Trade of Toolmaking	
Module 3:	Milling
Unit 3:	Face and End Milling
	Phase 2

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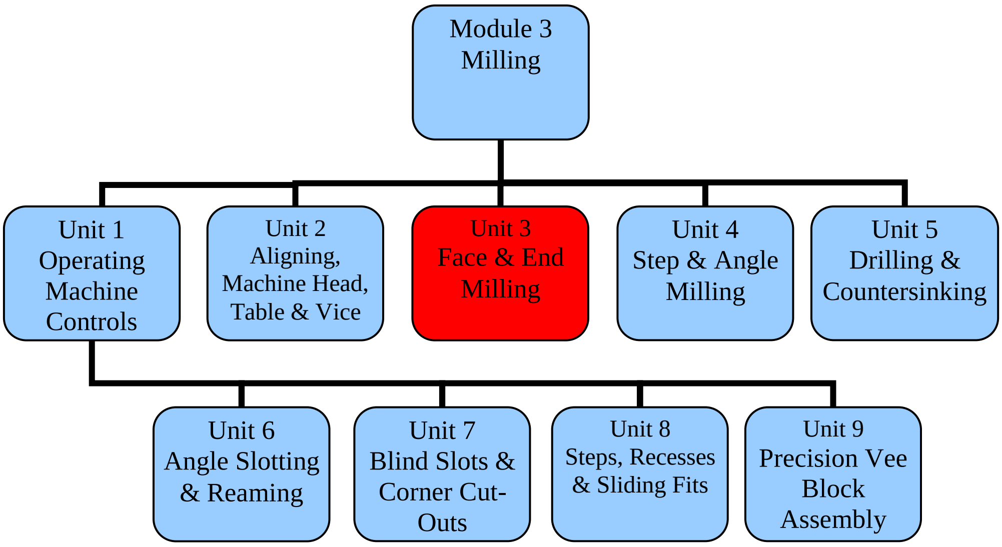
Unit Objective

On completion of this unit you will be able to construct first and third angle projection drawings, select and mount milling cutters and use the correct coolant. You will also be able to setup the workpiece and perform end and face milling operations.

Introduction

Module three of this course covers milling. This is the third unit in module three and explains how to draw to first and third angle projection and explains geometric tolerancing. This unit introduces the techniques associated with mounting the correct milling cutters and setting up and milling the workpiece. It explains the differences between the various milling cutters such as slot drills, end mills and fly cutters, and the various methods of mounting the cutter in the spindle. This unit also covers the different types and use of coolants and hazards associated with some types of coolant.

It is important to know how to safely setup the workpiece, use an edge finder for accurate location and to calculate the correct speeds and feeds when using a particular material. *Up and Down* cutting is also explained and warns about the dangers of using the *Down* cutting method of machining.



By the end of this unit you will be able to:

- Draw first and third angle projection drawings of milled components.
- Identify, select and mount milling cutters for specified tasks.
- Identify and select coolants for use during metal cutting.
- Safely set up, end and face mill workpieces to given dimensions.

1.0 Drawing First And Third Angle Projection Drawings

Key Learning Points

First and third angle projection of solids: plan, elevation, end view and symbols to BS 8888. Interpretation of geometric tolerances to include: symmetry, squareness and parallelism, surface texture symbols

1.1 First And Third Angle Projection Of Solids: Plan, Elevation, End View And Symbols To Bs 8888

Multi-view orthographic projection is used in engineering drawing, working to BS 8888. There are two systems of projection, First Angle and Third Angle, which are based on a framework of planes at right angles. In First angle projection, each view shows what would be seen by looking on the far side of an adjacent view. In Third angle projection, each view shows what would be seen by looking on the near side of an adjacent view. The plan view is normally viewed by looking at the horizontal plane of the component, it can also be called the front view. The elevation view is normally positioned above or below the plan view and can also be called the top or bottom view. The end view is positioned left or right.

Ref: Simmons, Colin H & Maguire, Dennis E 2004, *Manual of engineering drawing*, 2nd edn, Elsevier Science & Technology, chapter 4, *Principles of first and third angle orthographic projection*, p. 33.

ISBN-13: 9780750651202

1.2 Interpretation Of Geometric Tolerances To Include: Symmetry, Squareness And Parallelism, Surface Texture Symbols

Geometric tolerancing, which uses symbols such as symmetry, squareness, parallelism, etc, on drawings to define the form and size of a tolerance zone within which the feature needs to be contained.

Ref: Simmons, Colin H & Maguire, Dennis E 2004, *Manual of engineering drawing*, 2nd edn, Elsevier Science & Technology, chapter 20, *Geometrical tolerances and datum's*, p. 160.

ISBN-13: 9780750651202

2.0 Identifying, Selecting And Mounting Milling Cutters

Key Learning Points

Milling cutters, selection criteria, use and care. Assembling and dismantling of autolock chucks. Use of autolock chucks and collets, assembly/attachment, use of edge finders. Constitution/characteristics of bright mild, medium carbon and high carbon steels. Use of catalogues and technical data to select new cutting tools and tool holders.

2.1 Milling cutters, selection criteria, use and care

Cutters such as Slot Drills, End Mills, Face Mills and Fly Cutters are used on the vertical milling machine. The *Slot Drill* has two straight or helical cutting teeth on the cylindrical surface and end teeth that are cut to the centre. This type of cutter can be driven directly into the workpiece and then fed length ways to form a groove. The *End Mill* has multiple cutting teeth. The end teeth do not run all the way to the centre, so therefore cannot be sunk into the workpiece. They can be used for cutting light slots and for machining the side walls of the workpiece. The *Face Mill* is used for facing large surfaces. It is usually of inserted tooth type and is mounted directly onto the spindle. The *Fly Cutter* is a single point cutting tool and is clamped into the holder with screws. The holder has a taper to suit the spindle of the milling machine. The feed rate has to be kept low because it has only one cutting tip.

Ref: Black, Bruce J 2004, *Workshop processes, practices and materials*, 3rd edn, Elsevier Science & Technology, chapter 11, *Milling*, sec. 11.3, *Milling cutters*, p.179.

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2.2 Assembling And Dismantling Of Autolock Chucks

Slot drills and end mills with straight shanks are either held in a spring collet or in a tapered adapter such as an autolock chuck. The spring collet fits snugly around the cutter and is placed into the tapered spindle and held in position with a drawbar. The autolock chuck also consists of a spring collet, but this is secured by a locking sleeve, which is screwed into the main body of the chuck. The chuck assembly, which is tapered at one end, fits into the tapered spindle and is held in place with a drawbar.

Ref: Black, Bruce J 2004, *Workshop processes, practices and materials*, 3rd edn, Elsevier Science & Technology, chapter 11, *Milling*, sec. 11.4, *Cutter mounting*, p.182.

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2.3 Use Of Autolock Chucks And Collets, Assembly/Attachment, Use Of Edge Finders

The autolock chuck locks the milling cutter very securely in place. The cutter cannot move in or out during the milling operation, The heavier the cut the tighter the grip on the cutter.

The *Edge finder*, which rotates in the spindle, is used to accurately find the datum edge/s of a workpiece. The digital readout is then set to zero for both the X and Y axis.

Ref: Black, Bruce J 2004, *Workshop processes, practices and materials*, 3rd edn, Elsevier Science & Technology, chapter 11, *Milling*, sec. 11.4, *Cutter mounting*, p.182.

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2.4 Constitution/Characteristics Of Bright Mild, Medium Carbon And High Carbon Steels

Mild Steel is used for many engineering application because of its good tensile properties, it can easily be machined and it can also be welded and forged. It is available in rod, various shaped bars, sheets and wire. The disadvantage of mild steel is that it is subject to corrosion. Typical uses of mild steel are nuts, bolts, car bodies, bridges and in construction work. The carbon content is approximately 0.3%.

Medium carbon steel has higher tensile strength than mild steel and is more suitable for engineering components that are subjected to bending stresses. It is also harder with better wear and abrasion properties. Medium carbon steel is used for applications such as lathe tool holder, which should not bend or deflect due to the cutting forces. It is also used for rails in railways. The carbon content is up to 0.6%.

High carbon steels are used for applications such as springs, spring collets, chisels, punchers and files. The carbon content is up to 0.9%.

Ref: Black, Bruce J 2004, *Workshop processes, practices and materials*, 3rd edn, Elsevier Science & Technology, chapter 13, *Materials*, sec. 13.4, *Plain carbon steel*, p.215.

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2.5 Use Of Catalogues And Technical Data To Select New Cutting Tools And Tool Holders

Catalogues can be used when selecting millings cutters and other equipment. The manufactures data sheets will recommend the correct cutter or associated equipment for your application.

3.0 Identifying And Selecting Coolants

Key Learning Points

Benefits of the applications of coolants. Selection of coolants for selected materials and cutting tools. Hazards associated with coolants and methods of disposal.

3.1 Benefits Of The Applications Of Coolants

Most machines are fitted with equipment for pumping coolant onto the tool. Milling can be done ‘wet’ or ‘dry’, but there are advantages to using coolant such as, higher cutting speeds, longer tool life, better surface finish and better swarf removal.

Ref: Black, Bruce J 2004, *Workshop processes, practices and materials*, 3rd edn, Elsevier Science & Technology, chapter 7, *Cutting tools and cutting fluids*, sec. 7.5, *Cutting fluids*, p.124.

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3.2 Selection Of Coolants For Selected Materials And Cutting Tools

There are four main types of coolant: soluble oil, mineral oil, synthetic and chemical.

Ref: Black, Bruce J 2004, *Workshop processes, practices and materials*, 3rd edn, Elsevier Science & Technology, chapter 7, *Cutting tools and cutting fluids*, sec. 7.6, *Cutting fluids*, p.125.

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3.3 Hazards Associated With Coolants And Methods Of Disposal

Barrier creams can be used to protect hands from any oil and chemicals that may be present in the coolant. Coolants and lubricating oils should be disposed of safely and in an environmentally friendly way.

Ref: Black, Bruce J 2004, *Workshop processes, practices and materials*, 3rd edn, Elsevier Science & Technology, chapter 7, *Cutting tools and cutting fluids*, sec. 7.8, *Safety in the use of cutting fluids* p.127.

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4.0 Safely Setting Up, End And Face Milling Of Workpieces

Key Learning Points

Safe machine operations/sequences. Job planning, sequencing, care of cutters, tools and equipment. Calculation of spindle speeds and feeds, calculation of cutting times. Setup of work holding devices on the milling machine. Setup of work in the machine vice. Up-cut and down-cut milling. Function of backlash eliminator on milling machine. Machining of components: end and face milling.

4.1 Safe Machine Operations/Sequences

When using a milling machine it is important to observe the following:

- Wear safety goggles and suitable clothing.
- Keep the machine and surrounding area clean and tidy.
- Use a brush to remove swarf from the machine.
- Use correct tools and equipment.
- Store all cutters in a safe place.
- Use correct lifting methods.
- Switch off machine when not in use.

4.2 Job Planning, Sequencing, Care Of Cutters, Tools And Equipment

Job planning is important prior to starting any task. The drawing should first be studied and understood. The drawing can initially be used to calculate the material requirement for the component to be manufactured. The workpiece needs to be cut from bar stock by using the bandsaw. The sequence of operations should be planned so as to minimise the number of setups in the vice.

Cutters, tools and equipment must be handled carefully and stored safely. Never pile cutters among other tools. Cutters are sharp and can easily cause a hand injury. If a cutter is dropped it may chip. Always check the cutter before use.

4.3 Calculation Of Spindle Speeds And Feeds, Calculation Of Cutting Times

The correct spindle speed needs to be set for each cutter. This is calculated by entering the cutting speed and the cutter diameter into the RPM formula, where the *Cutting Speed* is expressed in meters per minute. Charts are available that recommend the correct cutting speed for a particular material, e.g. a typical cutting speed of 30 meters/min is used for mild steel and 20 metres/min for tool steel. Therefore the spindle speed will be lower for the tool steel when compared to that of mild steel.

Recommended cutting speed in metres per minute:

Material	High Speed Steel (metres/min)	Carbide Cutter (metres/min)
Tool Steel	21 - 33	68 – 158
Mild Steel	33 – 42	98 – 188
Cast Iron	21 – 30	68 – 98
Brass	42 – 75	120 – 180
Aluminium	60 – 105	180 - 350
Plastic	60 - 450	unlimited

To find the correct RPM (revs per minute) setting of the spindle the following formula should be used;

$$\text{RPM} = \frac{\text{Cutting Speeds in metres per minute x 1000}}{\text{Circumference of cutter in millimetres}}$$

$$= \frac{\text{S x 1000}}{\pi \text{ x D}}$$

For example, for a mild steel part a cutting speed of 30 m/min is chosen from the above table. If it is to be machined with a 20mm High Speed Steel end mill, the RPM is calculated as follows:

$$\text{RPM} = \frac{30 \text{ x } 1000}{3.14 \text{ x } 20} = 478$$

Feed Rate

Feed rate is the speed at which the workpiece is moved relative to the cutter.

0.05 is chosen from the cutter manufacturers tables. The feed rate is calculated as follows:

Feed Rate = feed/tooth x No. of cutting teeth x RPM

= 0.05 x 4 x 478

= 96 mm/min

Time to Cut

If the workpiece is 100mm long, then the time to cut is calculated as follows:

$$\text{Time to cut} = \frac{\text{length of cut in mm}}{\text{Feed rate in mm/min}}$$

$$= \frac{100}{96}$$

= 1.04 minutes

= 62.5 seconds

Ref: Black, Bruce J 2004, *Workshop processes, practices and materials*, 3rd edn, Elsevier Science & Technology, chapter 9, p.185.

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4.4 Setup Of Work Holding Devices On The Milling Machine

There are various methods and devices for holding workpieces such as a vice, rotary table, dividing head and clamping directly onto the table. Large workpieces can be clamped directly onto the table by using the t-slots in table. The rotary table can be used when a radius or a series or radii need to be machined into a workpiece. The dividing head can used when for example a series of holes or slots need to be machined around a cylindrical workpiece, which is held in a workpiece in a chuck similar to that of a lathe.

Ref: Black, Bruce J 2004, *Workshop processes, practices and materials*, 3rd edn, Elsevier Science & Technology, chapter 11, *Milling*, sec. 11.5, *Workholding*, p.184.

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4.5 Setup Of Work In The Machine Vice

The vice is the most common way of holding a workpiece when milling. Prior to machining the workpiece should be securely locked in a vice and properly seated by tapping it down with a mallet.

Ref: Black, Bruce J 2004, *Workshop processes, practices and materials*, 3rd edn, Elsevier Science & Technology, chapter 11, *Milling*, sec. 11.5, *Workholding*, p.184.

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4.6 Up-Cut And Down-Cut Milling

Up-Cutting is generally used and involves feeding the work against the direction of the cutter. You should **not** attempt to use Down-Cutting at this stage in your training as it is only used in machines with a hydraulic feed and a backlash eliminator.

4.7 Function Of Backlash Eliminator On Milling Machine

If down milling is attempted on a machine with slack guides and no backlash eliminator, the cutter may dislodge the workpiece, dig in or break. This is dangerous and may cause injury. The backlash eliminator will prevent this.

4.8 Machining Of Components: End And Face Milling

The width of the top face of a workpiece can be machined with an end mill, but this is limited by its diameter and will take many passes to complete the task. It is therefore better to use a face milling cutter, which will produce a complete the task faster and produce a better finish. The sides of the workpiece can be machined with the side of an end mill.

Ref: Black, Bruce J 2004, *Workshop processes, practices and materials*, 3rd edn, Elsevier Science & Technology, chapter 11, *Milling*, sec. 11.6, *Milling operations*, p.185.

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Summary

Drawing first and third angle projection: Multi-view orthographic projection is used in engineering drawing working to BS 8888. There are two systems of projection, First Angle and Third Angle, which are based on a framework of planes at right angles. In First angle projection, each view shows what would be seen by looking on the far side of an adjacent view. In Third angle projection, each view shows what would be seen by looking on the near side of an adjacent view. The plan view is normally viewed by looking at the horizontal plane of the component, it can also be called the front view. The elevation view is normally positioned above or below the plan view and can also be called the top or bottom view. The end view is positioned left or right.

Geometric tolerancing, which uses symbols such as symmetry, squareness, parallelism, etc, on drawings to define the form and size of a tolerance zone within which the feature needs to be contained.

Identifying, selecting and mounting milling cutters: Cutters such as Slot Drills, End Mills, Face Mills and Fly Cutters are used on the vertical milling machine. The *Slot Drill* has two straight or helical cutting teeth on the cylindrical surface and end teeth that are cut to the centre. This type of cutter can be driven directly into the workpiece and then fed length ways to form a groove. The *End Mill* has multiple cutting teeth. The end teeth do not run all the way to the centre, so therefore cannot be sunk into the workpiece. They can be used for cutting light slots and for machining the side walls of the workpiece. The *Face Mill* is used for facing large surfaces. It is usually of inserted tooth type and is mounted directly onto the spindle.

Slot drills and end mills with straight shanks are either held in a spring collet or in a tapered adapter such as an autolock chuck. The spring collet fits snugly around the cutter and is placed into the tapered spindle and held in position with a drawbar. The autolock chuck also consists of a spring collet, but this is secured by a locking sleeve, which is screwed into the main body of the chuck. The chuck assembly, which is tapered at one end, fits into the tapered spindle and is held in place with a drawbar.

Identifying and selecting coolants: Most machines are fitted with equipment for pumping coolant onto the tool. Milling can be done 'wet' or 'dry', but there are advantages to using coolant such as, higher cutting speeds, longer tool life, better surface finish and better swarf removal. There are four main types of coolant: soluble oil, mineral oil, synthetic and chemical. Barrier creams can be used to protect hands from any oil and chemicals that may be present in the coolant.

Safely setting up, end and face milling workpieces: The workpiece should be securely locked in a vice and properly seated by tapping it down with a mallet. Up-Cutting is generally used and involves feeding the work against the direction of the cutter. You should **not** attempt to use Down-Cutting at this stage in your training as it is only used in machines with a hydraulic feed and a backlash eliminator.

Suggested Exercises

1. List three types of cutters used on the milling machine.
2. What are the carbon contents of Mild, Medium and High Carbon Steels.
3. List some of the uses for the above steels.
4. What are the benefits of using coolant when milling.
5. Calculate the spindle speed for milling tool steel with a Ø10mm end mill.

Questions

1. Explain the difference between First Angle Projection and Third Angle Projection.
2. Describe a Slot Drill and list some of its uses.
3. Describe an End Mill and list some of its uses.
4. Describe a Fly Cutter and explain how it is held in the spindle.
5. What is the difference between the spring collet and an autolock chuck.

Answers

1. In First angle projection, each view shows what would be seen by looking on the far side of an adjacent view. In Third angle projection, each view shows what would be seen by looking on the near side of an adjacent view.
2. The Slot Drill has two straight or helical cutting teeth on the cylindrical surface and end teeth that are cut to the centre. This type of cutter can be driven directly into the workpiece and then fed length ways to form a groove.
3. The End Mill has multiple cutting teeth. The end teeth do not run all the way to the centre, so therefore cannot be sunk into the workpiece. They can be used for cutting light slots and for machining the side walls of the workpiece.
4. The Fly Cutter is a single point cutting tool and is clamped into the holder with screws. The holder has a taper to suit the spindle of the milling machine.
5. The spring collet fits snugly around the cutter and is placed into the tapered spindle and held in position with a drawbar. The autolock chuck also consists of a spring collet, but this is secured by a locking sleeve, which is screwed into the main body of the chuck. The chuck assembly, which is tapered at one end, fits into the tapered spindle and is held in place with a drawbar.

Recommended Additional Resources

Reference Books

Black, Bruce J 2004, *Workshop processes, practices and materials*, 3rd edn, Elsevier Science & Technology.

ISBN-13: 9780750660730

Simmons, Colin H & Maguire, Dennis E 2004, *Manual of engineering drawing*, 2nd edn, Elsevier Science & Technology.

ISBN-13: 9780750651202

Bird, John 2005, *Basic engineering mathematics*, 4th edn, Elsevier Science & Technology.

ISBN-13: 9780750665759