Computer Numerically Controlled Machine CNC932 – Volume 2 CNC Machining

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On the other hand students may be less distracted if all that appears on their working disc is their own output, in which case a separate write-protected disc with a copy of the software is appropriate, and students will also require a spare disc for saving their workpiece-programs. This should be formatted in accordance with the computer maker's instructions, but not write protected.

The manual envisages these possibilities, but students may need local guidance on exactly what they are expected to do.

Discs and disc drives should be protected as effectively as possible from dust and swarf generated by the machine, since they can destroy both discs and the drive. Careful siting and the provision of adequate storage for discs are essential.

The Appendix gives more details about the nature and operation of the software.

Printer

A printer provides the facility to record part-programs on paper, using the LIST command. This is not a necessity, but will be convenient for instructors who wish to mark their student's work and can provide students with a record for future reference. The printer can of course be used with any other applications of the computer also if required.

It should be of the type normally used with the computer. For the BBC computer this is a parallel-data printer. For the Apple computer either serial or parallel types may be used, but the appropriate Apple-to-printer interface must be provided.

See also the Appendix for details of interactions between software and printer.

Milling capability

This machine is not intended for any but light milling, using small cutters on selected materials. An especially suitable material is Toysteel, obtainable in the UK from Denford Machine Tools Limited, Birds Royd, Brighouse, HD6 1NM, West Yorkshire. Machinable wax is another suitable material, obtainable from Portisle Limited, 8 Charman's Close, Horsham, West Sussex.

EXERCISES CHAPTER 3

EXERCISE 1 INTRODUCTION TO COMPUTER CONTROL

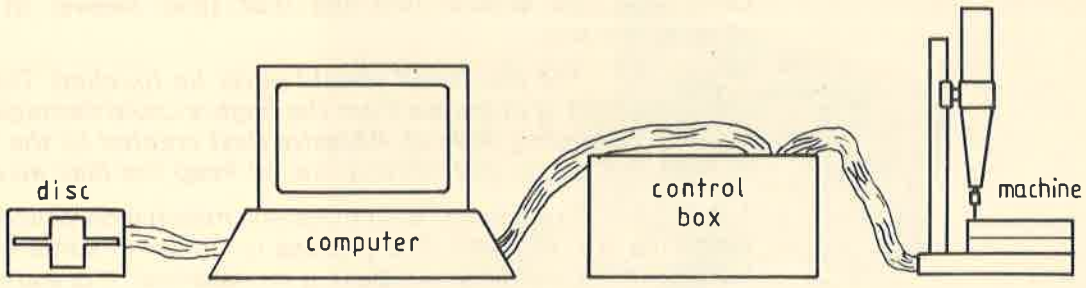


Fig 1.1

Introduction

Fig 1.1 shows the communication path between you and the machine. You can communicate with the computer by means of its keyboard and display screen. It communicates with the control box via a cable. Finally the control box translates the computer's signals into power to drive the machine's motors.

(The machine also sends data back the other way, but that will come later).

No computer can do anything useful unless it has been told what to do. It needs lots of instructions, and the complete list of them is called a 'program'. The computer programs you need have been recorded on a special sort of disc that the computer can read quickly. (Workshop CNC systems usually have the program 'built in', so that you do not have to worry about it).

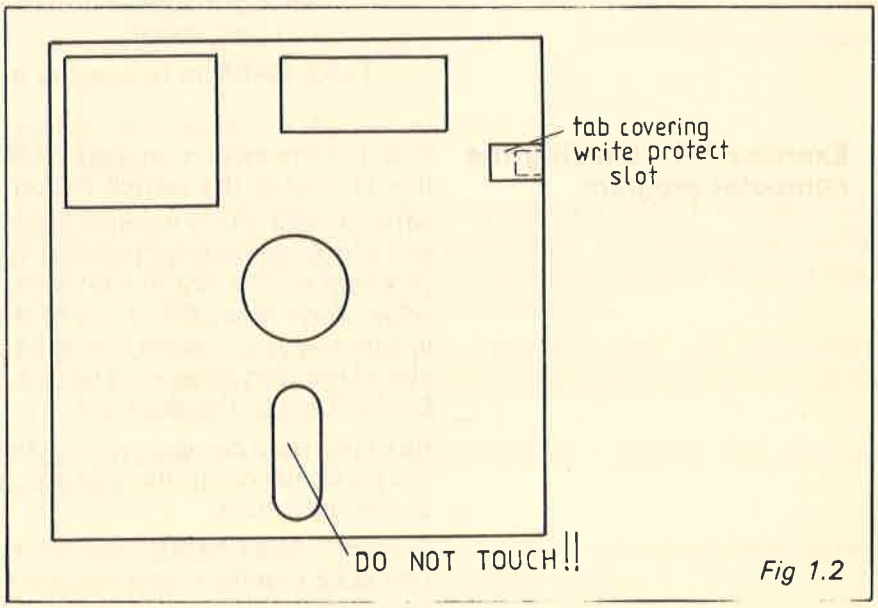


Fig 1.2

Preparation

Your instructor may have provided special instructions to get you started. If so follow them, but if not carry on as follows. Find the program disc, but do not touch it until told. It is permanently contained in a square sleeve about 130mm square, Fig 1.2, with a label stuck on (saying 'CNC COPY MASTER' or similar). Usually the expression 'disc' refers to the assembly of the disc itself and its permanent sleeve.

However virtually all the work covered by this volume deals with motion *of the cutter relative to the workpiece.* All references to motion should be understood in this way unless stated otherwise. We shall therefore ignore the distinction between X and X', Y and Y' from here on.

If the clamps on the machine's table are present, remove each in turn by sliding it to the hole at the centre of the slot and lifting it out.

Switch on the machine's drill motor (press 'I'). If it moves or makes a noise, switch off again, and repeat Exercise 1.1. The system should be quiet, with no lamps on except the green 'power on' lamp and possibly the X or Y limit lamps.

If all is well, try pressing the 'R' key. The machine will move and lights on the control box will show the signals being sent, first to the X drive motor and then to the Y drive motor. If 'R' is pressed again, the machine will make a small movement in X and Y, and come back to the same place as before. It is said to have been 'reset to datum'. Datum is the standard position from which movements are measured.

Next press the X key briefly. The machine will move 1 mm in the X direction. Notice that the movement is recorded under the letter X on the screen.

Try pressing the X key several times, rapidly. Notice that the computer stores up X signals and goes on driving the machine after you release the key. The same effect happens on some computers if you simply hold the X key down for a while. You must be careful not to lose control of the machine in this way.

Type '−' and then use the X key as before. The machine will move in the opposite direction.

Type '+' and then try the same experiment using the Y key instead of X. The table moves in the direction at right angles to the X direction.

Try + and − motions in the Z direction.

The D command can switch the spindle (drill) on and off. Take special care when the spindle is running. (It is not possible actually to do any drilling at this stage, because we have insufficient control of the machine in this exercise).

Finally reset the machine to datum by the R command.

A program is a series of 'blocks' each showing a set of functions and/or co-ordinates. We shall write the contents of one block in a single line. A typical example is

Fig 2.1

N	G	F	M	X	Y	Z	I	J
1	00	-	-	60	30	-	-	-
2	-	-	02	-	-	-	-	-

N is simply a serial number for the line.

Entering a block

Type ENTER. This command is used to enter a new program. You want to do this, so answer the question by typing Y.

Again a menu of possibilities, fig 2.2 is displayed, related to several of the letters appearing in fig 2.1.

```
YOU MAY ENTER THE FOLLOWING FUNCTIONS:-

G 00 POINT TO POINT POSITIONING
G 01 LINEAR INTERPOLATION
G 02 CLOCKWISE CIRCULAR INTERPOLATION
G 03 ANTI-CLOCKWISE CIRCULAR INTERPOLATION
G 05 HOLD
G 12 CLOCKWISE HOLE MILLING
G 13 ANTI-CLOCKWISE HOLE MILLING
G 25 JUMP TO BLOCK NUMBER
G 53 RESET CHANGE OF REF. POINT
G 58 CHANGE OF DATUM
G 80 CANCEL FIXED DRILLING CYCLE
G 81 FIXED DRILLING CYCLE
M 00 PROGRAM STOP
M 02 END OF PROGRAM, RETURN TO DATUM
M 03 SPINDLE MOTOR ON
M 05 SPINDLE MOTOR OFF

TYPE Y TO CONTINUE  (brings up the next page)

  F _ FEEDRATE MAY HAVE THE FOLLOWING
      VALUES ONLY:

      1, 2, 3 AND 4 MM/SECOND

THE X AND Y CO-ORDINATES ARE SPECIFIED
WITH RESPECT TO THE MACHINE DATUM.

THE Z ORDINATE IS SPECIFIED FROM
THE POINT THE CUTTER IS AT PRIOR
TO RUNNING THE MACHINE, HENCE Z CAN
HAVE POSITIVE OR NEGATIVE VALUES.
```

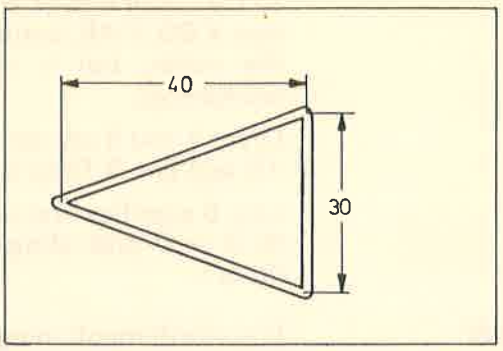


Fig 2.3

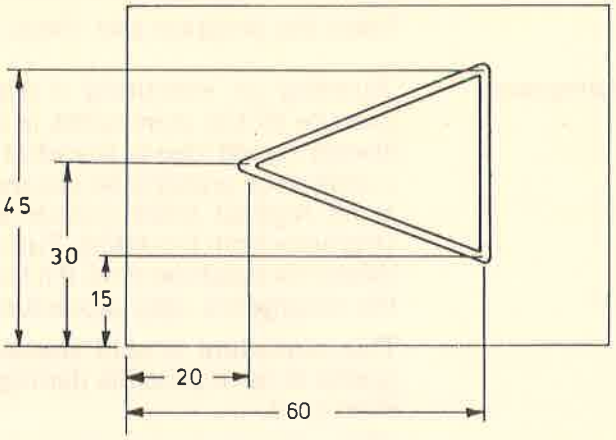


Fig 2.4

N	G	F	M	X	Y	Z	I	J
1	00	–	–	20	30	–	–	–
2	01	2	03	–	–	–6	–	–
3	–	4	–	60	45	–	–	–
4	–	–	–	–	15	–	–	–
5	–	–	–	20	30	–	–	–
6	–	–	02	–	–	–	–	–

Fig 2.5

Let us consider what each line does.

Line 1 is simple positioning as in the previous example

Line 2 uses the G 01 function, linear interpolation. Since Z is the only co-ordinate which has changed, from 0 to –6, the cutter moves downwards, the negative direction. (If 6 had been entered it would have tried to move upwards). The downward feedrate is set by F = 2, so the cutter descends at 2mm/second into the material to start the cut. At the same time setting M = 03 switches on the spindle motor (in the cutter head); a complementary function M = 05 will stop the spindle, but is often not needed because this happens automatically at the end of a program.

To check it, first alter your program by using EDIT to convert the first line to M = 02. If you then select LOAD from the main menu, you will again have a chance to see what is on the disc, after which you will be asked for the program name. Type it (exactly). The program should then be loaded.

To check that your program is now loaded, you could use EDIT again.

G 02 Clockwise circular interpolation

One of the powerful features of CNC machines is their ability to describe circles and circular arcs. Suppose we modify the design of the previous workpiece to that of fig 2.6.

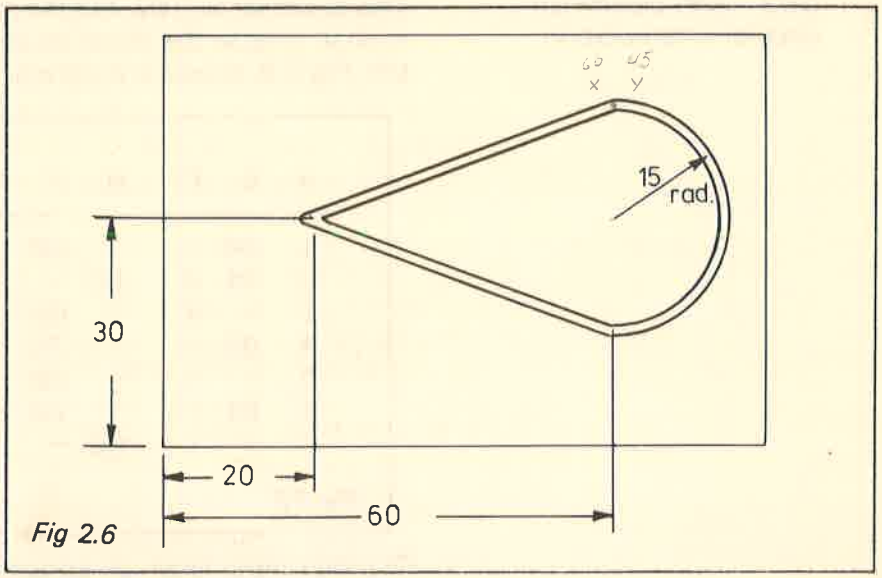


Fig 2.6

Remember that in the program all X,Y & Z dimensions are specified in relation to the reference point. A program to produce this item might look like fig 2.7.

N	G	F	M	X	Y	Z	I	J
1	00	-	-	20	30	-	-	-
2	01	2	03	-	-	-6	-	-
3	-	4	-	60	45	-	-	-
4	02	-	-	75	30	-	0	-15
5	-	-	-	60	15	-	-15	0
6	01	-	-	20	30	-	-	-
7	-	-	02	-	-	-	-	-

Fig 2.7

Lines 1 to 3 are the same as in the previous example.

Line 4 calls G 02, clockwise circular interpolation. The G 02 and G 03 functions both require values I and J to be specified. These specify the position of the centre of the circular arc *relative to the cutter* position at the start of the cut (and are not absolute co-ordinates like X, Y and Z). Thus line 3 brought the cutter to X 60, Y 45. From here the centre of the arc is at the same X value, so in line 4 the difference I is 0. The centre of the arc is at Y = 45-15, so J is -15.

Line 5 is like line 4, except that the cutter is now at the point P, from which the distance to the circular centre is I = −15 for the X-component and J = 0 for the Y-component.

Lines 6 and 7 are the same as the last two lines of the previous example.

We can use the right-angled triangle BDC. Its hypotenuse is the radius R. CD is 5mm. Calculation of the remaining side BD is straightforward in this case, using Pythagoras' Theorem.

From Pythagoras, $CB^2 = CD^2 + DB^2$

$$\therefore DB^2 = CB^2 - CD^2$$

$$\therefore DB = \sqrt{CB^2 - CD^2}$$

Inserting millimetre dimensions,

$$DB = \sqrt{10^2 - 5^2}$$
$$= \sqrt{100 - 25}$$
$$= \sqrt{75}$$
$$= 8.66 \text{ approximately.}$$

The value of Y for point B is this amount greater than that for point C, i.e it is

$$Y = 20 + 8.66$$
$$= 28.7$$

after rounding to the nearest figure recognised by the machine (nearest 0.1 mm).

In other cases trigonometry may be required for calculations. Even in this simple case those practised in the use of some modern calculators could use the simple relationships shown in fig 2.11 to do the calculataion more quickly.

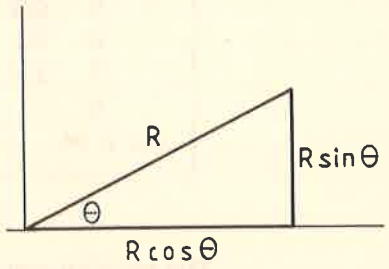


Fig 2.11

N	G	F	M	X	Y	Z	I	J
1	00	-	-	10	10	-	-	-
2	01	2	03	-	-	-6	-	-
3	-	4	-	-	30	-	-	-
4	-	-	-	20	-	-	-	-
5	02	-	-	25	28.7	-	0	-10
6	01	-	-	-	10	-	-	-
7	-	-	-	10	-	-	-	-
8	-	-	02	-	-	-	-	-

Fig 2.12

However in this simple case, not even the simplest trigonometry is needed, since DB can be calculated by Pythagoras' rule.

By now you know how to test-run a program and then use it. It will be assumed that your instructor has given guidelines on how many workpieces you are actually to cut.

G 25 Jump to Block No. (Loop)

If there is some task in your program that must be executed several times, it is possible to go back to an earlier point in the program and repeat it using the G 25 function. G 25 obviously needs to be told where to go back to. The value of J supplies this. It also needs some further information to prevent it looping back every time the G 25 is reached for ever. I specifies the number of times the program is to jump back.

The most common use of G 25 is in conjunction with G 58, so we will look at that before giving an example.

G 58 Change of Reference Point

If the reference point were changed before executing a program, the shape produced by it would appear in a different place. Suppose that the shape in fig 2.2 (the second program) were to be milled several times in different parts of a workpiece. It would be possible to write out several copies of the program with the X and Y values altered accordingly, but a simpler way is provided by using just one copy several times and changing the reference point instead.

G 58 shifts the reference point in X, Y and Z by specified amounts. (A specification is required for each of them; '–' will not do).

To demonstrate its use let us cut two triangles like fig 2.2 with the program of fig 2.15.

N	G	F	M	X	Y	Z	I	J
1	00	–	–	20	30	–	–	–
2	01	2	03	–	–	-6	–	–
3	–	4	–	60	45	–	–	–
4	–	–	–	–	15	–	–	–
5	–	–	–	20	30	–	–	–
6	–	–	–	–	–	0	–	–
7	58	–	–	0	40	0	–	–
8	25	–	–	–	–	–	1	1
9	–	–	02	–	–	–	–	–

Fig 2.15

The first five lines are like the original triangle program. (If you SAVEd that program earlier you could save typing by LOADing it now).

Line 6 has had the M 02 instruction removed and G 01 added to take the cutter out of the workpiece.

Line 7 changes the reference point by 40mm in the Y direction. Notice that all three of X, Y and Z are specified by numbers, which can be zero or negative but not '–'.

Line 8 causes the program to loop back to line 1 (the J value). It does this only once (specified by the I value).

Line 9 which ends the program resets the machine to its fixed reference point or datum.

A common use of G 58 and G 25 is to take several passes at a cut with increasing depth, by changing the reference in Z and looping back.

G 53 Cancel a change of reference point

This function may only be used after G 58 has been used once, and cancels the effect of the G 58. If G 58 has been used several times, the reference should be reset by another G 58 with X, Y, Z values the negative of the total previous change.

G 05 Hold

This function causes the machine to wait (in the state it reached at the previous block) until the operator presses the G key. It then executes the block following the G 05 block. During the wait period no feed motion takes place, but the spindle will go on rotating if it was rotating before (and in a real machine coolant and other functions would be unaffected).

M 00 Program stop

This function causes the program and the machine itself to stop after execution of the remainder of the block. This may be required to enable a tool change or for any other reason. Execution of the next block of the program continues after the operator presses the G key.

The difference between G 05 and M 00 is demonstrated in the very simple program of fig 2.18. The machine will wait after executing block 1 with the spindle running, and at the end of block 3 will wait again, but this time with the spindle stopped.

N	G	F	M	X	Y	Z	I	J
1	00	–	03	10	20	–	–	–
2	05	–	–	–	–	–	–	–
3	00	–	00	20	–	–	–	–
4	–	–	03	–	–	–	–	–
5	–	–	02	–	–	–	–	–

Fig 2.18

It is good practice (especially in systems using stepping motors or other devices which rely on counting rather than absolute measurement) to end the program with a programmed return to X = 0, Y = 0, Z = 0, followed by G 05, before the final M 02. Then if there is any doubt about the accuracy with which the machine has performed, a check (perhaps with dial gauges) can be performed before and after the reset to datum caused by the end of program (M 02).

Other G functions

The full list of standard functions should be looked up in a standards document, (e.g BS 3635 Part 1 in UK, or equivalent EIA, DIN and ISO R/-series standards). However a few examples are given below to give an idea of some of the functions covered.

Examples

G 13 to 16	Axis selection (for equipment using common equipment to control several axes).
G 08, 09	Control acceleration and deceleration.
G 22, 23	Coupled motion (e.g two axes coupled by engaging gears).
G 33 to 35	Thread cutting functions.
G 40 to 52	Various cutter radius compensation functions.

Other miscellaneous functions (examples only)

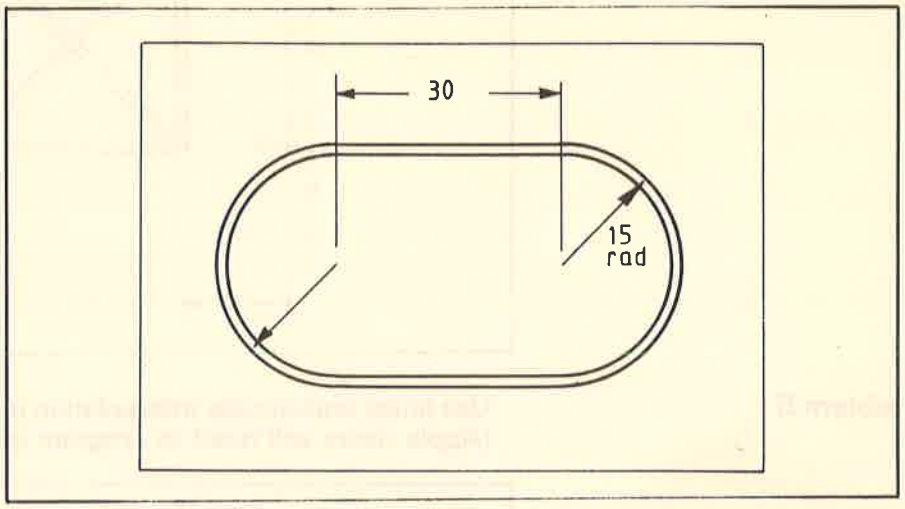
M 04	Reverse rotation of spindle
M 07 to 09 & M 50, 51	Coolant controls
M 10, 11	Clamp, unclamp
M 68, 69	Clamp, unclamp workpiece
M 78, 79	Clamp, unclamp slide

PROBLEMS

CHAPTER 4

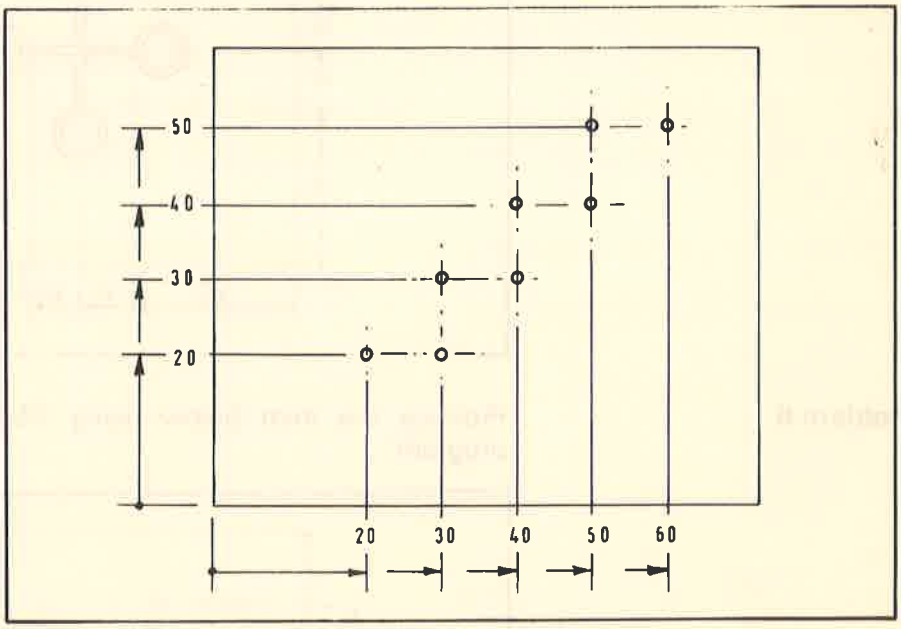
Problem 1

Write a program to produce the shape drawn below.



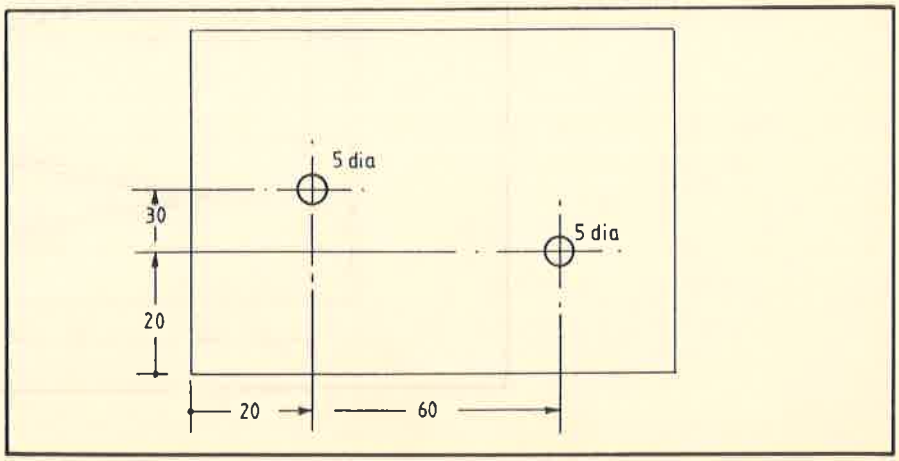
Problem 2

Write a program to produce the drawing below. Use G58 to shift the reference point.



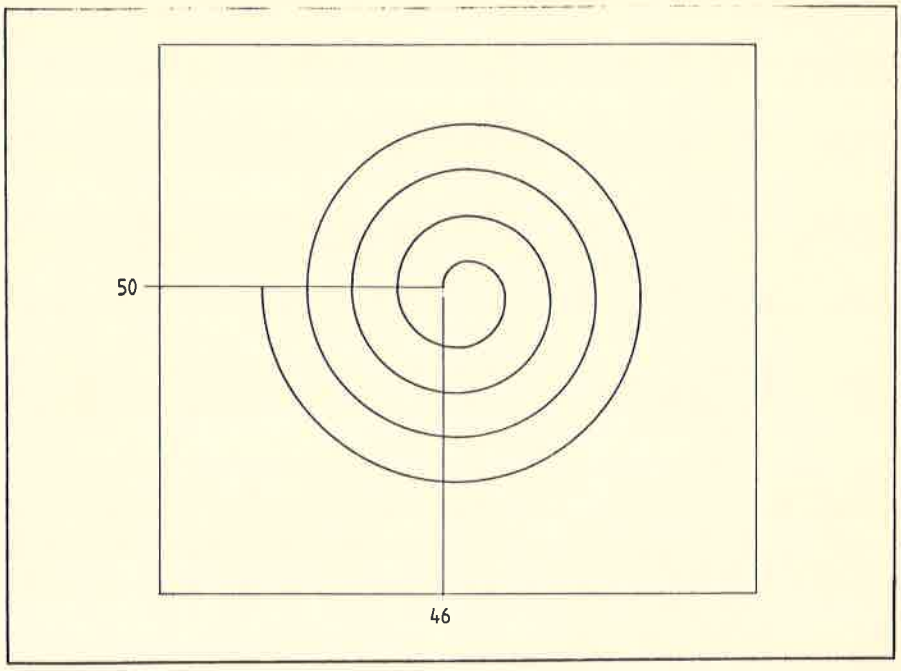
Problem 3

Write a program to mill the holes in the drawing below.



Problem 7

Write a program to produce the spiral below, use 90-degree arcs to simplify the construction. Start with a 4mm radius and increase the radius in 2mm steps every 90 degrees. Start at X46, Y50.



Solutions to problems

Problem 1

N	G	F	M	X	Y	Z	I	J
1	00	-	-	40	40	-	-	-
2	01	1	03	-	-	-10	-	-
3	-	-	-	70	-	-	-	-
4	02	-	-	85	25	-	-	-15
5	-	-	-	70	10	-	-15	0
6	01	-	-	40	-	-	-	-
7	02	-	-	25	25	-	0	15
8	-	-	-	40	40	-	15	0
9	-	-	02	-	-	-	-	-

Problem 2

N	G	F	M	X	Y	Z	I	J
1	81	2	03	20	20	10	-	-
2	-	-	-	30	30	10	-	-
3	-	-	-	40	40	10	-	-
4	-	-	-	50	50	10	-	-
5	58	-	-	10	0	0	-	-
6	25	-	-	-	-	-	1	1
7	-	-	02	-	-	-	-	-

Problem 3

N	G	F	M	X	Y	Z	I	J
1	00	-	-	20	30	-	-	-
2	01	1	03	-	-	-10	-	-
3	12	-	-	-	-	-	5	2
4	01	-	-	-	-	0	-	-
5	00	-	05	60	20	-	-	-
6	01	-	03	-	-	-10	-	-
7	13	-	-	-	-	-	5	2
8	-	-	02	-	-	-	-	-

Problem 4

N	G	F	M	X	Y	Z	I	J
1	00	-	-	20	20	-	-	-
2	01	2	03	-	-	-10	-	-
3	-	-	-	-	60	-	-	-
4	-	-	-	60	-	-	-	-
5	-	-	-	-	20	-	-	-
6	-	-	-	20	-	-	-	-
7	-	-	-	60	60	-	-	-
8	-	-	-	-	-	0	-	-
9	00	-	05	-	20	-	-	-
10	01	-	03	-	-	-10	-	-
11	-	-	-	20	60	-	-	-
12	-	-	02	-	-	-	-	-

Problem 7

N	G	F	M	X	Y	Z	I	J
1	00	-	-	46	50	-	-	-
2	01	4	03	-	-	-6	-	-
3	02	-	-	50	54	-	4	0
4	-	-	-	56	48	-	0	-6
5	-	-	-	48	40	-	-8	0
6	-	-	-	38	50	-	0	10
7	-	-	-	50	62	-	12	0
8	-	-	-	64	48	-	0	-14
9	-	-	-	48	32	-	-16	0
10	-	-	-	30	50	-	0	18
11	-	-	-	50	70	-	20	0
12	-	-	-	72	48	-	0	-22
13	-	-	-	48	24	-	-24	0
14	-	-	-	22	50	-	0	26
15	-	-	-	50	78	-	28	0
16	-	-	-	80	48	-	0	-30
17	-	-	-	48	16	-	-32	0
18	-	-	02	-	-	-	-	-

SOFTWARE DETAILS — APPENDIX 1

This Appendix is intended to help those who wish to alter or extend the functions of the software provided, or to track down the causes of any troubles which may be encountered. It assumes that the computer handbooks are available.

The software and the text have been arranged on the assumption that only one disc drive is used (or if two are present the one bearing the lowest number).

The software disc is in each case arranged so that a standard procedure (described in Exercise 1) will with a minimum number of keystrokes enable a student to load and run the program he needs.

Exercise 1 is extremely unlikely to give rise to computer-based problems, and no special provision has been made to protect the student from them. If strange messages appear on the computer screen, a repetition of the starting procedure should restore normal working.

Exercise 2 provides numerous opportunities for things to go wrong. Examples are:

Trying to load a non-existent part-program from disc.

Trying to save a part-program with an illegal name.

Trying to do anything which requires a disc, when the disc is not in the drive with the door closed.

Taking 'emergency stop' action.

In order to prevent the student being plunged into an unfamiliar 'computer world', the computer program for Exercise 2 responds to any error by giving the student a chance to manoeuvre the machine out of any mechanical dilemma it is in, and then starting again from scratch. (This will normally be little trouble provided that part-programs are saved regularly).

If problems are encountered or the program is to be altered for any reason, it may be desirable to 'enter the computer world' (e.g to receive the computer's error messages). This can be done by disabling the ON ERROR function. It can be bypassed by inserting an instruction on a new line 105 thus

```
105 GOTO 120
```

The exact procedure doing this is described below for each computer.

BBC computer

The disc has been set by the command *OPT4 3 to *EXEC the file named !BOOT. This file contains the commands

```
LOAD"XBOOT"
RUN
```

XBOOT is the BASIC program which initialises the ports controlling the CNC932, makes the initial announcement and asks which exercise is required. The response '1' causes file E932EX1 to be *EXEC'd. This in turn loads and runs the BASIC program A932EX1. The response '2' similarly uses E932EX2 and A932EX2.

A932EX1 can be exited by using 'escape' in the normal way. A932EX2 will respond to 'escape' with a sequence ending in a RUN command, and requires special measures for an exit. These are:

load A932EX2 in the usual way
press 'break'
type the command OLD (followed by 'return')

LIST,120 *return*

Line 110 of the listing will contain 'GOTO ' followed by a number.

Type the command,

LIST *number, return*

where 'number' means the number shown in line 120.

This will list the last few lines of the program, one of which will be a number followed by ON PM GOSUB and several more numbers. Make a note of the last of them.

Type the command

LIST *number1, number2*

where *number1* is the last number you noted, and *number2* is that number plus 60.

If (and only if) the requirement is to avoid hang-ups when no printer is present, simply type

number1 RETURN

If a printer is to be used in another slot, look among the command lines now listed for one containing PR# 1. To avoid mistakes, write this line down on a piece of paper, with the '1' changed to the number of the slot your printer will use. Type the whole of the line in to the Apple (ending with return as usual). Check the result by using the LIST command as on the last occasion.

You have now created the required alterations to the program in memory. For the program to be loaded on subsequent occasions automatically it must be saved with the appropriate name, which is A932EX2 for an Apple-IIe, or APL+932EX2 for Apple-II plus or other version which produces nonsense messages on start-up of the 932 software. The following further steps will do this.

Type

CATALOG *return*

If the appropriate name is listed with '*' against it, type

UNLOCK *name return*

Type

SAVE *name return*

This causes the old version of the program to be over-written by the new version. To protect it you should now type

LOCK *name return*

Further protection can be given by applying a write-protect tab. Make sure the disc is adequately labelled.

Keep this disc and use it only a secondary master from which to copy further working copies.

Known bugs.

The initial issue of software for the Apple computer may not always handle circular interpolation correctly when data values are only approximate. An experimental program should be SAVEd before being RUN, and if the program fails, editing it so that the approximation error has the opposite sign may provide a more satisfactory result. This does not affect any of the worked or unworked examples and exercises.

The Apple's circular interpolation also is limited in that, if either X or Y axis is required to change direction, a new program line is needed. It can therefore at most do 90° of an arc on one line.

PROGRAMMING FORM

Drwg. No.	Machine	Page of	Program by (name)
Designation	Material	Dim.	Date

N	G	F	M	X	Y	Z	I	J

INDEX