Unit 26: Computer Numerical Control of Machine Tools

NQF Level 3: BTEC National

Guided learning hours: 60

Unit abstract

To reduce costs and improve efficiency, machine tools need to be able to work automatically without the intervention of a skilled operator. This unit introduces learners to the principles and use of computer numerical control (CNC) to regulate the operation of machines which cut metal and other types of material.

There are three basic principles to CNC machining. These are: positional control of the cutting tool relative to a workpiece using axes coordinates eg x, y and z; setting of cutting speeds, eg spindle rotation and linear feed rate; and control of other functions such as the application of cutting fluid. To do this a machine tool needs to be loaded with a series of instructions which are acted upon in sequence. These instructions are called programme code and in this unit learners will be shown how to produce a working programme using an industry-standard language.

The unit will consider two aspects of CNC machining. Firstly, learners will investigate machine tools which have an in-built computer system. These are set up by a skilled operator who interprets data taken from an operational plan and converts this into programme code.

Learners will then look at machine tools which are downloaded with code generated by a remote computer system running computer aided design/manufacturing (CAD/CAM) software. The advantage that this type of system has over the stand alone CNC machine is that a full three-dimensional (3D) simulation of the machining process can be carried out before any cutting of material takes place. This is an important aspect of economic manufacture because incorrect machining of a component will result in lost production and additional costs.

The unit has a high practical content and learners are expected to manufacture actual components. Learners will follow the various steps in the CNC process, starting with interpreting the requirements of the drawing and choosing a suitable machining process, correct cutting tools and work holding devices. They will then write and prove a part programme, machine the product and carry out dimensional checking against specification.

The final part of the unit investigates the integration and use of CAD/CAM in the CNC machining process. Learners will be given a drawing file containing details of a component which they will then use to produce a three-dimensional image of the component. Its functionality is confirmed before moving on to the simulation of the machining process using CAM software. Once the machining operation has been proven and any problems corrected, the data needed to control the movements of cutting tools and other machine operations is downloaded from the computer into the machine's control unit. Machining then takes place with the programme data saved for future use.

Learning outcomes

On completion of this unit a learner should:

1 Understand the principles of computer numerical control (CNC) and machine structures

2 Be able to interpret a component specification and produce an operational plan for its manufacture

3 Be able to produce a part programme and manufacture a component

4 Be able to use a CAD/CAM software package to generate a part programme and manufacture a component.

Unit content

1 **Understand the principles of computer numerical control (CNC) and machine structures**

CNC principles: system eg machine control unit, drive mechanisms, tool/workpiece interface, transducers, feedback, correction; datum points eg machine, component; definition of parameters using numerical coding eg position, movement, spindle speeds, cutting tools, clamping, application of coolant; CNC process eg select machine, select tooling, identify machining sequence, calculate positional coordinates, calculate spindle speeds, programming, post-processing, setup sheet, verify and edit, store for future use

Machine structures: types eg milling, drilling, turning centre, machining centre; designation of axes eg 2 axis, 3 axis, x, y, z; motor and drive units eg spindles, stepless drives, ball screw, stepper motors; transducers eg positional, linear, rotary, analogue, digital, optical encoders, inductive, capacitive, magnetic; tooling eg modular, quick change, turret; tool transfer eg automatic, chain magazine, circular magazine; work holding eg pallets, sub tables, rotary work changer, grid plate; swarf removal eg chutes, chip controllers, conveyors; cooling eg cutting fluid, cooling systems; computer hardware eg keypad, display, Central Processing Unit (CPU), storage, cabling links, machine control unit (MCU); computer software eg programming language, CAD/CAM DXF files; safety eg overloading the cutting tool, guards, light barriers, interlocks, operator safety

2 **Be able to interpret a component specification and produce an operational plan for its manufacture**

Component specification: detailed drawing; material eg steel, aluminium, polymer, other stable material; reference points eg edge datum, centre line datum; dimensional eg external, internal, centres distances, bore diameters, tolerances; surface finish eg Ra, Rz values

Operational plan: zero datums; work holding eg clamps, fixtures, chucks, vices, setting points; changing components eg pallets, sub tables, rotary work changer, grid plate; sequence of operations eg loading, machining, roughing and finishing operations, measurement, unloading; calculations eg cutter path coordinates for intersections, polar centres, arc centres, cutter compensation, cutting speeds, feed rates; use of trigonometric ratios eg sine, cosine, tangent; cutter speed (surface speed/π x cutter diameter); feed rate (feed per tooth x no. of teeth x spindle speed); grouping of similar operations; canned cycles eg irregular pockets, geometric, hole patterns; tooling eg cutters, drills, reamers; other reference data eg cutting fluids, special requirements relating to specific materials; inspection eg first off proving against specification, on machine measurement; set up sheet and tool list

3 **Be able to produce a part programme and manufacture a component**

Part programme: user interface eg menu bar, identification line, tool display window, system status; work/tool relationships eg position, direction, amount of movement; rates of change eg feed rates, spindle speeds; auxiliary functions eg metric/imperial units, tool selection, cutting fluids, workpiece loading and holding, tool changing; CNC codes eg block number, preparatory functions (G codes); miscellaneous functions (M codes); other letter addresses (arc centres, spindle speed, feed rate); dimensional information eg axis coordinates (x, y, z), absolute, incremental; words eg modal, non modal; block format eg block number, G code, coordinates; special function G codes eg movement system, measuring system, tool compensation, canned cycles, subroutines; M codes eg coolant, tool change, work holding, spindle speed, spindle direction

Manufacture: post-processing eg transfer of files/data between systems, download programme to machine tool; pre-manufacture eg run through using graphics display on machine tool, prove programme, dry run, load workpiece, stepping, adjust feed rates; run programme eg machine workpiece, first off inspect and check against specification, store verified programme for future use, quality monitor; shutdown

4 **Be able to use a CAD/CAM software package to generate a part programme and manufacture a component**

CAD/CAM package: hardware eg CAD workstation, data storage, hard copy equipment, network system to download data to machine tools; software eg Autodesk Inventor, Esprit, Solid Works, Edge CAM, Denford VR milling/turning; universal formats eg extensions (such as DXF, IGS, AI, EPS, PLT, NC), proprietary formats (such as DWG, CDR, CDL, GE3, NC1, BMP, MSP, PCX, TIF)

Part programme: eg 3D geometric model using CAD software, select machining operations, select tooling, generate CNC programme using CAM software, simulation of tool changing and tool paths in the machining process, correction and editing

Manufacture: post-processing eg transfer of files/data between systems, download programme to machine tool; manufacturing eg load and clamp workpiece, set tooling, initiate programme cycle, machine workpiece, first off inspect and check against specification, store verified programme for future use, quality monitor; shutdown

Grading grid

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all of the learning outcomes for the unit. The criteria for a pass grade describe the level of achievement required to pass this unit.

Grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the principles on which a machine tool operates when controlled by a CNC system P2 describe, with the aid of suitable diagrams, the structure of a given CNC machine type P3 interpret the specification of a given component and produce an operational plan for its manufacture P4 produce a part programme for a given component P5 manufacture a component using a two- or three-axis CNC machine P6 use a CAD/CAM package to produce a part programme from a given component detail drawing P7 manufacture a component on a CNC machine using a post-processed programme generated using CAM software.	M1 explain the importance of producing an accurate and detailed operational plan for a component which is to be manufactured using a CNC machine tool M2 explain the importance of correct programming and setting up in order to produce a component to a required specification.	D1 evaluate the cost benefits of using CAD/CAM software when programming CNC machines D2 compare and contrast the effectiveness of a CAD/CAM method of manufacturing a component to that of using CNC part programming.

Essential guidance for tutors

Delivery

To establish the context of the unit, delivery could begin with a general overview of computer numerical control of machine tools, its use in manufacturing and a brief history of its origins. This could start with first-generation manual machines and how numerical control (NC) systems were added to provide positional control of the workpiece relative to the cutting tool. The point to make here is that the intervention of a skilled operator was needed for the selection of cutting tools, setting of speeds and feed rates, and to adjust the machine for tool wear.

Learners should be introduced to the basic principle of NC which is to achieve positional control by using axes and a coordinate system related to datum points. The main point to emphasis is that although modern machine tools are very complex, requiring powerful computers and software to control them, the basic principle of representing actions using coded numbers still applies.

Learning outcome 1 relates to machine tools in general and much of the background information can probably be supported by the use of videos or industrial visits. Links to *Unit 31: Computer Aided Manufacturing* could be made at this point as common evidence could be gathered during any onsite visits. Care needs to be taken when delivering learning outcome 1 not to go too deeply into the complexity of machine structures — much of the unit content can be taught using a black box approach with perhaps more specific reference being made to just one particular type of machine. There is no requirement to consider machines with more than three axes.

Learning outcomes 2 and 3 are closely linked and might best be delivered as a series of learner-centred activities. It should be noted that learners taking *Unit 31: Computer Aided Manufacturing* are asked to design and generate a part programme for a simple component. However, for this CNC unit they should be working with components which are significantly more complex. To effectively cover learning outcome 2 learners will benefit from being shown examples of operational plans used in industry, provided that they are not overly complex.

Learning outcome 3 is a practical activity and, in preparing for the assignment covering P4 and P5, three or four components would be a suitable number to experiment with. Learners could be given pre-produced operational plans to work from as the emphasis is on part programming and machine operation.

The starting point could be a two-axis exercise involving the manufacture of a simple stepped bar turned on a lathe, followed by something more complex such as that requiring machining on a three-axis mill. This should then lead on to a component which has repeated features such as a number of identical undercuts in a turned bar or a pattern of drilled holes in a flat surface.

There is no specific requirement for learners to have access to a three-axis machine but it will add interest if this facility is available to them.

When delivering learning outcome 4 it should be remembered that some learners will have limited CAD experience and that this unit is not intended to make them experts in the use of CAD/CAM software. It is suggested that learners be given drawings to work from which have been saved as CAD files and can be easily opened up and converted. A suitable number of components to be produced would be two.

It should be noted that in the delivery and assessment of learning outcomes 3 and 4 the types of material to be machined are not specified. There is no requirement to cut metal and centres can use any medium they like provided that the components are sufficiently stable for measurement and inspection purposes.

Note that the use of ‘eg’ in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an ‘eg’ needs to be taught or assessed.

Assessment

This unit could be assessed through the use of five assignments. To achieve a pass grade, learners need to have an understanding of the principles of CNC and be able to manufacture a component. It is not expected that they should be able to programme and set up CNC machines at an expert level and this should be taken into account when designing assignments.

It is suggested that the first assignment covers grading criteria P1 and P2, with learners being asked to produce a written report. Evidence for P1 should be generic and not specific to a particular type of machine. There is a lot of material that learners will have access to and care should be taken to ensure the validity of the evidence they provide.

P2 relates to a given type of machine, details of which should be specified in the assignment brief. Some learners may be working in a CNC environment and if they have specialised knowledge about a particular machine tool they could use this towards their evidence for P2.

Grading criteria P3 and M1 complement each other and can be assessed through a second assignment. The assignment brief covering P3 should provide learners with hard copy information about the component and a detailed drawing presented in printed form to an acceptable industry standard. The brief could also include a pro forma for setting out the operational plan, although learners working in a CNC environment may wish to use their own style of layout. Care should, however, be taken to ensure there are sufficient aspects of an operational plan covered and ranged by the content section for learning outcome 2. It must be remembered that a plan for CNC machining is different to one for traditional machining.

Further evidence in the form of annotated drawings and specification sheets, calculations to support machining decisions such as speeds and feeds and trigonometric ratios to calculate coordinates and intersections will also be needed to support P3. Evidence presented for M1 should make reference to the operational plan produced for P3 but additional evidence drawn from wider sources should be included.

The third assignment could be designed around P4, P5 and M2. It will add realism if the same component is used for both pass criteria. Learners should be given a pre-produced operational plan to work from, although if they wish they could use the one produced for P3, providing it is fit for purpose. The only requirement is that the part programme and manufacturing relate to a single component which is significantly more complex that the one looked at in *Unit 31: Computer Aided Manufacturing*. Three-axis machining would be the preferred option, using something like a vertical milling machine. As the assignment involves a lot of practical work, evidence presented for assessment should include screenshots, witness statements, observation records and annotated digital images.

The fourth assignment could cover P6, P7 and D2. Learners who wish to gather evidence for D2 will probably want to use the component specification provided in the third assignment so that they can contrast the effectiveness of the two methods of programming. The starting point for P6 is a detailed drawing and this should be given to learners as a file which can be opened using CAD/CAM software. With the agreement of the tutor, some learners who are taking the CAD unit may wish to use a component which they have previously drawn but it needs to be in a form which can be easily processed.

Evidence presented for assessment should include screen shots showing tool path simulation, witness statements, observation records and annotated digital images. A written task will need to be given asking learners to compare and contrast the effectiveness of a CAD/CAM method of manufacturing a component to that of using CNC part programming (D2). They will obviously need to identify benefits and limitations of each approach and draw valid supported conclusions. The focus of D2 is very specific and some of the evidence presented could relate to the tasks undertaken to achieve P4, P5, P6 and P7.

When writing about their experiences learners should include an evaluation of their own effectiveness in using the two systems of manufacture. Factors to be considered might include something on how easy it was to learn the software packages, ease of programme editing and the lead times needed to produce the components. Discussions with a manufacturing engineer who works for a company using both systems or which has moved from CNC part programming to an integrated CAD/CAM setup could be used as further evidence.

The fifth assignment could cover D1 and be a piece of detailed evaluative writing supported by evidence gathered from published case studies. Learners should consider the effectiveness of CAD/CAM programming in the wider context and not just concentrate on the components that they have manufactured.

Some of the evidence for D1 could be come from work produced for *Unit 31: Computer Aided Manufacturing* and it may be possible to integrate assignments across units. Because there are well documented examples of the cost benefits achieved by companies who use CAD/CAM software to programme CNC machines, care must be taken to ensure that what the learner presents as evidence is authentic. Use could be made of experience from *Unit 30: Setting and Proving Secondary Processing Machines*, particularly about workholding and machining parameters. Where appropriate, employed learners should be given the option of using examples taken from their own company.

Links to National Occupational Standards, other BTEC units, other BTEC qualifications and other relevant units and qualifications

This unit links to *Unit 17: Computer Aided Drafting*, *Unit 30: Setting and Proving Secondary Processing Machines* and *Unit 31: Computer Aided Manufacturing*.

This unit covers some of the knowledge and understanding associated with the SEMTA Level 3 National Occupational Standards in Engineering Technical Support, particularly:

- Unit 29: Providing Operational Support for Computer Control Programmes
- Unit 30: Loading and Proving Computer Control Programmes
- Unit 36: Producing Off-line Programs for NC/CNC Turning Machines
- Unit 37: Producing Off-line Programmes for NC/CNC Milling Machines
- Unit 38: Producing Off-line Programmes for NC/CNC Grinding Machines
- Unit 42: Producing Off-line programmes for NC/CNC Machining Centres.

This unit also covers some of the knowledge and understanding associated with the SEMTA Level 3 National Occupational Standards in Mechanical Manufacturing Engineering, particularly:

- Unit 30: Loading and Proving NC/CNC Machine Tool Programmes
- Unit 31: Carrying out CNC Machine Tool Programming
- Unit 32: Setting NC/CNC Turning Machines for Production
- Unit 33: Machining Components using NC/CNC Turning Machines
- Unit 34: Setting NC/CNC Milling Machines for Production
- Unit 35: Machining Components using NC/CNC Milling Machines
- Unit 36: Setting NC/CNC Grinding Machines for Production
- Unit 37: Machining Components using NC/CNC Grinding Machines
- Unit 50: Setting Machining Centres for Production
- Unit 51: Machining Components using NC/CVC Machining Centres.

Essential resources

In order to deliver this unit centres will need to have 2D/3D commercial CAD software and CAM software that integrates with the CAD package used for designing. They will also need to have access to a two- or three-axis CNC machine tool and a two- or three-axis machine tool which can be downloaded with data from a computer system.

Indicative reading for learners

Textbooks

Evans K, Polywka J and Gabrel S — *Programming of CNC Machines* (Industrial Press, 2001) ISBN 0831131292

Nanfara F, Uccello T and Murphy D — *The CNC Workshop* (Schroff Development Corporation, 2000) ISBN 158503083X

Timings R L — *Basic Manufacturing* (Newnes, 2004) ISBN 0750659904

Key skills

Achievement of key skills is not a requirement of this qualification but it is encouraged. Suggestions of opportunities for the generation of Level 3 key skill evidence are given here. Staff should check that learners have produced all the evidence required by part B of the key skills specifications when assessing this evidence. Learners may need to develop additional evidence elsewhere to fully meet the requirements of the key skills specifications.

Application of number Level 3		
When learners are:	**They should be able to develop the following key skills evidence:**	
• interpreting the specification of a given component and producing an operational plan for its manufacture • producing a part programme for a given component.	N3.1	Plan an activity and get relevant information from relevant sources.
Communication Level 3		
When learners are:	**They should be able to develop the following key skills evidence:**	
• describing the principles a machine tool operates on when controlled by a CNC system • describing, with the aid of suitable diagrams, the structure of a given CNC machine type.	C3.3	Write **two** different types of documents each one giving different information about complex subjects. One document must be at least 1000 words long.
Information communication technology Level 3		
When learners are:	**They should be able to develop the following key skills evidence:**	
• producing a part programme for a given component.	ICT3.2	Enter and develop the information and derive new information.

Problem solving Level 3	
When learners are:	**They should be able to develop the following key skills evidence:**
• interpreting the specification of a given component and producing an operational plan for its manufacture • manufacturing a component using two- or three-axis CNC machines.	PS3.2 Plan and implement at least one way of solving the problem. PS3.3 Check if the problem has been solved and review your approach to problem solving.