so on.

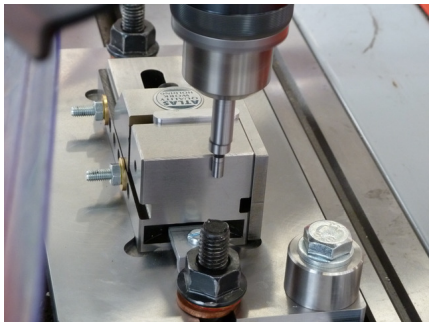
The aluminium blank is held in a small toolmaker's vice which needs to be bolted down to the table such that its jaws are parallel to the machine's y-axis. To check the alignment, you will use a *dial test indicator* (DTI) mounted in the machine's spindle via a three-jaw chuck, as shown in the photograph below.

[2] A *rebate* is a step-shaped recess cut into a workpiece. The beam you will make has two rebates, one on the top face and one on the bottom face, to accommodate the locking tabs of the Lego pins when they are pushed through the holes.



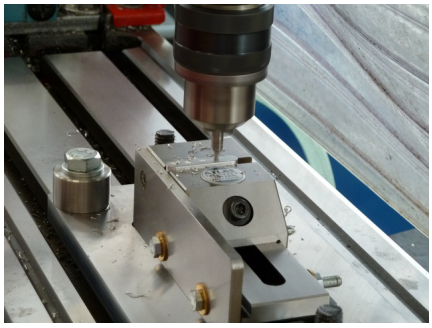
On the rear of the DTI is a small, spring-loaded probe. As the probe is depressed, the dial indicates the amount it has displaced. The idea is to bring the probe into contact with the flat face that runs at right angles to the vice's jaws: this face needs to be aligned with the machine's x-axis. We check the alignment by traversing the machine's table in the x direction, causing the DTI to translate along the flat face. Any significant movement of the dial indicates misalignment which we correct by loosening the bolts that attach the vice to the table, making small adjustments by tapping the "bumpers" with a rubber mallet, tightening up the bolts, and then repeating the checks and adjustments until a satisfactory alignment is achieved.

The next step is to calibrate the x and y displacements between the workpiece and the spindle. To do this, we mount an *edge finder* in the chuck. At the tip of the edge finder is a spring-mounted cylinder that wobbles as the tool is spun. In this photograph, the machinist is using the x handwheel to slowly bring the wobbling cylinder into contact with the fixed jaw of the vice. The wobbling gradually reduces until the cylinder's circumference is perfectly aligned with the edge of the jaw, when the cylinder suddenly jumps to one side.



At this point, we zero the x-axis on the digital readout. We then traverse the table in the x direction by a distance $a + b + c$, where a is the known radius of the edge-finding cylinder, b is the known width of the vice's fixed jaw, and c is half of the known width of the aluminium workpiece. The centre of the spindle should now be located precisely above the centerline of the workpiece, where we zero the readout again. Since all the cutting operations are located on the centerline, we will not need to touch the x handwheel again.

A similar edge finding operation in the y direction allows us to locate the spindle directly above the location of the first hole to be drilled. This is a convenient location for the (x, y) origin, so we zero the y readout at this point.

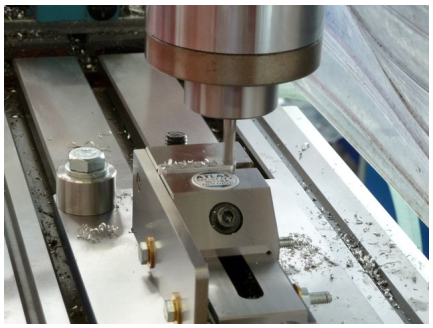


We start each hole using a *centre drill*, stepping along in the y direction and using the *quill feed lever* to plunge the tool a millimeter or two into the workpiece. The centre drill provides a good starting point for each hole: as it is short and less slender than a traditional twist drill bit, its tip stays reasonably well aligned with the spindle axis.

We then complete the holes using a twist drill bit. We could have started with the twist drill, but they do tend to wander a little on an unprepared surface. A centre-drilled hole provides a reliable starting point for the twist drill to follow.

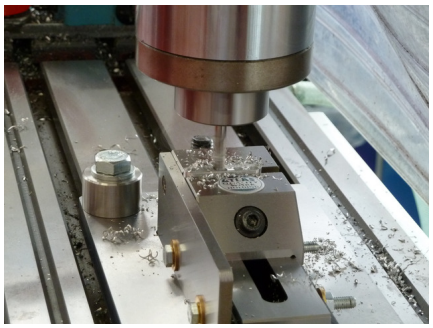
It remains to cut the slot rebate along the top of the holes. We use a three-fluted *slot drill* to do this. Key-operated chucks (left) are not designed to hold milling and slot-cutting tools, so your demonstrator will remove the chuck and instead mount the slot drill in a *collet* (right).

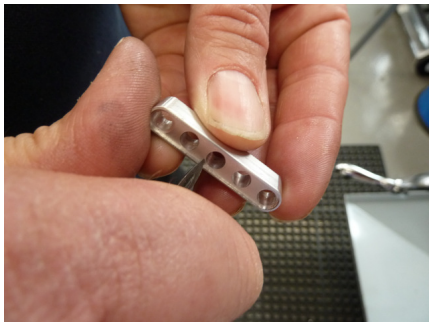
With the spindle directly above the first hole (i.e. at the (x, y) origin), we use the knee elevation handwheel to *just* touch the slot drill onto the workpiece.



At this point, we zero the knee elevation gauge, then advance it to the depth of the rebate, causing the tool to cut down into the material.

We then traverse the table in the y direction to cut the length of the rebate. All that remains is to cut a matching rebate on the other side of the beam. The vice has been designed to allow repeatable mounting of the workpiece at the same location, so you should be able to remove the beam, flip it upside down and then cut the second slot directly, without the need to realign the axes or recalibrate the (x, y) coordinate origin.



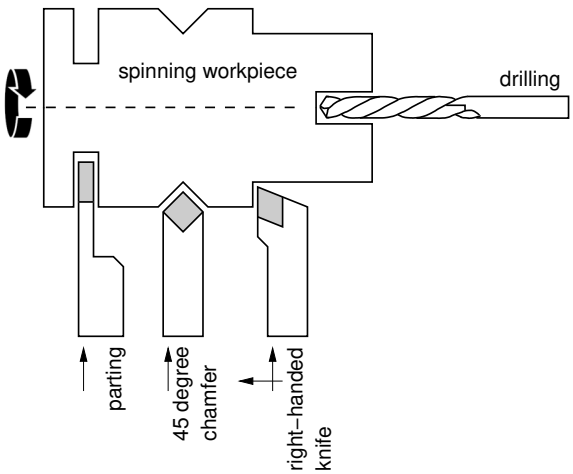


Finally, any small raised edges (*burrs*) around the cut edges can be removed with a manual deburring tool.

3 Making a wheel on a lathe

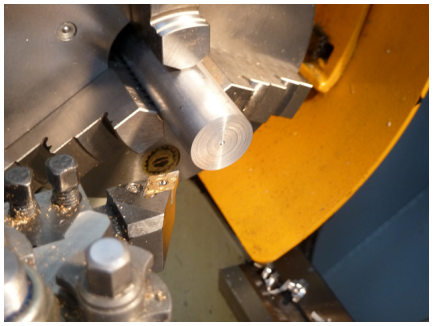
Watch https://www.youtube.com/watch?v=H0AyVUfl8-k now

Lathes like the XYZ Trainer are used to subtractively manufacture solid objects with symmetry around an axis of rotation. Unlike the milling machine, the cutting tool is stationary and it is the workpiece which is spun on the spindle. The relative position of the cutting tool and the workpiece can be controlled accurately in the radial and axial directions using the various handwheels and levers, allowing material to be removed from the workpiece in a highly controlled manner. Tools can be mounted on the *tool post* (obscured by the screen in the image above), approaching the spinning workpiece radially or axially in order to reduce its length or diameter. Alternatively, tools (e.g. drill bits) can be mounted on the *tailstock* and used to remove material from the central axis of the workpiece. Like the milling machine, the XYZ Trainer has a digital readout (not shown in the photograph) which displays the displacements of the carriage (axial) and the cross slide (radial) to a precision of $5\,\mu\mathrm{m}$. The displacements of the top slide and the tailstock must be read from the analogue gauges on their handwheels.

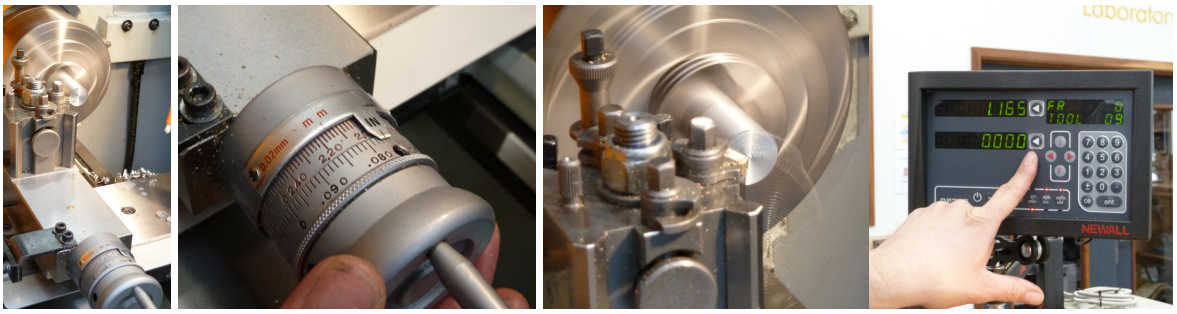


These are the tools you will use to make the wheel. On the tool post, you will use a right-handed knife tool to cut one of the wheel's flat faces and then turn its diameter. You will then use a centre drill and a twist drill in the tailstock to cut the central hole. Next, you will use a $45°$ chamfer tool on the tool post to cut the groove for the tyre. Finally, you will use a parting tool on the tool post to separate the wheel from the remaining cylindrical rod.

This photograph shows the stock aluminium rod held in the three-jaw chuck mounted on the lathe's headstock spindle. The right-handed knife tool is mounted on the tool post. The first operation you will perform is called *facing off*.

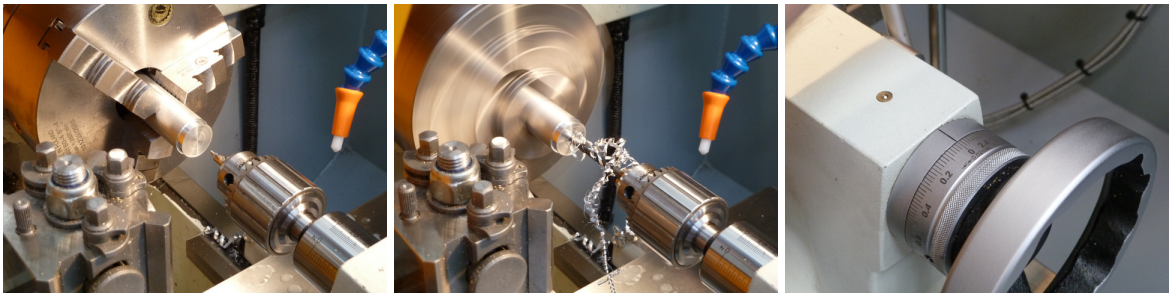


This involves spinning up the lathe and bringing the tool gently into contact with the workpiece's flat face from the axial direction (below left). We then withdraw the tool radially, advance the tool by around $0.2\,\mathrm{mm}$ in the axial direction using the top slide handwheel (below, second left), cut along the face in the radial direction (below, second right) before zeroing the axial displacement on the digital readout (below, right). The result is a clean, flat face on the workpiece corresponding to axial zero on the digital readout.



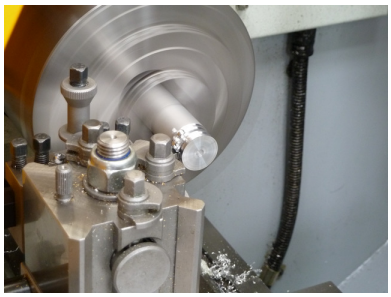
The next task is to reduce the workpiece's diameter to the correct value for the wheel. It is not good practice to assume that the workpiece is clean and round. Instead, we turn down (i.e. reduce) the diameter by a small amount (below, left), advancing the tool axially and using the digital readout to make sure we go far enough to cover the width of the wheel. We can now be sure that we have a clean, circular cross-section, whose diameter we measure using calipers (below, second left). With the tool at the same radial position as when we made the cut, we enter the measured diameter into the radial displacement of the digital readout (below, second right): this will now display the workpiece's diameter as we make further cuts after advancing the tool radially (below, right). We would typically remove a little material at a time, and no more than $0.1\,\mathrm{mm}$ at the final cut for a clean surface finish.

Next, we remove the right-handed knife tool from the tool post, insert a chuck in the tailstock and a centre drill in the chuck, and use the centre drill to start the hole through the centre of the wheel (below, left). Changing the centre drill for a traditional twist drill bit, we then complete the hole (below, centre), using the tailstock's handwheel gauge (below, right) to ensure we have penetrated sufficiently deep to account for the width of the wheel.



The next step is to cut the groove for the tyre using the $45°$ chamfer tool on the tool post. Since the groove's axial location is not tightly toleranced, we can align the tip of the tool with the edge of the workpiece by eye (below, left) and then zero the axial displacement on the digital readout (below, centre). Next, we advance the tool to the desired axial location for the groove, touch the tip of the tool onto the workpiece, zero the radial displacement and then advance the tool radially (below, right) up to the correct depth of the groove.

It remains just to sever the wheel from the rest of the bar, an operation known as *parting off*. We mount the parting tool on the tool post, touch it on to the front face of the wheel, zero the axial displacement on the digital readout, and then advance the tool axially to the correct position for parting off, accounting for the known width of the tool as well as the desired width of the wheel (below, left). Finally, we advance the tool radially to cut clean through the workpiece (below, centre), which will fall into the bin beneath the lathe's bed. After retrieving it, we remove any burrs from the hole using a manual deburring tool (below, right).




4 Further training opportunities

This laboratory is designed to give you a taste of precision manufacturing using machine tools, but two hours is not enough time for you to gain sufficient expertise to use the tools unsupervised. If you wish to develop your skills further, you can sign up for further training (or assessment, if you already have some prior experience) using the booking facilities on the Dyson Centre's website. In addition to the manual lathes and milling machines, training is also available for the 3D printers, laser cutters and, for expert users, the CNC lathe and milling machine. The various student-led societies are good places to put your nascent manufacturing skills into practice, while the Part II MET course provides a world-class education in Manufacturing Engineering.

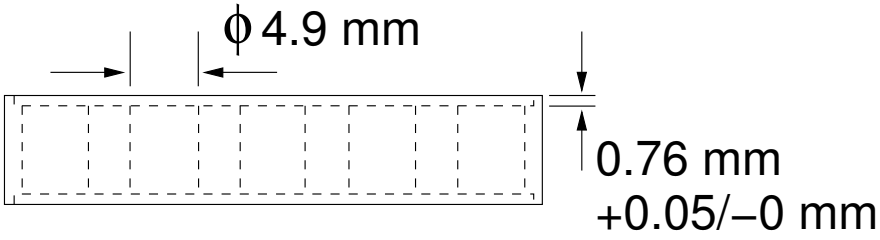
Checklist

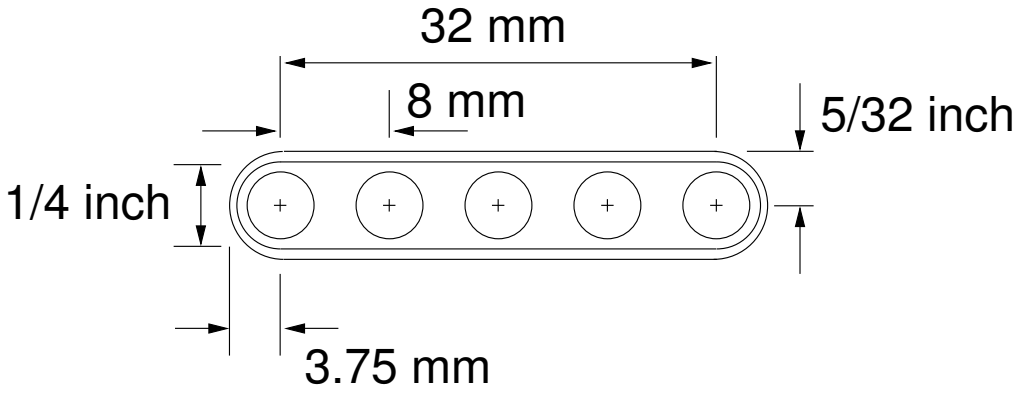
Before arriving at your timetabled laboratory session:

- Have you read this handout and watched the two videos?
- Have you read, signed and dated the risk assessment?
- Are you prepared to answer some basic questions about the handout and the risk assessment?

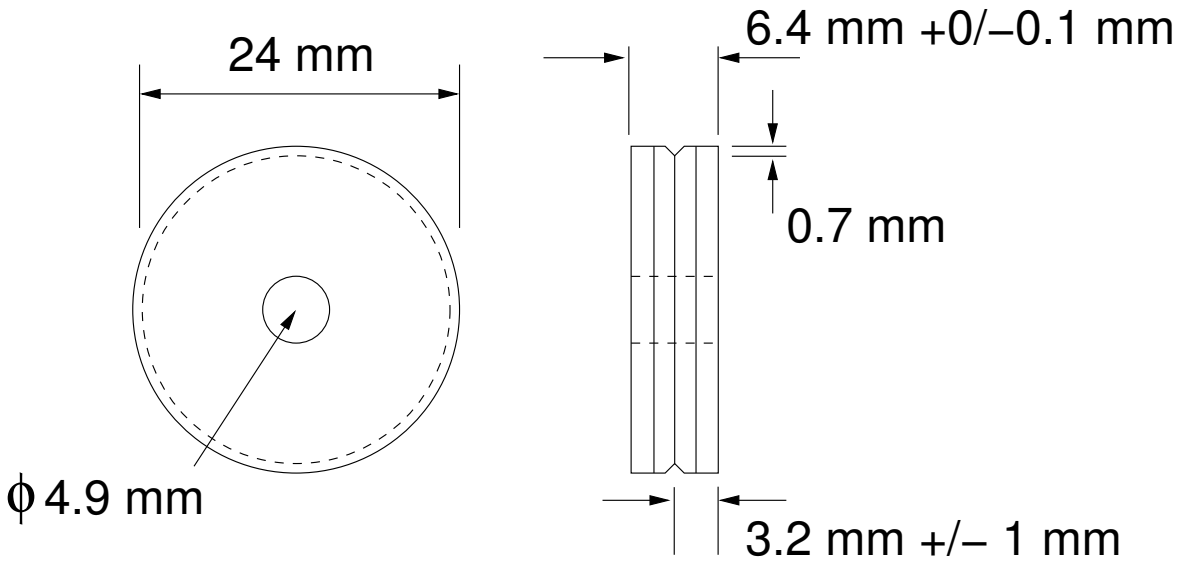
Your demonstrator will not expect you to understand everything about all the operations described in this handout: that is, after all, what the laboratory itself is for! But you will need to show that you have a very rough idea about what you will be doing, and that you have read the risk assessment.

A Technical drawings





All tolerances +/– 0.05 mm except where stated otherwise



Appendix B: Risk Assessment for Part 1A Machine Tool Lab Participants

This is a risk assessment for participants in the above supervised lab only. For further use of the machines involved in this lab, a more detailed risk assessment will be required. Please seek advice from an appropriate machine tool instructor.

This will hopefully be an enjoyable lab for you, giving you the chance to operate some 'powerful' machinery, capable of slicing through metals, however please pay careful attention to the notes below to help keep you safe.

Location: Please see lab sheet.

Activity: Familiarisation and first use of a lathe and a milling machine. Please see lab sheet for further details.

Hazards:

- Human or unintended machine contact with rotating workpieces, cutters, or chucks/collets (i.e. the items used to hold rotating workpieces and cutters).
- Long hair, loose clothing (e.g. open cardigans, ties, etc.) and some jewellery can become entangled in the moving (high speed rotating and manually translating) parts of the machines.
- Work pieces which become loose, broken cutting tools and swarf (the sharp chips or spirals of metal cut or peeled away from the parent piece of metal) can be violently ejected.
- Closing movements can result in finger trapping.
- Sharp edges on cutters, workpieces and swarf can cause cuts.
- Hot cutters, workpieces and particularly swarf (which can be ejected) can cause burns.
- Contact with cutting fluids, oil, grease, etc. can irritate skin, and hands should be washed after the lab and before eating to remove such contaminants, which could otherwise cause ingestion of bacteria.
- Swarf can jam the machines or be ejected if allowed to build up.
- Accidental starting of machines.
- Lack of sufficient space around the machine can lead to the operator being pushed into the machine by passers-by resulting in an injury.
- Multiple people operating any machine is always a serious safety risk (e.g. you don't know where the other persons finger, face, etc. is located): care should be taken to always alternate who is operating the machine, and be clear who that is – there should never be two people operating different controls on a lathe or milling machine at the same time.
- Ensure that you are wearing suitable footwear – preferably 'sensible' shoes or stout trainers: e.g. no shoes with heels, no open-toed or canvas-topped shoes which a knife-tool could pierce if dropped on them.
- An operator slipping into the machine can result in an injury.
- An operator being distracted by theirs or someone else's mobile phone or other electronic device could inadvertently injure themselves or damage one of the machines – please turn all such devices off, or do not bring them into the machine tools area.
- Clutter, such as bags and coats, can present a trip hazard in the machine tools area, please consider leaving them in the Dyson Centre pigeonholes (opposite the Dyson Centre bridge) – if you are concerned about valuables, please ask to leave your bags in the Technician Hub.
- No running or fast movements in the machine tools area as it could present a slip or push hazard (as above).
- Chuck keys (placed in the side of chucks to tighten/loosen their grip on workpieces), collet-holder-spanners and drawbar-spanners must not be left in the side of chucks or in place on collets or drawbars, at any time, in case they are forgotten about, and fly out/off, strike or trap the operator on the machine being started up.

Risk Control Measures (not already covered above)**:**

- Eye protection must be worn at all times: safety glasses will be available for you in the machine tools area.

- You must ensure you know where all the emergency stop, interlock switches and brake buttons and foot pedals are located (brakes will stop the lathe/milling-machine rotating, rather than letting it coast to a stop) on the machines and in the machine tools area – the demonstrator should explain, but if in doubt, do ask. Interlocks are present on some <u>but not all</u> safety guards.
- You should turn the machine off with the isolator when working to set the machine up, or ensure at least one of the interlock switches is operated – this avoids an electrical fault (not impossible on a machine with metal swarf and sometimes coolant liquid seemingly everywhere) causing the machine to start.
- You should ensure that guards are in a place and used on the machines to keep a barrier between operator and certain hazards – note that interlocks are present on many (<u>but not all</u>) guards, so that the machine will not start if the interlocked guards aren't in place.
- Loose hair, clothing, jewellery either needs to be suitably secured or not worn, and suitable footwear needs to be worn, as detailed above.
- Gloves should not be worn as they can get caught on moving parts, turning risk of abrasion into an operator being dragged into a machine.
- Do not allow swarf to build up to the point where is may become ejected from the machine.
- Swarf should be removed using implements such as the brush provided or pliers, noting that handling sharp swarf can cause cuts.
- Care should be taken not to stand with one's mouth open (including talking) whilst standing in front of a machine tool which is running when there is potential for sharp, hot swarf to be launched into the open mouth.
- Participants should ensure that they are in a fit state to take part in the lab (e.g. do not show up hungover, concussed, tired, etc.). If a person does feel unwell, or has any other issue meaning it would not be sensible to take part in the lab, then they should discuss this with one of the demonstrators. Poor physical state could cause a participant to fall into the machine tool, or have another accident.
- Moving chucks, collets and cutters must be allowed to come to a complete stop before the machines 'space' is entered to take measurements, clear swarf, change tooling, make adjustments, etc. A brake lever is available on the milling machine to speed up the stopping process.

<u>Declaration</u>

Please print out these two risk-assessment pages, sign the declaration below and hand them in to the demonstrator at the start of the laboratory session.

I have read and understood this risk assessment.

Name (please print clearly): **College:**

CRSid (e.g. dab21): **Date:**

Signed: