SPECIAL REPORT

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PERS 249 **AN INITIAL STUDY OF THE SELECTION AND TRAINING REQUIREMENTS OF NUMERICALLY CONTROLLED MACHINE TOOL PERSONNEL**

NATIONAL INSTITUTE FOR PERSONNEL RESEARCH
COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH

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BY

M E RENDALL

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SUMMARY

This is an initial study of the impact of numerically-controlled machine tools on occupational structure and job content in machine shops.

OPSOMMING

Hierdie is 'n aanvangsondersoek na die uitwerking van numeriesbeheerde-masjienwerktuie op beroepstruktuur en werkinhoud in masjienwerkwinkels.

FOREWORD

This report covers the initial investigations for what was to be a more detailed study of the job requirements of and appropriate selection and training for jobs connected with numerically controlled machine tools. This project has had to be discontinued following the disbanding of the Automation Advisory Service.

CONTENTS

AN INITIAL STUDY OF THE SELECTION AND TRAINING REQUIREMENTS OF NUMERICALLY CONTROLLED MACHINE TOOL PERSONNEL

INTRODUCTION

Numerical control of machine tools is an area of automation which has been commercially available for the last 20 years in America but only much later in South Africa. Most types of machining can now be numerically controlled (i.e. controlled by numbers) eg. milling, boring, reaming, tapping, metal turning and three-dimensional profiling and contouring.

The numerical control (NC) machines are very suitable for short runs at repeated intervals since they are highly flexible. This was true in the past but applies even more so today as the cost of these machines is reduced and their programming made easier. The typical production run in South Africa is short because of the relatively small market, and thus NC equipment seems well-suited. The shortage of skilled machinists further enhances the value of NC and its use will certainly increase.

After a brief look at the types of systems available and the stages necessary for the manufacture of a machined piece, the changes in occupational structure and the job content of each level of personnel will be examined. Special emphasis will be placed on the part programmer and operator, but consideration will also be paid to management, design engineers/draughtsmen and tooling personnel.

1. NUMERICAL CONTROL MACHINE TOOLS.

1.1. Definition of Numerical Control.

Numerical control has been defined as"a control of a servo device or system to perform an ordered sequence of events along a path at a rate predetermined by a group of alpha-numeric characters necessary to produce a workpiece with entirely predictable events and physical parameters" . In other words, an NC system accepts digital inputs on paper tapes, magnetic tape etc. and uses these to control a machine to perform certain movements.

1.2. Types of Numerical Control Machines.

Numerical control machines tools vary widely in terms of complexity,with later systems becoming increasingly sophisticated although not necessarily more complex to operate. The variation between the machine tools can be looked at from two angles:

1.2.1. Functions that are controlled.
1.2.2. Type of control.

1.2.1. Functions that are controlled.

On conventional machine tools, complete control of the machine tool is in the hands of the operator. As the NC machine tools become more complex, more areas of control are taken away from the operator. The decision-making aspects are transferred to the parts programmer, while the actual physical movement is device controlled. The more complex systems do not require any operator and take over some of the decision-making exercised by the parts programmer.

The first aspect of the conventional machine tool to be controlled was movement along the axes. The first NC machines had what is described as 2½ axis control, i.e. automatic control along the x-and y-axes and manual control along the z-axis. As the control systems became more complex all three axes, x, y and z, were automatically controlled and in addition, the workpiece could be rotated. Today, some of the most complex machine tools can be controlled in ten axes simultaneously.

Another aspect that has been brought under control is tool changing. Without this facility, an operator has to be present to stop the machine tool, read the worksheet to ascertain which tool is required, manually change the tools and restart the machine tool, but now, on some machine tools the controller commands the machine to select and change a tool automatically. This increases the ratio of cutting time to waiting time and considerable efforts are being made to reduce the duration of automatic tool changing. Some manufacturers claim that their systems can complete a tool change in 2½ seconds.

Manual tool-setting can also be eliminated. On conventional machine tools, the operator has to set the tools using feeler gauges and micrometers to ensure the correct depth of cut. M A Maas describes a system in which this is done automatically." To use the system, an operator rolls his toolcart over to the machine and advances the tool matrix on the machine until an empty pocket is in the ready position. An encoder on the tool matrix indicates to the computer which pocket is in this position. From a table in memory, which has been established by the parts programmer, the number of the tool assigned to this pocket is determined and registered on the display.

Next the operator removes the tool from the cart and inserts it into the electronic tool gage. The gage, which contains an optical encoder, measures the tool to within 0,001 inch and displays that measurement on its digital display. The operator pushes a button on the gage panel, and the 8-bit reading in the gage registers is transmitted serially to the computer memory and stored along with the tool pocket location. He then leads the tool into the pocket and repeats the procedure". (p112)

On some of the earlier NC machine tools spindle speed and feedrate were left to the discretion of the operator but on later machines this function has been passed to the parts programmer who inserts the necessary commands in the control programme. The latest systems have adaptive control where the control device automatically calculates spindle speeds and feedrates for optimal cutting speeds based on information from sensors on the machine tool.

The above-mentioned functions have all related to a single machine for which an operator is still necessary for loading and unloading parts and monitoring the machining process, even for the most complex system. However, the development of robots and sophisticated materials handling techniques eliminates even the operator. Systems of machine tools linked by transfer equipment already exist in the development stage in several parts of the world.

1.2.2. Type of control.

K Kasper has classified NC systems into three:

- Conventional numerical control
- Computer numerical control (CNC)
- Direct numerical control (DNC)

According to Kasper, the conventional NC system is "nothing more than a special purpose data processing system and is designed to act on a known predictable set or range of digital inputs. A numerical control system acts upon these inputs to control a machine in a predetermined manner through hardwired logic modules" (p115)

Computer numerical control, a higher level system, is more adaptable and involves the use of a dedicated mini computer which can accept an arbitrary set of inputs. The way in which these inputs are acted upon is determined by the software (programmes).

Direct numerical control is the most highly sophisticated and the most expensive of the three. A main computer controls a number of machine tools on a time-sharing basis and thus can co-ordinate them.

1.3. Point-to-Point and Continuous Path Machines.

Two other terms that are useful in describing the capabilities of a machine tool are " point-to-point"or "positioning "and "continuous path". Point-to-point is a simpler system where a machine moves in one axis at a time. The machine is required only to reach an endpoint and the path between the two points does not need to be controlled e.g. drilling. In a continuous path system continuous movement on different axes is combined to get the correct path to follow, cutting a line or curve. In this case the machine has to carry out some operation at all intermediate points e.g. in cutting a groove.

This broad classification can be broken down further as has been done by Olesten (p 13) who divides the machine tool control systems into four:

a) Positioning system e.g. drilling
b) Positioning/straight cut system which can perform milling and facing operations along the machine tool axes.
c) Contouring system which, in addition to the operations defined above, can cut any mathematically defined path such as circles, ellipses,etc. Virtually any part can be manufactured on such a system.
d) Contouring /positioning combination system which, as its name suggests is a combination of the positioning system and the contouring system.

The advantages of each are encorporated so that an optimal system is obtained.

1.4. Four Levels of Machine Tools.

These concepts have been combined below to give four typical levels of machine tools as described in an article by Morris.

Level I machines are relatively simple and have been on the market for the last 18 to 20 years. The controller reads a paper on a magnetic tape or a plugboard and directs machine tool movement in the x,y-and z axes and controls spindle speeds and feedrate. These machines can perform point-to-point operations and continuous path movements along the machine axes. Machine tools at this level are capable of such operations as drilling,tapping, milling etc. A computer is not required since the part to be programmed is simple enough to be manually programmed, being no more than the specification of sequences of co-ordinates. The control unit is what was described earlier as conventional N.C.

Level II machines are more complex, being capable of continuous path operations, rotation of the workpiece and automatic tool changing. Computer-assisted programming is essential since intermediate points on continuous paths have to be interpolated.

Third level NC machines are highly complex, capable of simultaneous movement in from three up to ten axes. These machines carry out tasks that would be impossible for human operators. Some have been fitted with adaptive control over spindle speeds and machine feedrates to optimize cutting conditions, reducing toolwear and achieving the best possible surface finish. This level machine is particularly useful in the aerospace industry for machining wings or impellor turbine blades. Control is via computer which, depending upon the complexity of the machine tool, is either a minicomputer or a general purpose computer. Programming is computer-assisted.

Level IV, NC manufacturing systems, are still in the future i.e. completely unmanned, automatic factories under control of time-sharing general purpose computers.

1.5. Effect of Machine Level on Job Control.

The level of machine tools used in a machine shop determines the content of jobs for all personnel from management to operator. Generally speaking, as the machinery becomes more complex, operational planning and decision-making on the factory floor is progressively transferred to the parts programmer and higher levels of management.

2. MANUFACTURING STAGES

Conventionally, the design office produces the engineering drawing which passes to the planning department where the machining steps are planned. A process planning sheet is drawn up for the operator and various other aids such as drawings and templates are prepared. When the piece is machined the tools, jigs and fixtures are set up and the operator interprets the process planning sheet. Every action he undertakes involves making a decision and he spends a considerable amount of time checking and rechecking the piece with measuring instruments,adjusting feeds and speeds and changing tools.

Under an NC process, the engineering drawing passes to the part programmer who writes a programme for the machining steps and verifies it with the assistance of the operator. The operator loads a workpiece, puts the control medium into the control unit, starts the machine and monitors the machining process, possibly manually changing the tools. At the end of the cycle he unloads the workpiece.

3. IMPACT ON OCCUPATIONAL STRUCTURE

Numerically controlled systems have advantages over conventional systems that have implications both for occupational structure and job content. Numerically controlled systems are more flexible, more reliable, more accurate and faster than operator controlled machine tools, are capable of performing operations too complex for a machinist, and require simpler fixtures and reduced set-up time. These factors result in a reduction in skilled labour requirements. This is particularly significant where continuous path machining is required to make highly complex parts as in the aerospace industry. Further, an NC machine takes less time to machine a part than a machine operator since it works almost continuously whereas the machine operator stops for breaks and checks. Typical figures quoted indicate an increase in actual cutting time from 20/30 per cent on conventional equipment to over 80 per cent on NC equipment. Furthermore, once the programme is correct, unsatisfactory work seldom occurs whereas the operator may have to redo a piece through an error on his part.

The impact of NC will depend upon the rapidity with which it is introduced and the type of NC system that is used. Where there is a shortage of labour little displacement will result but if there is a more than adequate labour supply job displacement may occur. In either event, the proportions of each type of worker to each other will almost certainly change.

3.1. Operators.

The U.S. Dept. of Labour's pamphlet, Outlook for numerical control of machine tools reports reductions in operator requirements in various industries in the United States in 1965:

Industry	Reduction in labour requirements.
Aircraft	Reduced number of machine tool operators from 5 to 1.
Aircraft	50 per cent reduction in labour costs.
Electrical Equipment	Saved 78 man-hours in machining time per piece.
Electrical Equipment	43 per cent reduction in direct labour costs.
Machine Tool	Set up and machining labour costs reduced by 57 per cent per part.

Industry	Reduction in labour requirements.
Autoparts	57 per cent saving in cost per unit.
Machine Tool	Reduced number of machine tool operators from 6 to 1. Total machining time reduced by 65% from 1.86 to 0.65 per part.
Special Machinery	Machining time reduced to ¼ of former time.

Source: Summary of Table 9, p 30. op cit.

As these figures indicate, the machine operators will suffer a drastic reduction in number.

3.2. Parts Programmers.

Numerical control creates a new position, that of " parts programmer", who writes the computer programme which runs the machine tool.

3.3. Tooling Staff.

Numerical control reduces the number of tooling staff required since jigs and fixtures become simpler and automatic tool setting is used. Furthermore, NC systems can make the required tools quickly due to its flexibility, resulting in a reduction in toolmakers.

3.4. Maintenance Staff.

Numerical control increases maintenance staff, but this does not outweigh the reduction in operating staff.

3.5. Draughtsmen.

There may be a decrease in the number of draughtsmen required since highly accurate drawings are no longer a prerequisite.

4. OCCUPATIONAL REQUIREMENTS.

4.1. Management.

4.1.1. Choice of System.

One of the major problems that arise for management when NC is first introduced is deciding what system to buy. For many managers, NC equipment is a relatively new approach to machining and few have had much experience with it. The physical parameters of the NC machine have to be evaluated in the same way as conventional machines but there are other aspects to be considered e.g. automatic or manual tool changing, type of control etc. Each manufacturer will recommend a different way of setting up the system with his equipment, the pros and cons of which one hard to evaluate. Few will give completely objective advice and mistakes will be very costly.

Once the equipment has been installed, NC imposes heavy requirements on management for planning and sequencing because of the higher expense of downtime.

4.1.2. Production Planning.

Hetem (p 28) lists five areas where proper planning is essential: people, planning (procedures), programming, tool and fixture control, and quality.

Planning for people involves more careful selection of staff and more thorough training. Procedures need to be drawn up for process planning so that requirements for such things as programmes and work sheets for operators can be determined in good time. Procedures for programming and documentation also need to be established. Tool and fixture and quality control policies must be established and maintenance schedules drawn up. These are - apart from programming - common to NC and conventional machine shops but NC has different implications. For example, people planning will involve recruiting and training part programmers for an NC system, a function that does not exist on a conventional system. Similarly, programming planning is a new aspect of procedures planning. Furthermore, staffing requirements, the needs for production scheduling, tool and fixture, quality control and maintenance are more stringent in view of the higher cost of downtime.

4.1.3. Financial Planning.

Financial planning is simplified since some of the variables that previously made it difficult are removed e.g. different skill levels between operators and differences in operator performance at the beginning and at the end of a shift, both resulting in variations in product quality and in lengths of production time. This change of emphasis from " management of men to management of machines" (Morris, p 96) means that management has more precise information on which to base detailed decisions, resulting in more accurate cost estimates.

4.1.4. Inventory Planning.

The ease with which programs can be interchanged and rerun, plus the simplified tool setting, allows parts to be made in small batches. This means a smaller inventory of finished goods but a larger of raw materials. Thus greater attention must be paid to the raw materials inventory to meet both a wider range of requirements and the faster consumption.

The main impact on management is, therefore, a greater emphasis on foreseeing in considerable detail all eventualities well ahead of time, and planning for them, and less emphasis on the stimulus-response form of management commonly associated with conventional systems. A difficulty is that foresight requires a foundation of past experience, but past experience with conventional systems needs considerable filtering and re-evaluation before application to NC systems.

4.2. Design and drawing-office.

On conventional machines costs increase as parts become more complex, tolerances are reduced and time is spent on tool changes. Thus in the past the design engineer has spent a great deal of time designing parts which are simple, do not require narrow tolerances and do not require many tool changes. On NC systems, complex parts with narrow tolerances are no more difficult to machine than straightforward parts, with wide tolerances. It is still desirable to keep tool changes down to a minimum but these are quicker and therefore less costly than on conventional equipment. Thus the end-use of the product, the limitations imposed by raw materials and structural design will figure more prominently in design considerations. These imply a wider perspective and a stronger theoretical background and a flexibility that can convert past experience into a springboard instead of a shackle.

A similar situation exists for the draughtsman. A highly accurate, detailed, machine-drawing is no longer necessary for most parts, a rough sketch with the important cartesign co-ordinates will be sufficient. On the other hand, greater emphasis will be placed on his ability to visualize, without the aid of detailed machine drawings, completed parts and how they fit together. On this basis he must check that the parts will have the required tolerances and strength, and then, visualizing the operation of the machine, he must specify the essential co-ordinates . He may also have to double as a parts programmer.

4.3. Part Programmer.

Part programming is a new job created by NC. The part programmer's function is to translate the data from the engineering blueprint into a form that the control system can understand. He must determine each step i.e. the manufacturing process: identify the material, the type of cutting tool, the duration of the cut and from tables obtain the appropriate cutting speeds, feedrates and coolant flow and incorporate them at the proper positions in his programme.

Depending upon the system, the programmer may have to calculate intermediate coordinates and look up function codes himself or he may have the advantage of a computer which, given the minimum geometric and other information in ordinary language, will perform all calculations and translations. Eventually the complete programme for a machining operation is put on paper or magnetic tape or stored in a computer's memory. The programme is then verified on the machine and finally, is documented for repeated use.

The programming aspect of the part programmer's job is similar to that of other programmers. He requires a thorough knowledge of the programming language he uses, and some knowledge of computer structure and operation. He must be able to translate specified activities into computer operations, locate the source when errors appear, and in both be as economical of human and computer time as possible. Finally, he must document his programme intelligibly for other users.

In addition, the part programmer requires a thorough knowledge of the operation of machine tools, of strength of materials and the action of cutting tools, of drawing office practice and the geometry of design.

The crucial stage is the verification of the programme which in the simplest form involves running it on the machine with some cheap material such as wood or plastic. However, this is expensive of machine time and other methods are used which require some power of visualization on the part of the programmer in matching the simulated operation to the actual. Such methods include using a plotter or graphics display, the more advanced of the latter being equipped with a light pen with which modifications can be made, for two-dimensional representations of the operations of the programme.

The most recent developments raise programming to a higher level of abstraction for the part programmer dictates his programme in a limited formalised language to the computer and then edits the simulated operation of the machine on a visual display unit.

In addition to his technical background the part programmer requires the social skills normally required of programmers. He must be able to co-operate with designers, draughtsmen, foremen and operators, and in some larger installations he may be a member of a programming team with responsibilities for supervision and training.

4.4. Machine Tool Operator.

Depending upon both the type of machine and management's decision as to what his job functions should entail, the operator's job can vary from semi-skilled loading and unloading of workpieces to skilled operator cum programmer. The newer, more expensive, complex machines can take over may of the operator's functions, and in some of the most highly developed, level IV systems still being worked on, the operator is no longer required.

On the less complex, level I systems, the operator loads and unloads the workpiece, ensuring that the clamps do not fall in the path of the cutter. This entails picking up the part to be machined which may be a rough cutting or a partially machined part, filing away any unwanted projections, which may be in the way, and placing the part in a jig, ensuring that the reference marks are in the correct position. The part is then clamped securely in place.

The tape may be loaded by a foreman but in most cases the operator loads the tape and starts the machine tool himself.

Where there is manual tool changing the operator must be able to follow a planning sheet to check that the tools placed in sequence by the tool setter are correct. He then loads each tool as required. On Level II and higher systems this function falls away.

One of the operator's most important functions is to monitor the machine tool. Should any malfunction occur he stops the machine and reports the fault to the foreman. It is unlikely that he would make the adjustments himself. Typical malfunctions that could arise include tool breaking or overheating, tool not cutting to the correct depths or cutting a jig, excessive tool wear, coolant blockage, chips fouling the tool etc.

The operator may be required to fulfil a quality control function by checking the dimensions of the finished part with measuring instruments, and reporting any parts of tolerance to the foreman.

Where there is an automatic tool setting system such as described by M A Maas, the operator may be required to do his own toolsetting automatically.

An area where an operator can apply his skill is in programme verification. The difficulty of specifying optimal feeds and speeds and cutter clearances beforehand provides the operator with scope for making criticism and suggestions during programme verification. He is not usually allowed to correct the programme himself.

The outstanding feature of the operator's job is the high level of responsibility he must exercise. Should he not notice any malfunctioning either within the machine or in an incorrectly machined piece, severe losses can result. In some cases he may be in charge of two or three machines and high levels of visual and acoustic vigilance are required under conditions of noise, vibration and moving machinery.

4.5. Tooling Personnel.

Personnel involved in the tooling jobs include the tool designer, the tool maker and the tool setter.

The tool designer's job does not change with the introduction of N.C.

However, the toolmaker's function can very largely be taken over by the NC machine tool which is ideal for one-off or small batch jobs. The skills of the toolmaker are thus passed on to the programmer. Furthermore, NC machine tools require fewer jigs and fixtures and these are not as complex as on conventional machinery, which again simplifies the toolmaker's job.

The toolsetter's function remains unchanged by NC unless an automatic gauging system is used in which case this function can be taken over by the operator (as described earlier on p.3) or remain with the toolsetter in its new form.

4.6. Maintenance and Installation Engineers.

Numerical control machines embody technical knowledge which was formerly in separate fields such as mechanics and electronics and for which engineers receive different training. Thus the application of NC to machine tools can enlarge the job of maintenance and installation engineers. In addition to the maintenance activities on the conventional equipment, the control system, which may be electronic, hydraulic or pneumatic, also needs maintenance. Some companies, particularly the smaller ones, train their workers in this new area. Other, generally larger, companies have two sets of maintenance engineers, one set to service the actual machine tool and the other to service the control system.

In some ways the problem of maintenance of the control system is diminishing as technology develops and the system becomes increasing more reliable and fault-finding procedures more carefully worked out. On the other hand, the systems themselves are becoming more complex.

5. SELECTION.

Numerical control has already been introduced into South Africa for certain applications e.g. flame cutting, milling, boring and although the number of machines is at present fairly small, it has been predicted that in the next few years there will be large imports, particularly as their cost relative to manual equipment is falling and their versatility increasing.

The use of NC will help to combat the shortage of machinists. However, at present there are very few South Africans with experience in NC and a great deal of training of personnel will be necessary.

5.1. Engineers.

Currently, most of the engineers responsible for installation and repair are recruited from outside South Africa, but the number of overseas trained engineers being recruited is not adequate and some South African engineers have been trained. Originally, mechanicalengineers were selected and given training in electronics but it has been found more satifactory to recruit electrical engineers and train them in mechanics.

Where separate teams are used for the maintenance of the mechanical and electrical systems selection requirements are unchanged, but where the job covers both aspects, men who are able to combine knowledge of several disciplines are required.

5.2. Design Engineers and Draughtsmen.

The selection of design engineers and draughtsmen does not change with the introduction of NC, although it is possible that fewer draughtsmen will be required.

5.3. Parts Programmers.

There is some divergence of opinion on the recruiting of part programmers. There are basically four main sources: trained computer programmers, machinists, drawing office staff and personnel from the planning department. Trained programmers appear unsatisfactory since they have very limited knowledge of machining specifications and skilled machinists appear to do better. It is said that it is easier to teach a machinist to programme than teach a programmer machine shop knowledge and this remains true, even though on more sophisticated machines adaptive control takes away the necessity for specifying feeds and speeds.

Draughtsmen have been found to make satisfactory parts programmers since they have a good knowledge of machining specifications and this is also true of personnel from the planning department.

Gettelman comes to the conclusion that "...the required programming skills are primarily related to the geometric complexity of the work piece. Everything else is secondary "(p 96) thus a machinist may be suitable in some cases, in other cases an engineer may be required. Gettelman has drawn up a table (see following page) indicating educational requirements as the work piece becomes more complex.

Group Number *	1	2	3	4	5	6	7	8	9
Workpiece Complexity / Educational Requirements	Point to Point and Straight Cuts 2½axis	Non formula Defined Curves	Repetitive Cuts & Family of Parts	Curves and Straight Lines (2½ axis)	Controlled Rotary Motion	Inclined Planes and Patterns	Sculptures Surfaces	Sharp cut formula Define & Regular Surfaces	Multiaxis Incl. Four Simultaneous Motions
Basic Machining Practices * *	•	•	•	•	•	•	•	•	•
Plane Geometry		•	•	•	•	•	•	•	•
Simple Algebra		•	•	•	•	•	•	•	•
Simple Analytic geometry			•	•	•	•	•	•	•
Solid Geometry				•	•	•	•	•	•
Algebra					•	•	•	•	•
Analytic Geometry						•	•	•	•
Basic Computer Programming(desirable)							•	•	•
Descriptive Geometry								•	•
Plane Trigonometry								•	•
Spherical Trigonometry									•
Digital Computation									•
Numerical Analysis									•

* Groups I through 5 may utilize computer assist programming or it may be done manually, depending on many factors Groups 6 through 9 because of mathematical complexity, should be thought of soley in terms of computer-assist programming.

* * Basic machining practices means:
Knowledge of machine tools and cutting tools
Machine shop procedures
Blueprint reading
Shop mathematics-arithmetic and right angled trigonometry
An understanding of NC tape formats
Manual part programming

* * * The foregoing educational requirement is not as significant at this level of complexity as in the simpler levels. More stress is on mathematical background.

All part programmers require a knowledge of basic machining practices which includes:

"Knowledge of machine tools and cutting tools
Machine shop procedures
Blueprint reading
Shop mathematics-arithmetic and right angled trigonometry
An understanding of NC tape formats
Manual part programming " (p 98)

As the workpiece becomes more complex additional skills are required, until one gets the most highly trained part programmer who is capable of numerical analysis.

5.4. Operator.

The type of operator required, as indicated previously, depends on the complexity of the system. For the older, less complex systems such as found at Level I, the operator must have some machining skills. At Level II such skills are less necessary e.g. automatic tool changing removes this function. Level III machines are capable of machining parts too complicated for the machinist which reduces the operator's job to loading and unloading workpieces and monitoring the machine's operation. Semi skilled operators would be capable of carrying out these functions and there seems to be no reason why Blacks could not be recruited for this position, provided they had sufficient education and the relevant training. Machines at Level IV are still in the developmental stage and unlikely to reach the South African market for many years. They require no operators at all in the machining area.

5.5. Tooling Personnel.

Tooling personnel can be drawn from the same sources as conventional systems but there will be a reduced need for toolmakers, since a machine tool can be programmed to make its own tools. The simpler jig and fixture requirements and the increasing use of automatic tool changing equipment will reduce the requirements of the toolsetter's job and thus a less highly skilled person will be suitable.

6. TRAINING

At present there is a great shortage of trained personnel in all areas of the NC field and there is a serious lack of training centres at universities or technical colleges. However, most suppliers of NC equipment will provide a one to two week course for part programmers and operators, but companies which desire additional training for staff have to develop their own training schemes.

6.1. Management

Management requires an introduction into the fundamental concepts of NC to enable it to choose a system, knowing the full implications of each alternative from both the technical and personnel point of view, Management needs to be given the administration and control procedures that have proved most effective in running NC systems. It also needs to be informed of the impact NC will have on each department in the company and the measures necessary to adjust existing procedures.

6.2. Training of a part programmer

The training of a part programmer will vary according to his background.

A fully qualified machinist will only have to be taught the capabilities of the system and how to programme. The CSIR presents courses on both manual programming (5 days) and computer assisted programming (8 days). The computer assisted programming course is based on the APT programming language which is the most universal language used (see appendixes A and B).

Part programmers with a computer orientation but without the necessary machine shop knowledge will have to be trained in this area.

Olesten, in his excellent introductory book, Numerical Control, pays special attention to the training of the part programmer. On page 599 he gives a recommended basic outline of a training course:

i.	Blueprint reading - Refresher	3 hr
ii.	Planning concepts - Function and flow	3 hr
iii.	Tooling and tool design	3 hr
iv.	Machining concepts and NC machine tools	15 hr
v.	NC orientation	15 hr
vi.	NC workflow and procedures	15 hr
vii.	NC Data processing	15 hr
viii.	APT training	120 hr.

This outline is further broken down into fairly great detail as to what each section should include and reference is made to other chapters in the book which cover the subject.

6.3. Operators

Operators of systems at all levels require much the same type of knowledge. The areas involved are:

6.3.1. Training in basic machining practices - blueprint reading, knowledge of machine tools and cutting tools, and machine shop procedures.

6.3.2. Loading and unloading of both the workpiece and the control medium.

6.3.3. In-process inspection - use of gauging and measuring instruments, and fault detection.

Below are two areas specific to a particular level system.

6.3.4. Tool changing where this is not done automatically i.e. some Level I systems.

6.3.5. Training in the use of the automatic tool setting equipment where this is used.

6.4. Maintenance engineer

Training to become a maintenance engineer is a long process. Firstly, a general technical background is necessary which can be acquired through a technical college where such subjects as mechanics and electronics can be studied. Secondly, training specific to the type of NC equipment used is required. This training is usually done within the manufacturing company.

A training by objectives approach results in a planned, goal-directed training scheme. Training aids such as flow charts can be of considerable use to the maintenance engineer.

Appendix A.

MANUAL PROGRAMMING OF NUMERICAL CONTROL MACHINE TOOLS

COURSE OUTLINE.

MONDAY:

Introduction to numerical control - The numerical control process - Glossary of terms - Axis and motion nomenclature - Introduction to programming - Miscellaneous and preparatory functions - Demonstration of machines and machining.

TUESDAY:

Geometrical principles - Cutter path calculations - Workshop on geometry and co-ordinate calculations - Format specifications - Workshop on programming.

WEDNESDAY:

Tape codes - Tape punching of first program - Cutting of first component - Programming of circles, slopes and threads.

THURSDAY:

Workshop on programming of second component - Cutting of second component.

FRIDAY:

Standardization - NC tooling - Introduction to computer assisted programming - General discussion and revision.

Appendix B.

N C COURSE PROGRAM

MONDAY

1. Introduction to NC - General course outline - Definition of N C - History of N C - Development control media - Language standardisation.

2. Introduction to APT - Origination & Development of APT - General APT process (flow chart) - Sections of computing - Printout interpretation - Usage of plots.

3. Surface definitions - APT words - APT statements - Statement modifiers - Spelling & Punctuation - Program format - Nested definitions.

4. Work on APT - Geometry definition exercises.

TUESDAY

1. Continue & finalise APT Geometry definition exercises.

2. APT control cards (Toler, CLPRNT, No post) - Cutter statements - Print/3, ALL - REFSYS - Geometry matrices - Pattern definitions.

3. Controlling surfaces - System sense of direction - point-to-point commands - Sample point-to-point program.

4. Three surface start-up - Part surface - drive surface - check surface - "From" statement - Direction modifiers - Motion commands.

WEDNESDAY

1. Continue with cutting motion commands and feedrate.

2. Work on motion command exercises.

THURSDAY

1. Write program to submit to computer for test run incorporating all APT surface definitions and motion commands.

FRIDAY

1. Role of computer in APT programming including software involvement.

2. Running and debugging test program at computer and transferring same onto magnetic tape.

MONDAY

1. Introduction to marwin Max-and-mill and other N C Machines at CSIR.

2. Running and cutting of test piece program on marlin machine.

TUESDAY

1. Advanced APT features including - Macro - Index - Looping - Copy - Drilling using patterns and looping - matrices - translations and rotations - macro variables - thick.

2. Writing of test program using special APT features.

WEDNESDAY

1. Introduction to manual programming and machines.

2. Comparison between manual and computer assisted programming.

3. Future trends in N C including CNC and DNC.

4. N C economics and justification.

5. General discussion and wind-up.

Appendix C.

Tech/5/5

SUMMARY OF JOB REQUIREMENTS FOR PROGRAMMING AND OPERATING OF NUMERICALLY CONTROLLED MACHINES

ACTIVITY	JOB CONTENT	JOB REQUIREMENTS
1. MANUAL PROGRAMMING	1.1 Interpreting engineering drawings	An understanding of the general principles of engineering drawing practice
	1.2 Determining the centre line co-ordinates of the desired cutter paths,and the cutters to be used	A comprehensive knowledge of the following: (i) Cutting tools: Their usage, geometry and compositions for different applications (ii) Feeds and speeds: As required for different materials and depths of cut with due regard to the available power of the machine. (iii) Machine tools: Their capabilities and applications (iv) Process engineering: Cutting sequences, etc. (v) Mathematics: Especially geometry and trigonometry
	1.3 Coding the calculated co-ordinates into an acceptable machine tool code	Knowledge of the code required for the tape that will control the machine movements. (Information on codes is obtainable either from the Machine Tool Manual or from Standards such as ISO or EIA)
	1.4 Tape preparation	Capability of operating typing machines
	1.5 Tape proving	Knowledge of the features and control of the machine

ACTIVITY	JOB CONTENT	JOB REQUIREMENTS
2. COMPUTER ASSISTED PROGRAMMING	2.1 Interpreting engineering drawings	An understanding of the general principles of engineering drawing practice
	2.2 Preparing the coded instructions in a computer assisted programming language	A comprehensive knowledge of the following: (i) Cutting tools: Their usage, geometry and compositions for different applications (ii) Feeds and speeds: As required for different materials and depths of cut with due regard to available power of machine (iii) Machine tools: Their capabilities and applications (iv) Process engineering: Cutting sequences, etc. (v) Mathematics: Especially geometry and trigonometry (vi) Computer assisted language Typical features such as the canonical form of geometric definitions, subscripted variables, matrices, macros, etc.
	2.3 Tape proving	Knowledge of the features and control of the machine
Depending on the organisational structure of a manufacturing concern, the programmer might be involved in the designing of work holding mechanisms and fixturing. The knowledge required for the design of such devices is similar to that required for conventional fixture designing.		
3. MACHINING	3.1 Tool and fixture loading and setting	A comprehensive knowledge of the capabilities of cutting tools, measuring tools and machine tools
	3.2 Work-piece loading	No special requirement
	3.3 Part machining	An understanding of gauging and measuring equipment, only for in-process inspection. In cases where quality control personnel is available, this function could be entrusted to them.

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