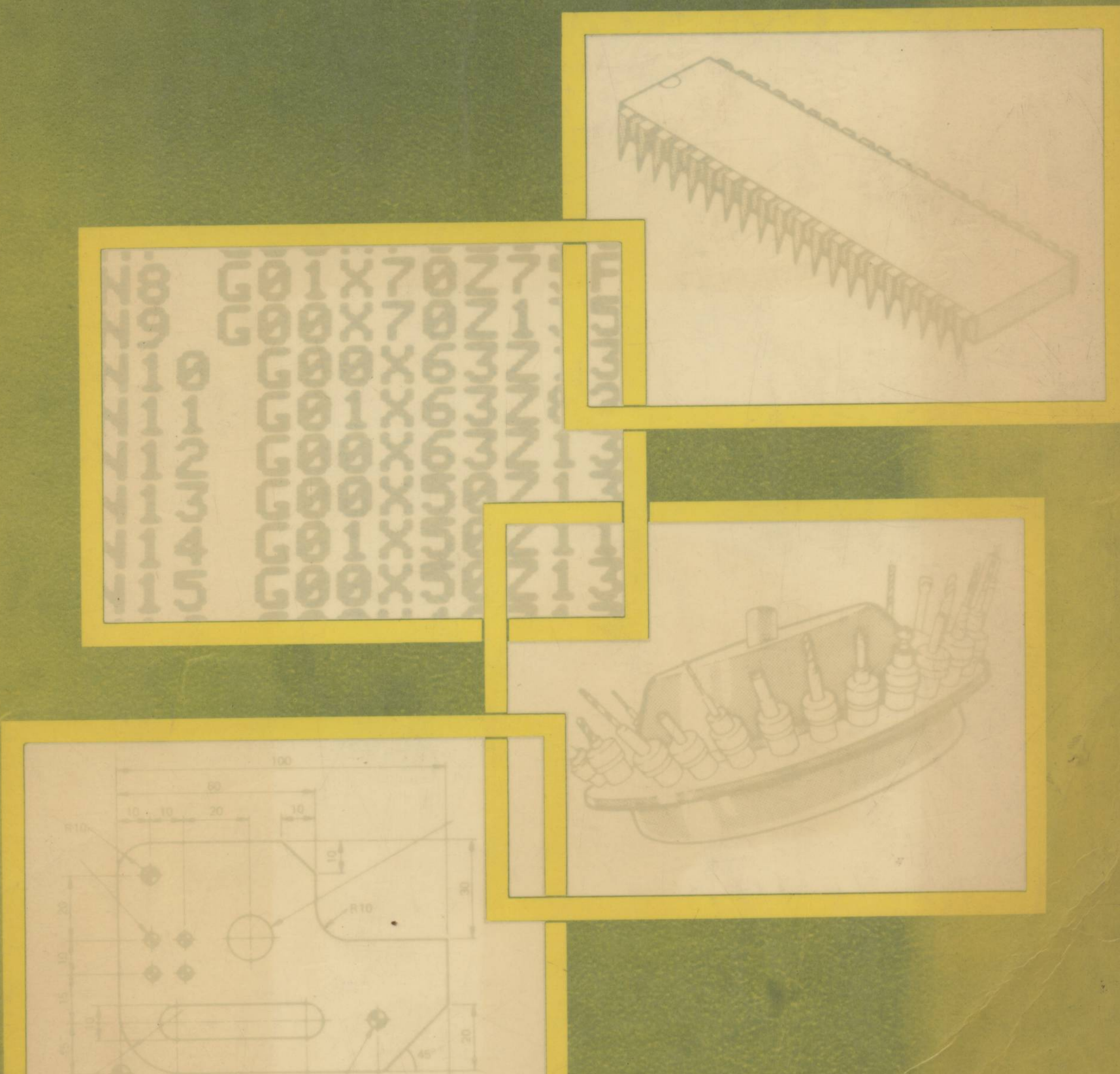
Introduction to

COMPUTER NUMERICAL CONTROL



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Introduction to Computer Numerical Control

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Preface

The marriage of computer technology and traditional machining disciplines has given birth to revolutionary new machine tools. CNC turning and machining centres are now capable of doing the work of three or four conventional machine tools at a single setting. Exciting new concepts in the organisation of production are creating production facilities that can adapt to batch or one-off manufacturing operations with comparative ease and the minimum of human intervention.

The inevitable demand for skilled personnel to respond to the challenges of this computerised manufacturing technology is now gathering momentum. Dedicated college courses are being established, and company training policies are being re-formulated to reflect the importance now attached to these emerging technologies.

This book has been written to offer a comprehensive introduction to Computer Numerical Control to those readers wishing to learn the fundamentals of CNC as applied to metal cutting machine tools. It is envisaged that such readers will be:

- Students of engineering being introduced to CNC for the first time through vocational or short college-based courses.
- Established engineers wishing to update their knowledge of CNC technology.
- Busy engineering managers who wish to gain an insight into how CNC operates in the manufacturing environment.

Since CNC is not an end in itself, I have attempted, throughout the book, to discuss the subject within a context of manufacturing that emerges from the use of conventional machine tools through stand-alone CNC machine tools to the modern concepts of an integrated, unmanned manufacturing environment.

The text covers fully the syllabus content of established courses in CNC, at both advanced craft and introductory technician levels. In support of these study areas, related questions appear at the end of each chapter and a number of programming examples are included.

In writing this book I am indebted to the various people and organisations that have responded so willingly to my requests for photographs to appear within the text.

The book was produced using a BBC microcomputer and the View word processor. I should like to express my sincere thanks to Epson UK Ltd. for supporting the project by so generously providing an Epson RX-100 printer on which the manuscript was prepared. All the part programming segments within the text are reproduced directly from the output of this printer.

Last, but by no means least, I must thank my wife Helen and my daughter Laura for their infinite patience and caring support during the preparation of the book.

S. B. Leatham-Jones
Hoghton 1985

To **Laura** . . . for whom all things are possible

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Economic considerations 1

1.1 NC and CNC explained

1.1/0 What is numerical control?

Numerical Control (NC) is the technique of giving instructions to a machine in the form of a code which consists of numbers, letters of the alphabet, punctuation marks and certain other symbols. The machine responds to this coded information in a precise and ordered manner to carry out various machining functions. These functions may range from the positioning of the machine spindle relative to the workpiece (the most important function), to controlling the speed and direction of spindle rotation, tool selection, on/off control of coolant flow, and so on.

Instructions are supplied to the machine as **blocks** of information. A block of information is a group of commands sufficient to enable the machine to carry out one individual machining operation. For example, a block of information may command the machine to move the worktable to a specific coordinate position under rapid traverse, or set speed and feed values to carry out the machining of contours. Each block is given a **sequence number** for identification. The blocks are then executed in strict numerical order.

A set of instructions forms an **NC program**. When the instructions are organised in a logical manner they direct the machine tool to carry out a specific task—usually the complete machining of a workpiece or "part". It is thus termed a **part program**. Such a part program may be utilised, at a later date, to produce identical results over and over again.

1.1/1 NC machine tools

Automatic control of NC machine tools relies on the presence of the part program in a form that is external to the machine itself. The NC machine does not possess any "memory" of its own and as such is only capable of executing a single block of information, fed to it, at a time. For this reason part programs are normally produced, and stored, on punched tape.

To machine a part automatically, the **machine control unit** (MCU) will read a block of information, then execute that block, read the next block of information and execute that block, and so on. With the punched tape installed it is also possible to "single step" a part program by instructing the machine tool to pause after the execution of each block. This is semi-automatic operation. It is also possible to enter data manually, by setting dials and switches, at the machine console. After each setting the machine will carry out the instruction and wait for the next setting. Thus, it is also possible to effect control by **manual data input** (MDI).

Since a part cannot be produced automatically without the tape being run through the machine block by block, they are often referred to as *tape-controlled machines*. The production of repetitive, identical parts thus relies on

a) the tape being present
b) the tape being in good condition.

Any number of identical parts being produced thus imposes harsh operating conditions on the punched tape and subsequent wear, especially of the feed holes used to transport the tape through the tape reader, is likely.

The features of early NC control systems, including any required options, had to be specified before purchase since, in most cases, they had to be built in as part of the hardware. They were known as *hardwired controllers*. It was difficult to add extra features at a later date and this made NC installations bulky and expensive. Since updating or upgrading was difficult, many NC machines soon became outdated and obsolete.

1.1/2 What is computer numerical control?

Computer Numerical Control (CNC) retains the fundamental concepts of NC but utilises a dedicated **stored-program computer** within the machine control unit. CNC is largely the result of technological progress in microelectronics (the miniaturisation of electronic components and circuitry), rather than any radical departure in the concept of NC.

CNC attempts to accomplish as many of the MCU functions as possible within the computer **software** which is programmed into the computerised control unit. This greatly simplifies the CNC hardware, significantly lowers purchase costs, and improves reliability and maintainability.

Updates and upgrades are relatively simple. In many cases it is only the stored **operating program** that needs to be modified. The main operating program is stored within the CNC control unit on a special memory chip. Any updates in the control system can be accomplished by replacing the chip with one containing the updated software. The memory chip removed can then be re-programmed with the current operating program. Any *circuit* modifications can be carried out with ease by simply replacing, or adding, components housed on a **printed circuit board** (PCB). Indeed, many modern electronic systems (from simple TV sets to sophisticated computer systems) are increasingly being constructed on a plug-in basis of electronic cards.

Modern CNC machines are thus tools with both current and future value. Obsolescence is, as far as possible, designed out.

CNC control units, like the computers on which they are based, operate according to a *stored program* held in *computer memory*. This means that part programs are now able to become totally resident within the memory of the control unit, prior to their execution. No longer do the machines have to operate on the "read-block/execute-block" principle. This eliminates the dependency on slow, and often unreliable, tapes and tape reading devices—probably the weakest link in the chain. Programs can, of course, still be loaded into the CNC machine via punched tape, but only one pass is necessary to read the complete part program into the memory of the control unit.

1.1/3 CNC machine tools

Many CNC machine tools still retain many of the constructional and physical design aspects of their NC counterparts. However, many new control features are made available on CNC machines, which were impossible, uneconomical or impractical to implement on early NC machines. Such new features include:

a) **Stored Programs** Part programs may be stored in the memory of the machine. The CNC can then operate directly from this memory, over and over again. Use of the tape reader (and its unreliability) is virtually eliminated. For long production runs the part program may be retained in memory, even when the power is removed (say at the end of a shift or at a weekend), by the use of *battery back-up* facilities that keep only the memory supplied with power. Often, more than one program may be resident in the control unit memory at one time with the ability to switch between them.
b) **Editing Facilities** Editing can be carried out on the part program held in memory. Thus, errors, updates, and improvements can be attended to at the machine. Such edits are stored in computer memory and override the tape information as read in. A new, and corrected, tape may then be punched directly from the CNC control unit. This ensures that the most up-to-date version of the part program is retained as current.
c) **Stored Patterns** Common routines such as holes on a pitch circle, pocketing sequences, drilling and tapping cycles can be built in and retrieved many times. There is facility for user-defined sequences (such as roughing cycles, start-up routines, etc.) to be stored and retrieved in the same way. Only certain parameters have to be specified and the computer control will carry out the necessary calculations and subsequent actions.
d) **Sub-programs** For repetitive machining sequences, sub-programs may be defined once and then be repeatedly called and executed as required. This considerably shortens part programs by eliminating the need to repeat sections of identical program code. For example, it may be required to machine the same set of holes but at a different position within the workpiece.
e) **Enhanced Cutter Compensation** When a part program is written, it is normally done with a particular type and size of cutter in mind. The positioning of the cutter relative to the workpiece will need to take account of the dimensions of the cutter. It may be the case that, when the part program comes to be run on the machine, the particular cutter specified is not available. CNC control units allow "compensations" and "offsets" to be made for the differences in dimensions between the actual cutter and the specified cutter. Thus, the part program is now independent of the cutter specified when writing the program. This facility can also be brought into play in the case of tool breakage during the machining cycle, where different cutters may have to be reloaded to continue the machining sequence.

f) **Optimised Machining Conditions** The extremely fast response of computer technology, coupled with sophisticated calculation ability, enables machining conditions to be constantly monitored by the control unit. Spindle speed on a CNC lathe, for example, can be perfectly matched (and adjusted automatically) as the depth of cut varies. It is common to witness the spindle speed increase when a facing cut is taken from the outside diameter of a bar to its centre. Feed rate can be optimised by monitoring power consumed.

g) **Communications Facilities** The utilisation of computer technology within the CNC control unit offers the advantage of being able to communicate with other computer-based systems. Part programs may thus be downloaded from other host computers. Such host computers may be simple databases of different part programs, or sophisticated computer aided design systems.

h) **Program Proving Facilities** Many modern control systems contain software that will process the resident part program information and indicate the component shape that will be produced before machining takes place. This is often displayed graphically on a visual display unit (VDU) on the operating console.

i) **Diagnostics** Most modern CNC machines come equipped with comprehensive diagnostic software for the self-checking of its electronic operation. For example, there might be a diagnostic routine to check the operation of the memory chips. It would write a known test pattern into memory and then read it out again, checking it for validity. Any discrepancy could indicate a memory fault.

j) **Management Information** Since the CNC system controls nearly all functions from the resident computer, much useful information on machine utilisation can be accessed, i.e., spindle-on time, part run time, downtime, etc., can be logged and output to other computer systems or peripheral devices for subsequent reading and analysis.

In addition, many modern CNC machine tools are now capable of automatic tool changing without manual intervention. A number of standard (and/or specialised) cutting tools may be loaded into a rotating turret or carousel, and called up under the control of the part program.

1.2 Industrial applications of CNC

1.2/0 Machining

Undoubtedly the biggest application area for CNC control, at present, is in the field of machining. Indeed, it was the response to a machining problem that originally gave birth to the first CNC machine.

(A three-motion NC milling machine was successfully demonstrated at the Massachusetts Institute of Technology in 1952. It was developed as a result of problems encountered with the complex machining of curved aircraft components, to close accuracies, on a repeatable basis.)

So great is the influence of CNC in this area that revolutionary new machine tools are being developed to harness its potential. Machines such as Turning Centres or Machining Centres, which can accomplish a wide variety of machining operations at a single setting, are now commonplace. Furthermore, the development of these machine tools is realising exciting new concepts in the way in which production itself is being organised. Machining Cells, Flexible Manufacturing Systems, Integrated Manufacturing are all current developments that have been spawned by the wide influence of CNC.

A typical CNC machining centre is shown in Fig. 1/1 and a CNC turning centre is shown in Fig. 1/2.

CNC control is also being applied to the more specialised techniques of metal removal, such as grinding and electro-discharge machining (EDM).

1.2/1 Fabrication and welding

Close behind machining activities are applications in fabrication and welding. Since CNC is basically a machine control, and not a machining control, it matters little what the machine is.

For example, by substituting an oxy-acetylene, plasma, or laser cutting head for the machine tool spindle, the result can be an extremely versatile and productive means of *cutting* plate material. Replacing the cutting head with a *welding* torch enables CNC fabrication to be achieved. It must be conceded, however, that robotic welding techniques probably represent an even more versatile option in pure welding applications.

Folding and *shearing* machinery represent other application areas for CNC control in the fabrication field. CNC *bending* equipment in pipe and tube applications is making a significant impact in areas such as car exhaust pipe manufacture. A variety of complex bending patterns can be reproduced quickly and accurately making optimum use of material.

1.2/2 Presswork

In parallel with, and in support of, developments in CNC fabrication and welding applications, piercing, notching and nibbling applications have now developed under CNC control.

Blanking and *piercing* are operations carried out on sheet material whereby a suitably shaped punch is pressed through the material under heavy, and often impact, loads. In piercing, the piece of material punched out is scrap, and it is the component that is left.

Nibbling and *notching* consist of a reciprocating punch that repeatedly "nibbles" away at the material being fed underneath it. These processes are utilised where holes, or edge contours of a complex shape, are required within sheet material and the production of a suitably shaped punch would be technically or economically impractical.

Punching apertures and hole patterns is an ideal application for CNC control. It basically only requires precise positioning in two (X and Y) axes. The ability to punch shapes ranging from the most simple to the very complex, utilising just simple standard punches, is very attractive from a production engineering standpoint. Press speeds in excess of 100 hits per minute are common. Where a range of punch options is required, automatic punch changing can be provided. Tool turrets comprising 36 punch stations are common. Integral slug conveyors, running continuously, provide an efficient means of removing the punched slugs without interfering with the press operation.

In many cases the computer can also be utilised to produce optimum "nesting" patterns for components being blanked from sheet material. *Nesting*

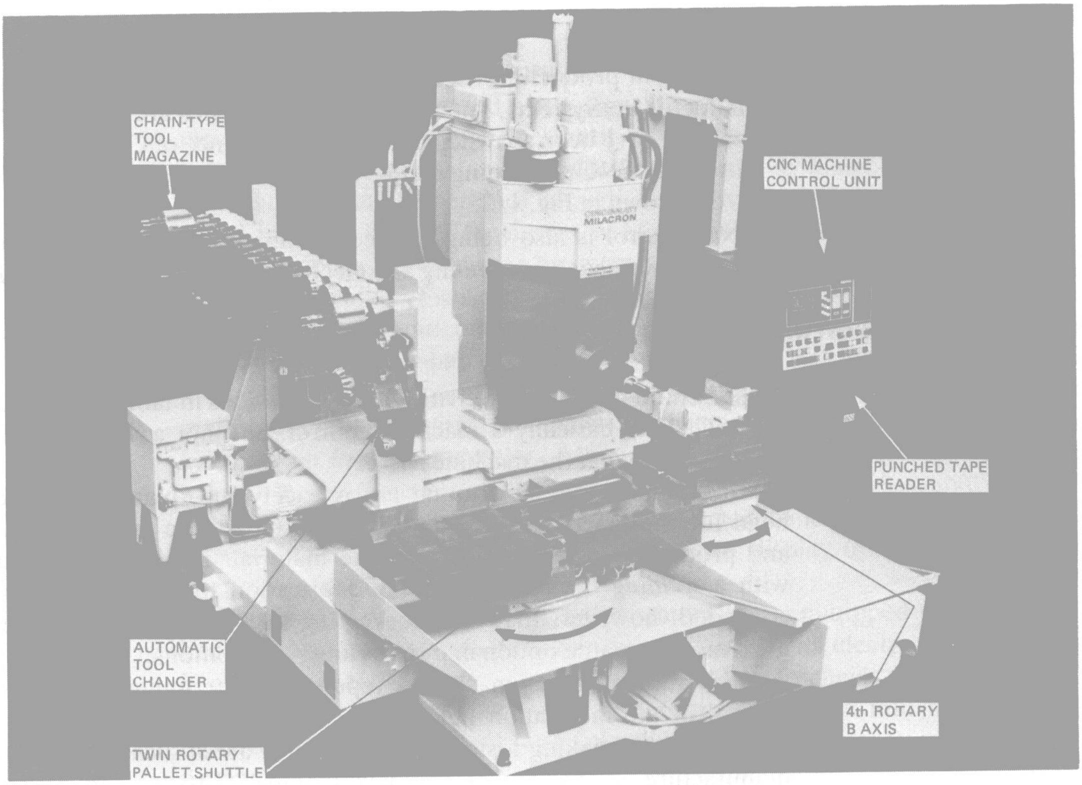

Fig. 1/1 A Machining Centre [*Cincinnati Milacron*]

Fig. 1/2 A Turning Centre [*Cincinnati Milacron*]