| Trade of Toolmaking | | | |
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| Module 3: | Milling | | |
| Unit 4: | Step and Angle Milling | | |
| | Phase 2 | | |

Published by



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Unit Objective

On completion of this unit you will be able to mark out workpieces as per drawing, mill steps and angles and calculate angular measurements.

Introduction

Module three of this course covers milling. This is the fourth unit in module three and explains how to mark out workpieces prior to machining. It is also explains how to calculate angles using trigonometry, setup the workpiece and mill the workpiece to the angle as specified on the drawing.

It is important to mark out a workpiece prior to milling, as these markings can be used when setting up the workpiece in the vice and as a guide when rough milling the workpiece. When the workpiece has been rough machined, measuring equipment such as the vernier callipers, micrometer and depth micrometer can be used when finish machining the workpiece.

When marking out a workpiece that needs to be machined at an angle, knowledge of trigonometry is essential to calculate an angle or to determine the length of one side of a right angled triangle. Calculation of the correct speeds and feeds will result in prolonging the tool life of the cutter and produce an acceptable surface finish. It is important that the machining operation is completed within an economical time period.



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

- Mark out workpieces as per drawing.
- Mill steps and angles as per drawing.
- Calculate angular measurements, set up and mill angles as per drawing.

1.0 Marking Out Workpieces As Per Drawing

Key Learning Points

Marking out: correct use of bevel protractor to mark out angles. Vernier height gauge, use of depth micrometer to measure steps and recesses.

1.1 Marking Out: Correct Use Of Bevel Protractor To Mark Out Angles

The surface to be marked out is usually coated in order to show up the scribed lines. The most common coating used is Engineer's Blue. The plates are marked out to the dimensions specified on the drawing with the vernier height gauge, which has a graduated vertical frame and a moveable jaw with a scribing blade attached. For angled lines use the bevel protractor and a scriber. The bevel protractor has a dial face graduated in degrees, with a straight edge that can be swivelled to the required angle and locked in position.

Ref: Black, Bruce J 2004, *Workshop processes, practices and materials*, 3rd edn, Elsevier Science & Technology, chapter 3, *Marking out*, chapter 6, *Measuring equipment*. ISBN-13: 9780750660730

1.2 Vernier Height Gauge, Use Of Depth Micrometer To Measure Steps And Recesses

The vernier height gauge has a graduated vertical frame and a moveable jaw with a scribing blade attached. The required height can easily be set prior to scribing the line on the workpiece.

The depth micrometer is used for measuring depths of steps, holes and slots in a workpiece.

Ref: Black, Bruce J 2004, *Workshop processes, practices and materials*, 3rd edn, Elsevier Science & Technology, chapter 6, *Measuring equipment*, p.105. ISBN-13: 9780750660730

2.0 Milling Steps And Angles As Per Drawing

Key Learning Points

Safe operation of machine, safe workholding. Calculation of speeds and feeds, effect on surface texture. Use of coolants. Surface texture of machined finishes; tactile testing using comparators. Side and face cutters, shell end mills. Slot drills and end mills (differences between and uses of). Job planning – sequencing of work holding to reduce unnecessary removal of workpieces. Machining of steps and recesses, setup of workpieces in for machining angular surfaces. Use of depth micrometer.

2.1 Safe Operation Of Machine, Safe Workholding

When milling a stepped workpiece, it should be first marked out as explained above. 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. ISBN-13: 9780750660730

2.2 Calculation Of Speeds And Feeds, Effect On Surface Texture

Cutting speed is expressed in meters per minute. This refers to the distance covered by the tool across the material when machining. A chart is available listing various materials and their corresponding cutting speeds. The revolutions per minute (RPM) is calculated by using the RPM formula:

 $RPM = \frac{S \times 1000}{\pi \times D}$

Ref: Black, Bruce J 2004, *Workshop processes, practices and materials*, 3rd edn, Elsevier Science & Technology, chapter 9, p.153. ISBN-13: 9780750660730

The feed rate is important when trying to achieve a good surface finish. A high feed rate increases the forces acting on the cutter and workpiece and causes the cutter to flex to produce a rough finish. This is fine when rough machining as explained above. For the final cuts the feed rate needs to be reduced, which will result in a better finish.

2.3 Use Of Coolants

The advantages of using *coolant* are 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.

Ref: Black, Bruce J 2004, *Workshop processes, practices and materials*, 3rd edn, Elsevier Science & Technology, chapter 11, *Cutting tools and cutting fluids*, p.124. ISBN-13: 9780750660730

2.4 Surface Texture Of Machined Finishes; Tactile Testing Using Comparators

As mentioned above, the feed rate is important when trying to achieve a good surface finish. Surface roughness comparison charts can be used to check the machined workpiece. To get a precise measurement, a surface roughness machine can also be used to measure the surface roughness of the machined part.

Ref: Black, Bruce J 2004, Workshop processes, practices and materials, 3rd edn, Elsevier Science & Technology, chapter 5, Standards, measurement and gauging, sec. 5.8, Surface roughness, p.92.

ISBN-13: 9780750660730

2.5 Side And Face Cutters, Shell End Mills

The *side and face cutters* are held on the arbour of a horizontal milling machine and are used for side milling and slotting. These cutters are narrow cylindrical cutters with cutting edges on the periphery and at the sides.

Shell end mills are also held on an arbour and are useful for milling right angled surfaces.

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. ISBN-13: 9780750660730

2.6 Slot Drills And End Mills (Differences Between And Uses Of)

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.

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. ISBN-13: 9780750660730

2.7 Job Planning – Sequencing Of Work Holding To Reduce Unnecessary Removal Of Workpieces

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 using the bandsaw. The sequence of operations should be planned so as to minimise the number of setups in the vice.

2.8 Machining Of Steps And Recesses, Setup Of Workpieces In For Machining Angular Surfaces

When milling a stepped workpiece, it should be first marked out as explained above. The workpiece should be securely locked in a vice and properly seated by tapping it down with a mallet. The steps can be rough machined by machining close to the scribed lines. The digital readout can be used to accurately position the cutter when finish machining the steps.

Angular surfaces can be machined by using one of the following methods: (i) tilt the head of the machine, (ii) tilt the workpiece in a vice and use a bevel protractor to setup the workpiece at the correct angle, (iii) clamp it to an angle plate and use a sine bar to setup the workpiece (iv) use a universal vice by setting the angle to the graduations on the vice and (v) hold the workpiece in a vice and use and angled cutter.

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. ISBN-13: 9780750660730

2.9 Use Of Depth Micrometer

The depth of a slot is measured with a depth micrometer. The depth gauge on the vernier caliper can also be used, but is not as accurate as the depth micrometer.

Ref: Black, Bruce J 2004, *Workshop processes, practices and materials*, 3rd edn, Elsevier Science & Technology, chapter 6, *Milling, Measuring equipment*, p.105. ISBN-13: 9780750660730

3.0 Calculation Of Angular Measurements, Setting Up And Milling Angles

Key Learning Points

Trigonometry: solution of right angled triangles, use of trigonometric tables/calculator.

3.1 Trigonometry: Solution Of Right Angled Triangles, Use Of Trigonometric Tables/Calculator

Trigonometry deals with the ratio between the sides of a right angled triangle and provides a method of calculating unknown sides and angles. Three important trigonometrical ratios are sine, cosine and tangent, usually written as Sin, Cos and Tan.

Ref: Bird, John 2005, *Basic engineering mathematics*, 4th edn, Elsevier Science & Technology, chapter 19, *Introduction to trigonometry*, p.142. ISBN-13: 9780750665759

Summary

Marking out workpieces as per drawing: The surface to be marked out is usually coated in order to show up the scribed lines. The most common coating used is Engineer's Blue. The plates are marked out to the dimensions specified on the drawing with the vernier height gauge, which has a graduated vertical frame and a moveable jaw with a scribing blade attached. For angled lines use the bevel protractor and a scriber. The bevel protractor has a dial face graduated in degrees, with a straight edge that can be swivelled to the required angle and locked in position.

Milling steps and angles as per drawing: When milling a stepped workpiece, it should be first marked out as explained above. The workpiece should be securely locked in a vice and properly seated by tapping it down with a mallet. The steps can be rough machined by machining close to the scribed lines. The digital readout can be used to accurately position the cutter when finish machining the steps. A micrometer and depth micrometer can then be used to measure the steps.

Angular surfaces can be machined by either (i) tilting the head of the machine or (ii) by tilting the workpiece. (i) Tilt the head by loosening the four bolts on the machine head and rotate the head to the required angle by aligning with the graduations on the head. (ii) Tilt the workpiece in the vice by setting it up at the required angle using a bevel protractor. Alternatively use a universal vice by setting the angle to the graduations on the vice.

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.

Calculation of angular measurements: Trigonometry deals with the ratio between the sides of a right angled triangle and provides a method of calculating unknown sides and angles. Three important trigonometrical ratios are sine, cosine and tangent, usually written as Sin, Cos and Tan.

Suggested Exercises

- 1. Coat a block of steel with engineers blue and scribe lines at the following angles with a bevel protractor: 20° 45′, 30° 15′, 40° 30′, 55° 45′ and 70° 15′.
- 2. Machine a block of mild steel with a Ø12mm end mill and determine the surface finish using a surface texture comparator.
- 3. List the four main types of coolant.
- 4. Sketch a *side and face cutter* and explain where it is used.
- 5. Sketch a slot drill and an end mill and explain where each one is used.

Questions

- 1. Why is important to mark out a workpiece prior to machining.
- 2. What equipment is used to mark out a workpiece?
- 3. What are advantages of using coolant when machining.
- 4. List three methods of machining angular surfaces on a vertical milling machine.
- 5. What are side and face cutter is used for?

Answers

- 1. The workpiece should be marked out a prior to milling, as these markings can be used when setting up the workpiece in the vice and as a guide when rough milling the workpiece. When the workpiece has been rough machined, measuring equipment such as the vernier callipers.
- 2. The most common coating used is Engineer's Blue. The plates are marked out to the dimensions specified on the drawing with the vernier height gauge. For angled lines use the bevel protractor and a scriber.
- 3. The advantages of using coolant are higher cutting speeds, longer tool life, better surface finish and better swarf removal.
- 4. Angular surfaces can be machined by using one of the following methods: (i) tilt the head of the machine, (ii) tilt the workpiece in a vice and use a bevel protractor to setup the workpiece at the correct angle, (iii) clamp it to an angle plate and use a sine bar to setup the workpiece (iv) use a universal vice by setting the angle to the graduations on the vice and (v) hold the workpiece in a vice and use and angled cutter.
- 5. The side and face cutters are held on the arbour of a horizontal milling machine and are used for side milling and slotting. These cutters are narrow cylindrical cutters with cutting edges on the periphery and at the sides.

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