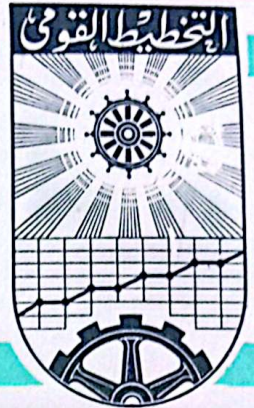


UNITED ARAB REPUBLIC

THE INSTITUTE OF NATIONAL PLANNING



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NUMERICAL CONTROL,
THE SECOND INDUSTRIAL REVOLUTION

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INTRODUCTION

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Anyone searching the literature on numerical control (NC) cannot go far without reading that NC HAS STARTED THE SECOND INDUSTRIAL REVOLUTION. Such words may at first seem toodramatic to describe the effect of automating a machine tool (m/c tool), but the excitement is indeed justified, for NC HAS CHANGED THE ENTIRE CONCEPTS OF COMPONENT DESIGN AND DEVELOPMENT. What's more, the greatest impact-on both design and manufacturing - apparently is yet to come. NC applications generally lower the cost of production and reduce tool inventory, the matter that causes great pleasure to the manufacturing management. On the other hand, the more sophisticated types of NC are CHANGING THE APPROACH TO PRODUCT DESIGN, and perhaps even the APPROACH TO PRODUCT PLANNING. Complex Surfaces, for example, can now be produced easily and rapidly without error. Designers can use mathematical equations to define contours of the m/c shop. Fewer design compromises are needed since complex shapes are easily specified and produced.

Due to NC, it is now often economical to sculpture intricate components from solid metal instead of using welded or riveted structures or metalforming processes. Also emerging are systems in which the design engineer will communicate directly with the m/c tool through computer - aided design.

WAYS TO CONTROL CUTTING TOOLS:

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All that is required to machine a part is relative motion between the cutting tool and the workpiece, either by moving the tool against a stationary workpiece or by moving the workpiece against a stationary tool. This motion is achieved in several ways:

- (1) MANUAL CONTROL
- (2) PRACER CONTROL
- (3) NUMERICAL CONTROL
- (4) TRANSFER CONTROL

Each of those methods has its own configurations, way of operation, advantages and disadvantages & role in industry. In order to focus the real sense and application of NC, those methods will be briefly illustrated and discussed.

The following figures illustrate way of operation.

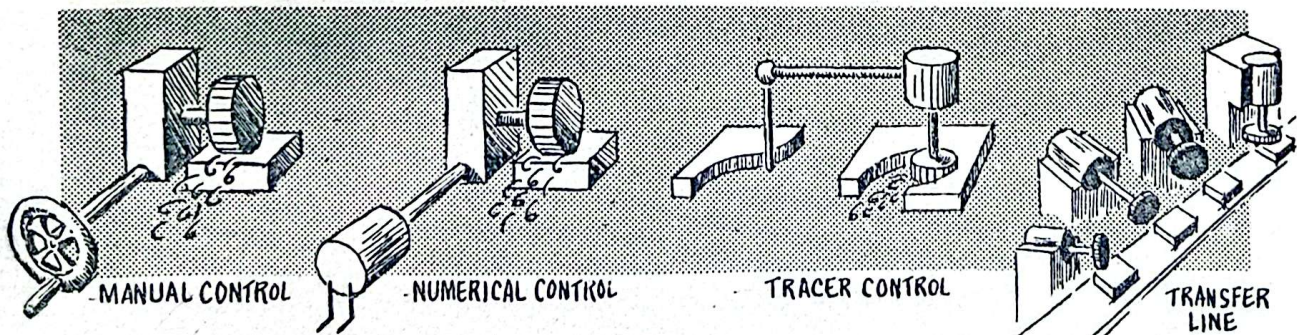


FIG. 1

(1) MANUAL CONTROL:

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Relative motion between cutting tool and workpiece is provided by an operator turning a leadscrew (or a similar mechanism).

Advantages:

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Low equipment and tool costs

Disadvantages:

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- * Slow Production
- * Difficulty of performing complex surfaces
- * High costs of labor
- * Frequent human errors

Role in Industry:

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- * Requires the least investment, but is considered slow and costly when large numbers of parts are required.
- * Provides the least uniformity and cannot easily produce complex contours.

(2) TRACER (OR CAM) CONTROL:

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In this type of control, position of the cutting head is controlled by a tracer riding against a template or model. Cams or special fixtures may also be used instead of templates to generate curves and to automate machine operation.

This type of control is used in cases of machining curved paths where the cutter moves along two axes simultaneously, and human operators cannot precisely coordinate motions of two leadscrews.

Advantages:

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- * Complex contours can be generated
- * Machines can be equipped for rapid production

Disadvantages:

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- * Guiding devices may be expensive and difficult to produce.

Role In Industry:

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- * Is used in cases producing complex contours
- * Its use is justified in mass-production operations (such as those found in automotive and appliance industries) because of costly tooling and set-up.
- * More economical where models (or templates) can be built easily and where large numbers of parts are required.

(3) TRANSFER LINE:

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Workpiece is automatically carried along a line where machining operations are performed successively at a series of work stations.

Advantages:

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- * Rapid Production
- * Repetitive Accuracy
- * Low Labor Costs

Disadvantages:

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- * High equipment costs, which makes the method economical only for mass production.

(4) NUMERICAL CONTROL:

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Principle is similar to manual control, except that precisely controlled servomotors replace the human operator. Servomotors drive the leadscrews to produce either curved or straight cuts (depending on the machine tool capability).

Advantages:

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- * Produces shapes that cannot be produced economically by any other method.
- * Provides short lead times
- * Provides repetitive high precision
- * Provides low scrap rate
- * Fixturing costs and labor costs are low
- * Provides short lead times

Disadvantages:

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- * High equipment costs
- * Need of skilled programmers
- * Complex shapes require computer assist to program.

Role in Industry:

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- * If the machining of the part is simple, numerical control (NC) may not be economical unless some 10 to 30 parts are needed. Below this number, manual control probably is least costly. But for larger quantities, labor savings and more rapid production possible with NC usually begin to outweigh the cost of preparing a tape. For several thousands of parts, transfer lines (and other special machinery) are generally faster and more economical than NC AS A RULE OF THUMB FOR MAXIMUM ECONOMICAL QUANTITIES FOR NC: SEVERAL HUNDRED PIECES.

- * Basic machinery and controls for NC are generally costly.

BASIC TYPES OF NUMERICALLY CONTROLLED MACHINES:

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Generally, in NC, a leadscrew driven by a motor provides motion in one direction. A second motor-driven leadscrew is put perpendicular to the first. Through those leadscrews we can position a device within a given area.

The classification of basic types of NC is based on the type of motors being used:

- * Synchronized Motors
- * Unsynchronized Motors

. CONTINUOUS-PATH NC

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This type is based on SYNCHRONIZED SERVOMOTORS. In such cases, the motors can be coordinated to operate at different speeds always at some precise ratio to each other, then controlled curves or off-axis paths can be generated by the two motors operating simultaneously.

Such machines can produce contours as well as straight line cuts, drilling & boring. In general terms, they are also required where any type of curved cutter path is called for

I. POINT-TO-POINT NC

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This type is based on UNSYNCHRONIZED SERVOMOTORS. In such cases only the final leadscrew position is controlled precisely. The position of the moving head can be assured only upon completion of a movement, or while only one motor is running.

Such machines are used for:

- * Straight line cuts (only one motor running)
- * Other operations that can be performed at a given position (all positioning motors stopped) such as:
 - Drilling
 - Boring

FUNDAMENTAL DIFFERENCE BETWEEN THE TWO TYPES OF NC:

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Suppose the motors were instructed to move the machining head from a point A of coordinates (2,0,0) to a point D of coordinates (0,1,3), (FIG. 2) the machining heads would move there by different paths:

For Point-To-Point m/c's:

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All three servomotors would begin operation, then each would shut off on reaching the proper station for its axis. Thus, motion goes as follows:

- * The three motors working simultaneously would carry the head from point A (2,0,0) to point B (1,1,1)
Then the y motor is stopped
- * The head would be carried to point C (0,1,2)
Then the x motor is stopped
- * The head is finally carried to point D (0,1,3)
Then the z motor is stopped.

For Continuous-Path m/c's:

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All three servomotors would begin operation, running continuously at speeds proportioned to generate a straight line from A to D directly.

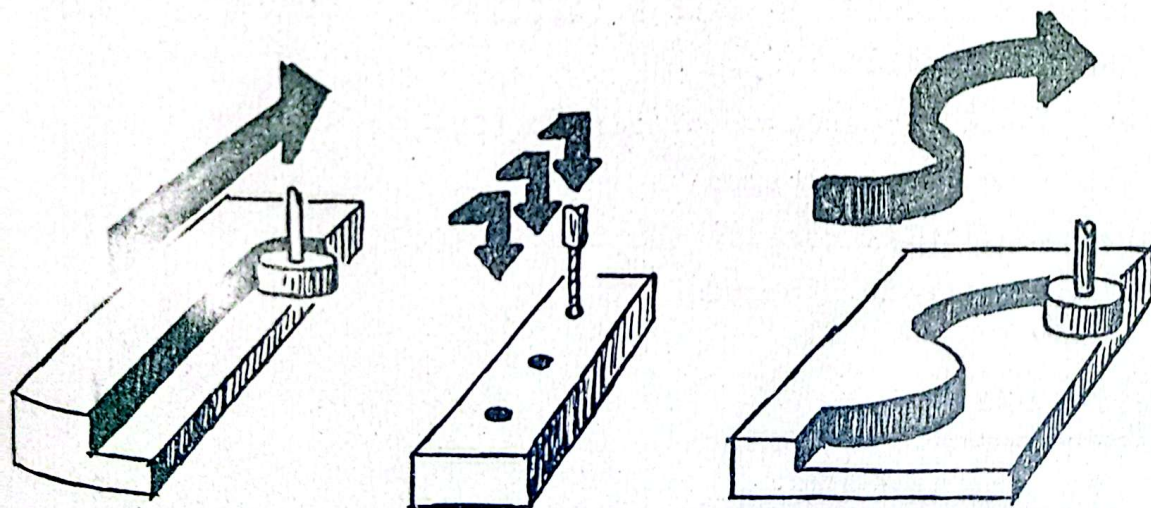
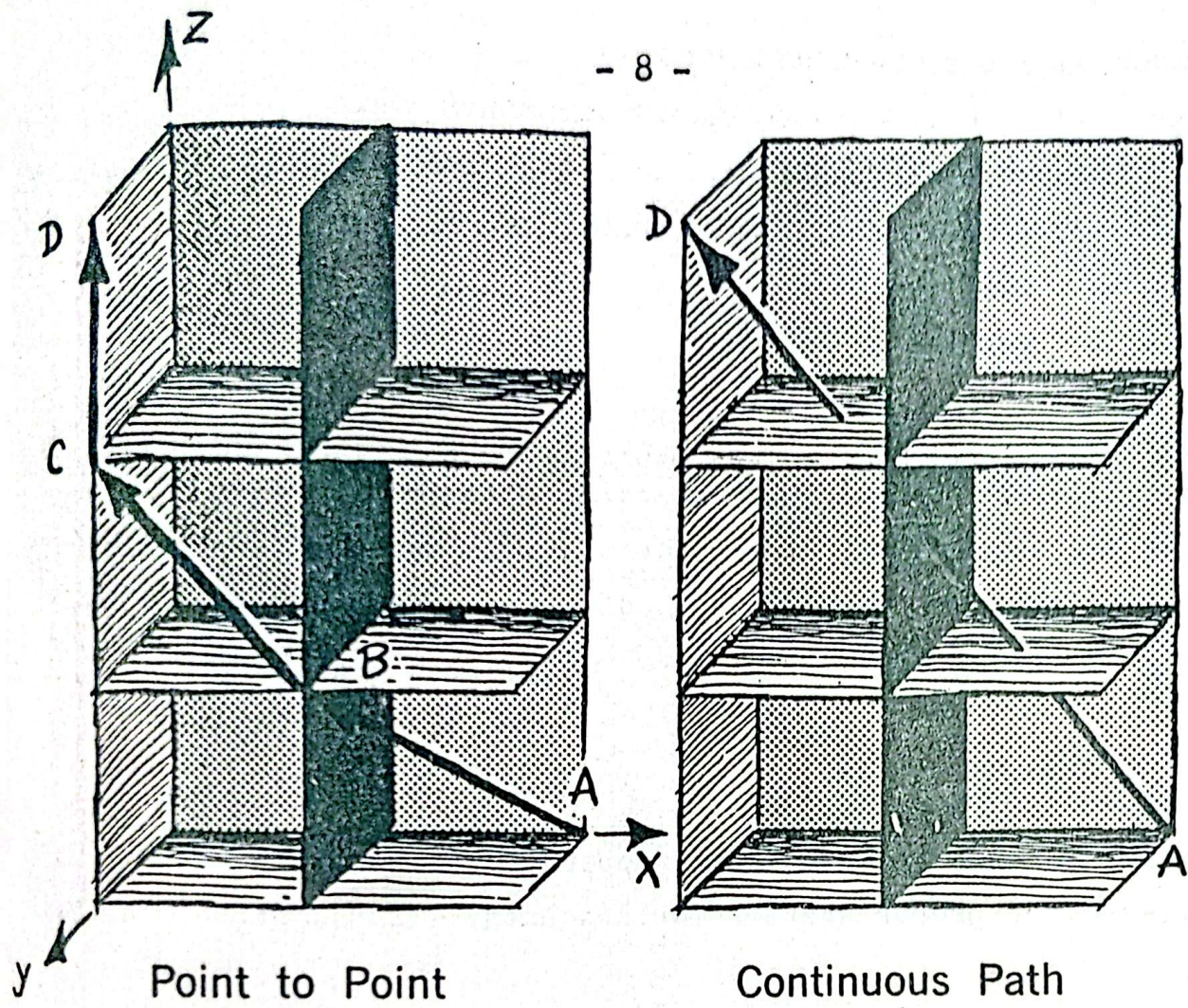


FIG. 2

Given below, typical uses for each of those classes in the two NC areas of operation:

TWO-AXIS, POINT-TO-POINT m/c's are generally used for parts requiring limited boring, drilling, or straight line milling, such as:

- * Drilling holes in a gear blank

THREE-AXIS - FIVE AXIS, POINT-TO-POINT m/c's are typically used to mill and drill parts such as:

- * Engine blocks and pump housings
- * Carriage fitting for jet transport

CONTINUOUS-PATH AREA

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TWO-AXIS, CONTINUOUS PATH m/c's are generally used to sculpture links, cams, brackets and "two-dimensional" structural members, such as:

- * Precise contouring of impeller walls

THREE-AXIS, CONTINUOUS PATH m/c's provide three-dimensional form for parts, such as:

- * Machining frames with ribs and rings
- * Engine nacelle fairing (for research aircrafts)

FIVE-AXIS, CONTINUOUS PATH m/c's are used for parts where design is tied closely to mathematical descriptions in three dimensions, such as:

- * Carving out pump impellers
- * " " compressor vanes
- * Spacers (sculptured from a tube)

In most of machining operations, more flexibility can be achieved by shifting the part from machine to machine to pick up whatever features each

has to offer. As an example, a pump housing may be shifted from a point-to-point machine (where numerous off-axis holes are drilled) to a continuous-path machine (where a compound-curve surface is milled).

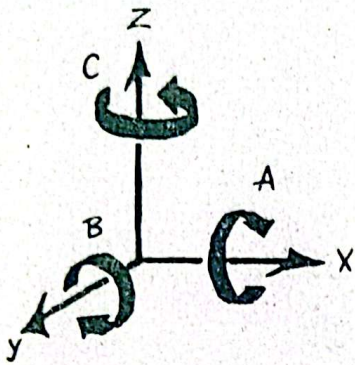
CLASSIFICATION OF NC ACCORDING TO THE NUMBER OF AXES AVAILABLE FOR
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CUTTER MOTION:
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Whether point-to-point or continuous-path, the capability of NC m/c depends on the number of axes in which it can operate. In specifying motions the conventional three-dimensional Cartesian coordinates are used, with motion along and about each of three axes. M/c's operating in more than three axes nearly always have continuous-path capability, but sometimes are used for point-to-point work.

GROUP A of sketches illustrates three different cases each with different no. of axis

GROUP B of sketches illustrates what NC can do in each of the three cases.



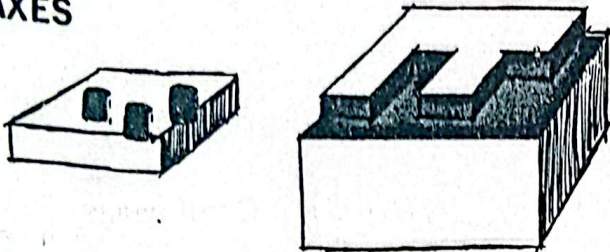
	Point to Point	Continuous Path
TWO AXES Movement or stepped motions to any point on a plane.		
THREE AXES Movement or stepped motions to any point in space, but with constant orientation of cutting tool.		
FIVE AXES Movement or stepped motion to any point in space with cutting tool oriented at any angle.		

GROUP A
FIG. 3

What NC Machining Can Do

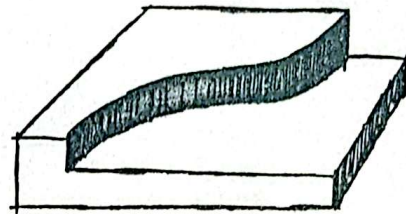
Point to Point

TWO AXES



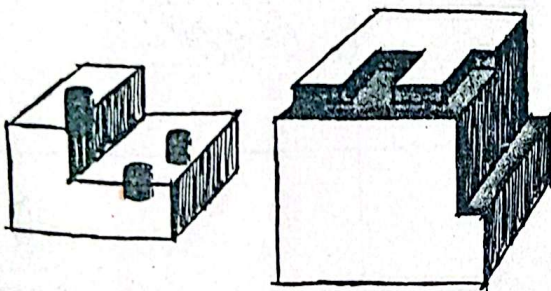
Straight-line cuts on a plane, or holes of equal depth drilled (or bored, tapped, etc.) anywhere on a surface.

Continuous Path

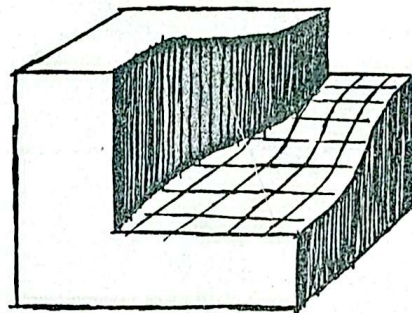


Contours in two dimensions.

THREE AXES

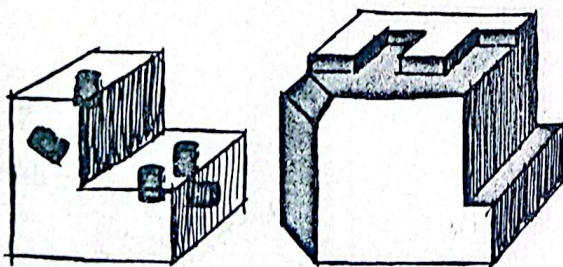


Straight-line cuts in three dimensions, or parallel-axis holes drilled to any depth from any starting point.

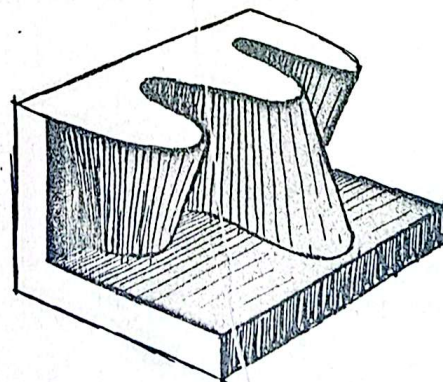


Contours in three dimensions, but with cutting head held at a fixed orientation.

FIVE AXES



Straight-line cuts in any direction, or holes drilled from any surface to any depth at any orientation.



Continuously controlled motion and orientation of cutting tool anywhere in space. Ruled surface (similar to that of a curved and twisted ribbon) possible with one pass of the tool.

GROUP B

FIG. 4

MANUAL PROGRAMMING & COMPUTER PROGRAMMING:

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Programming is the process of writing the group of instructions , telling the numerically controlled m/c where to move the cutter in order to form a part. This involves the following:

- (1) Defining the part to be cut.
- (2) Describing the sequence of m/c'g operations needed to obtain the final shape.
- (3) Defining the location of the tool relative to the w/p during each of the m/c'g operations.
- (4) Describing the sequence of events which occur as the location of the tool changes.

From this definition, we might expect programming not to be difficult since it seems merely to involve defining the surface of the part to be cut, the sequence of cutting operations and necessary tools. Actually programming is not this simple.

The complexities of programming derive from the necessity of defining precisely where the tool is to be at any given instant and the great number of mathematical calculations required to determine these points. The degree of complexity spans from the simplest algebra to the most rigorous solid and analytical geometry. The time required for their manual execution is commensurate with the degree of effort required. And this can be both speeded and simplified with computer assistance.

Another difficulty then occurs in combining this information about the tool movements with machining instructions in a format which a particular combination of machine tool and control system will understand. Computer programming will automatically take care of this..

A third complexity arises from dimensional considerations. Since the cutting tool has a radius, the path of the tool centerline (not the part surface) must be defined for the m/c. This added wrinkle may make it difficult to program even relatively simple two-dimensional shapes. In most cases, the tool offset calculations require only trigonometry, but the computations are so tedious and time-consuming that the required manpower is costly and errors are frequent. The alternative is to let a computer make the tool-offset calculations.

Based on this analysis, we notice that there are two types of programming:

- 1 - Manual Programming
- 2 - Computer Programming

Manual Programming:

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Manual Programming is widely used in industry, and the method contains the fundamental elements upon which the computer programming methods are based.

Basic Requirements In Programmers:

- 1 - Machining knowledge
- 2 - A Mind With Logical Thought Processes
- 3 - Good Visualization
- 4 - Attitude & Maturity
- 5 - Good Knowledge of Trigonometry & Arithmetic
- 6 - Background In Computer Programming

Generally, the programming operations can be classified as follows:

- A . Selecting The Cutting Tool
- B . Calculating The Cutter Path
- C . Specifying The Machine Parameters.

There are frequent cases where the part to be produced is of complex shape needing complicated machining operations. In such cases, manual programming ceases to be practical and we have to ask our sincere friend, the computer, for desperate help!

Computer Programming: =====

Before starting our brief presentation of computer programming, we would better bear in mind the following remarks:

- 1 - The computer cannot think, but it can do whatever we tell it to, and it is programmed by the smartest brains.
- 2 - The computer can do no more than what a man can do; but it is infinitely faster and does not get tired.
- 3 - The computer never makes a mistake unless he is programmed incorrectly. Then it will stop and tell us about it. More than likely, he will tell us exactly where the mistake is.

Instructing The Computer =====

We can describe the part to be machined in the appropriate NC language (some of which will be mentioned in the next chapter), and in seconds the computer will do all the mathematical calculations and prepare (by means of the postprocessor) a tape for the machine tool coded in the format that the tool will accept and understand.

The computer does more than that, too. For example, if there is a long departure to make, it knows how much the machine tool we are using can take in one step, and breaks it down into shorter segments if it is needed. Same thing about spindle speeds; if the programmer calls for a spindle speed that the machine cannot produce

the computer finds one that will work. So it is with feed - rate, too. The computer won't let you go too fast if the machine cannot go as fast as you would like to. These are only a few of the things that the computer knows about the machine and control system through the postprocessor.

PROGRAMMING LANGUAGES

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There are perhaps dozens of computer languages for programming NC equipment. Some languages are designed only for simple point-to-point work; others for continuous path operation. While most programs are designed for general-purpose use (processor and post-processor are separately used to allow the output to be used for any control system), some others are designed for specific equipment (in such cases there is no need to separate processor and post processor). Some programs can be used only on particular computers; others can be used on a variety of computers. In very particular cases, programs are developed within a single company to meet special needs. Among this wide array, the languages given in the following table are considered to be major languages.

NAME	MEANING	CLASSIFI- CATION	AXES	APPLIED TO	REMARKS	DEVELOPED & USED
APT	Automatic Programming for Tools	Continuous Path	5	IBM 7090 UNIVAC CDC		MII, IIT & IBM 1955
AD.APT	Mini APT	" "	2	IBM 1620	Not Widely used	UBM
AUTOSPOT	AUTOmatic SPotting of Tools	Point-To- Point		IBM 1620 IBM 1130	Used For Milling	IIT & IBM 1963
PROFILEDATA		Continuous Path	2½	ICL 1900		FERRANTI (ICL)
AUTOPOL	AUTOmatic Programming Of Lathes	" "	2	IBM 1130 IBM 360		IBM (very Recent)
2C,L	2 axis Continuous one axis straight Line	" "	2	UNIVAC ELLIOT ICL	Subset & Exten- Sion of APT	FERRANTI (ICL)
EXAPT I		Point-To- Point	3		Used for Drill- ling	
EXAPT II	Exceptional APT	Continuous Path	2	IBM 360	" " Turn- ing	3 German Institu- tions
EXAPT III		" "	2½		" " 2½ D Contouring	

In the field of Numerical control (NC), general purpose programming systems consist of two parts:

- 1 - A Programming Language
- 2 - A Number of Computer Programmes

THE PROGRAMMING LANGUAGE:

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Is used to describe:

- 1 - The geometry of the part to be produced
- 2 - The tools to be used
- 3 - The tool motion to cut the desired part

THE COMPUTER PROGRAMMES:

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They are divided in two main sets

- 1 - ~~THE PROCESSOR:~~
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- Is the first set of programs. This is used within the computer to interpret the statements written in the programming language by the part program, evaluate them and calculate a general solution.

THE GENERAL SOLUTION:

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Called "CUTTER LOCATION DATA", is the result of geometric calculations which were executed to solve the problem of calculating the path of one geometric body, the TOOL, over another geometric body, the PART. The General Solution is M/C TOOL INDEPENDENT. It will be stored on an intermediate storage device such as disc or magnetic tape.

2 - THE POST PROCESSOR
=====

Is the second set of programs. It is used to adapt the general solution generated by the processor to a specific M/C tool with a specific control unit. This is generally supplied by M/C tool manufacturer for each of his Machines.

The Relation between those different parts are shown by the following chart :

How the Tape Talks to the Machine Tool

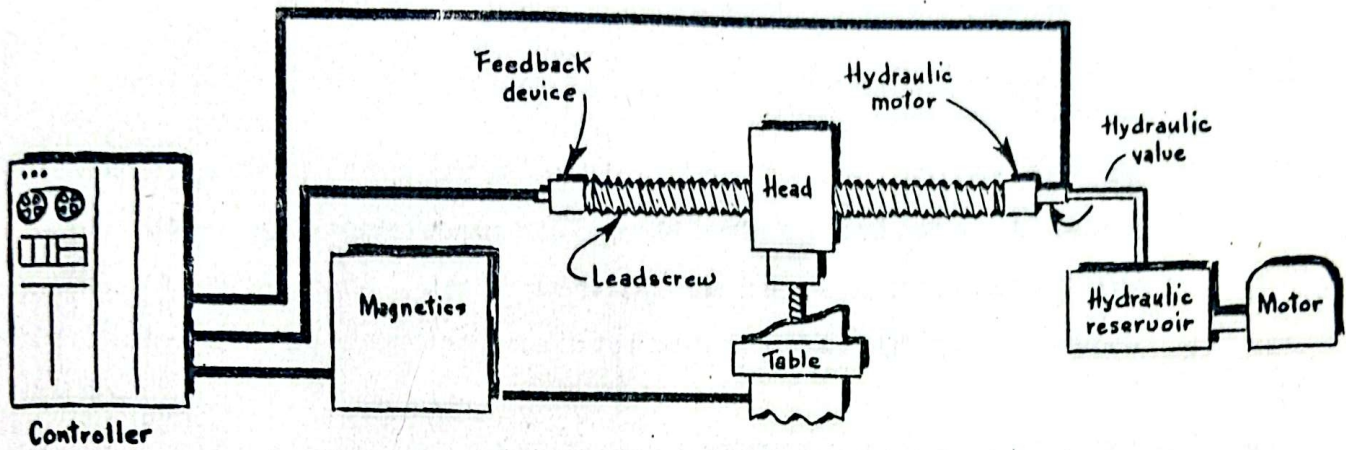


FIG. 5

How the Computer Talks to the Tape

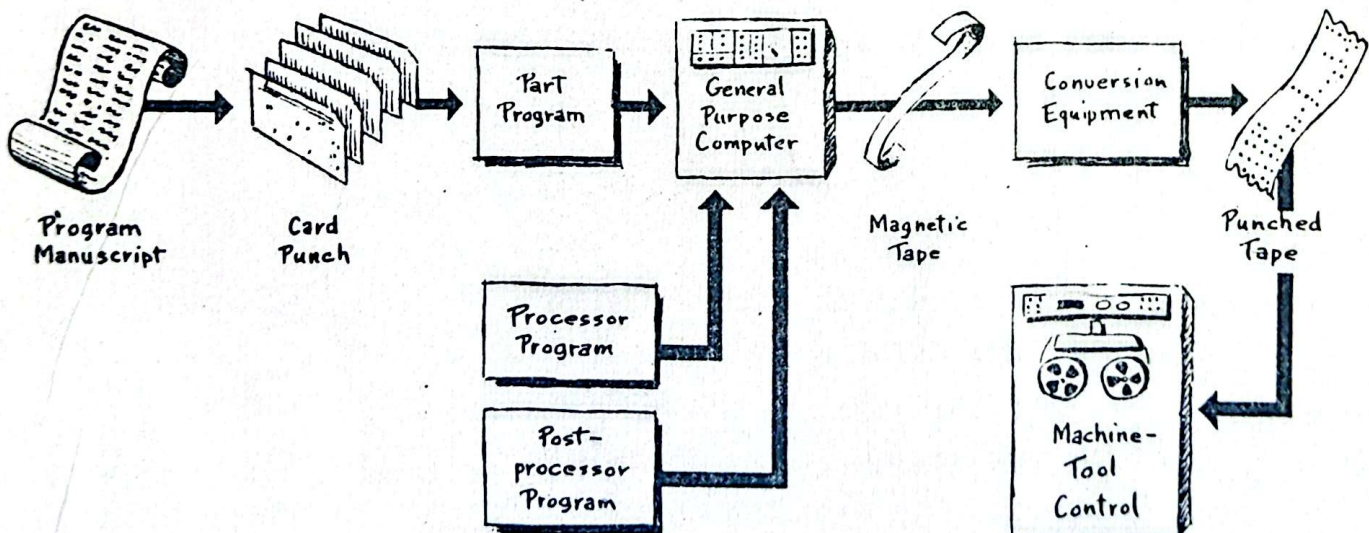


FIG. 6

STRUCTURE OF PART PROGRAM

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I . CONSTANTS:

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1. Type of M/C, either a or b
 - a) Standard M/C (Path control M/C)
 - b) One Dimensional M/C (Track control M/C)
2. Actual Power of the M/C
3. Maximum Torsion The M/C can stand
4. Cutting Reaction
5. Proportional Factor
6. Preceding Spindle Table
7. Post Processor Indicator

II . TOOL DETAILS:

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1. Type of Used Tool Set
2. Description, Specifications & Dimensions, of Each Used Tool as required by post processor.

III. AVAILABLE SPEEDS OF MOVING PARTS:

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1. Spindle Speeds (In Case of Lathes, For Example)

IV . GEOMETRY DESCRIPTION:

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1. Before Machining (Blank)
2. After Machining (Final Shape)

V . MACHINING OPERATIONS:

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Full Description of all Machining Operations (In The Right Sequence & In Specified Direction) which have to be performed on the blank to arrive at the final shape.

In the next few pages, an illustration Using The AUTOPOL is presented.

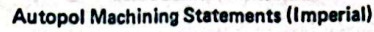
Autopol Machining Statements (Imperial)

Sheet 3 of MACHINING

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12345678910111213141516171819202122232425262728293031323334353637383940414243444546474849505152535455565758596061626364656667686970717273747576777879808182838485868788899091929394959697989910010110210310410510610710810911011111211311411511611711811912012112212312412512612712812913013113213313413513613713813914014114214314414514614714814915015115215315415515615715815916016116216316416516616716816917017117217317417517617717817918018118218318418518618718818919019119219319419519619719819920020120220320420520620720820921021121221321421521621721821922022122222322422522622722822923023123223323423523623723823924024124224324424524624724824925025125225325425525625725825926026126226326426526626726826927027127227327427527627727827928028128228328428528628728828929029129229329429529629729829930030130230330430530630730830931031131231331431531631731831932032132232332432532632732832933033133233333433533633733833934034134234334434534634734834935035135235335435535635735835936036136236336436536636736836937037137237337437537637737837938038138238338438538638738838939039139239339439539639739839940040140240340440540640740840941041141241341441541641741841942042142242342442542642742842943043143243343443543643743843944044144244344444544644744844945045145245345445545645745845946046146246346446546646746846947047147247347447547647747847948048148248348448548648748848949049149249349449549649749849950050150250350450550650750850951051151251351451551651751851952052152252352452552652752852953053153253353453553653753853954054154254354454554654754854955055155255355455555655755855956056156256356456556656756856957057157257357457557657757857958058158258358458558658758858959059159259359459559659759859960060160260360460560660760860961061161261361461561661761861962062162262362462562662762862963063163263363463563663763863964064164264364464564664764864965065165265365465565665765865966066166266366466566666766866967067167267367467567667767867968068168268368468568668768868969069169269369469569669769869970070170270370470570670770870971071171271371471571671771871972072172272372472572672772872973073173273373473573673773873974074174274374474574674774874975075175275375475575675775875976076176276376476576676776876977077177277377477577677777877978078178278378478578678778878979079179279379479579679779879980080180280380480580680780880981081181281381481581681781881982082182282382482582682782882983083183283383483583683783883984084184284384484584684784884985085185285385485585685785885986086186286386486586686786886987087187287387487587687787887988088188288388488588688788888989089189289389489589689789889990090190290390490590690790890991091191291391491591691791891992092192292392492592692792892993093193293393493593693793893994094194294394494594694794894995095195295395495595695795895996096196296396496596696796896997097197297397497597697797897998098198298398498598698798898999099199299399499599699799899910001001100210031004100510061007100810091010101110121013101410151016101710181019102010211022102310241025102610271028102910301031103210331034103510361037103810391040104110421043104410451046104710481049105010511052105310541055105610571058105910601061106210631064106510661067106810691070107110721073107410751076107710781079108010811082108310841085108610871088108910901091109210931094109510961097109810991100110111021103110411051106110711081109111011111112111311141115111611171118111911201121112211231124112511261127112811291130113111321133113411351136113711381139114011411142114311441145114611471148114911501151115211531154115511561157115811591160116111621163116411651166116711681169117011711172117311741175117611771178117911801181118211831184118511861187118811891190119111921193119411951196119711981199120012011202120312041205120612071208120912101211121212131214121512161217121812191220122112221223122412251226122712281229123012311232123312341235123612371238123912401241124212431244124512461247124812491250125112521253125412551256125712581259126012611262126312641265126612671268126912701271127212731274127512761277127812791280128112821283128412851286128712881289129012911292129312941295129612971298129913001



MACHINING

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PROCESSOR

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The PROCESSOR is composed of Two Phases:

PHASE I:

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Contains a series of Instructions & Logical Tests used to calculate Individual cuts (using Information In part Program), checks the feasibility of each cut and of all cuts together. If there are any errors, they are printed out. The errors might be due to one or more of the following items:

- a) Incomplete, or missing, blank specification
- b) Incorrect Geometry description
- c) Invalid Tools' Specification
- d) Invalid Feedrate or Speed
- e) Invalid Machining Operation
- f) Invalid Initial Blank Setting
- g) A Missing Part In the Part Program

If there are no errors, PHASE I generates:

- a) **CONTOUR TABLE:** Full accurate detailed description of the finally machined part including all dimensions, showing all special features such as Bevels, Grooves, Undercuts, counter-sinks if any is present in the part.
- b) **MACHINING TABLE:** Detailed description of exact sequence of machining operations using the right tools for specified distances and depths of cut.

PHASE II:

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The processor performs further checks to see whether the machining of the part altogether is feasible or not. Such as: Machining of adjoining Surfaces, Sequence of Machining Directions, Existence of Stochastic Machining Operations (which have to be divided into shorter and easier operations), Invalid Finishing, Invalid Grooving or Beveling, checking whether roughing comes before finishing (for different faces) or not. If there are any errors, they appear on the printout and post processing is interrupted. In case of Warning errors, post processing continues.

PROCESSOR SOFTWARE:

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The processor is composed of a deck of FORTRAN IV statements including all the Instructions & Validity Tests Necessary to perform the processor functions previously analyzed. The necessary SUBROUTINES for different cutting actions, tools placing and moving, adjusting feeds and depth of cuts; special Purpose subroutines are also included such as, for example,

- * Subroutine For Reaming
- * Subroutine For Thread Cutting
- * Subroutines For Grooving:
 - 1) Ordinary Grooves
 - 2) Grooves With Bevels
 - 3) Grooves With Inclined Roots.

As an example, the IBM AUTOPOL PROCESSOR is composed of 8000 FORTRAN IV cards stored on a disc, a FORTRAN IV COMPILER is needed.

HARDWARE NEEDS:

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Needs differ according to type of processor, the IBM AUTOPOL PROCESSOR needs, on the minimum:

	IBM - 360/25	DOS	32K	2 DISKS
or	IBM - 1130	Monitor	16K	1 DISK

NC TAPES:

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Although control information for an NC system may be on punchedcards, magnetic tape, or any of the data-processing media, eight channel tape is one of the most commonly used forms.

Each machine operation is represented by a "block" of information on the tape. Cutter path information (coordinate values), codes for auxiliary functions, and feed and speed values have to be combined in control blocks. The function of the postprocessor is to form those blocks in the core memory of the computer in the format that is required for the control unit utilizing the tape. Blocks are usually punched ten-by-ten on the tape and there are (at least) 10 blocks in the core storage kept for probability of alterations due to m/c tool dynamics considerations.

On the tape, blocks are separated by an end of block notation. The following tape shows an example of a tape from Dynapath Tape Preparation Manual (Bendix Industrial Controls Div., Detroit, Mich., USA).

TAPE CHANNEL 7 6 5 4 3 2 1							CHARACTER DIGIT OR CODE	DESCRIPTION
0							0	Digit 0
							1	Digit 1
							2	Digit 2
							3	Digit 3
							4	Digit 4
							5	Digit 5
							6	Digit 6
							7	Digit 7
							8	Digit 8
							9	Digit 9
							a	Angular dimension around x axis
							b	Angular dimension around y axis
							c	Angular dimension around z axis
							d	Angular dimension around special axis or third feed function
							e	Angular dimension around special axis or second feed function
							f	Feed function
							g	Preparatory function
							h	Unassigned
							i	Distance to arc center parallel to x.
							j	Distance to arc center parallel to y.
							k	Distance to arc center parallel to z.
							m	Miscellaneous function
							n	Sequence number
							p	3rd rapid traverse dimension parallel to x.
							q	2nd rapid traverse dimension parallel to y.
							r	1st rapid traverse dimension parallel to z.
							s	Spindle speed
							t	Tool function
							u	Secondary motion dimension parallel to x.
							v	Secondary motion dimension parallel to y.
							w	Secondary motion dimension parallel to z.
							x	Primary x motion dimension
							y	Primary y motion dimension
							z	Primary z motion dimension
							.	Decimal point
							, (comma)	Unassigned
							√ (check)	Unassigned
							+	Positive sign
							-	Negative sign
							Space	Unassigned (used as leader with parity)
							Delete	Error delete
							Carriage return	End of block (execute)
							Tab	Tab
							Stop code	Rewind stop
							Tape feed hole	Leader
							/	Slash code

FIG. 8

POST PROCESSOR

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As a result of PHASE II, information is obtained on a CLTAPE (or CLFILE). The CLTAPE and the post processor (usually stored on a disc or a magnetic tape) are fed into a computer together.

Here the post processor takes the data defining the previously calculated path of the cutter and adapts it to:

- (1) The specific m/c Tool that is to produce that part
- (2) The specific make and model of NC system used to run that m/c.

In more simple terms, the post processor does (automatically at a very high speed and accuracy) what a human would do if he were an expert in the particular combination of m/c tool and control system involved; knowing the capabilities, operating procedures and limitations of the m/c tool; being experienced in the format and coding that the control requires.

What Does A Post Processor Do?

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- (1) Takes the data from the CLTAPE and tailors it to the particular metalworking equipment to be used.
- (2) Checks limits of travel (to make sure the programmer hasn't programmed the work table off the slides of the m/c!)
- (3) Checks the speeds and feeds and dynamics of acceleration.

- (4) Interprets the auxiliary commands such as:
 - * Coolant control
 - * Spindle control
 - * Tool change
 - * Position of Indexing Table
 - * Feed control
 - * Tool Load
 - * Tool Length
 - * Position of the Turret
 - * Machining Tolerance
 - * Rewinding the control Tape
 - * Delay Time
 - * Program End
- (5) Recognizes and conflicts between the part program and the m/c tool and makes compromises if possible
- (6) Encodes all this information into the special Language of the particular make and model of control that is to be used.

As a result, a printout is produced containing:

- (1) A complete guide to the entire program
- (2) Information needed to help the programmer in trouble - shooting or to guide in operating the machine
- (3) Error & warning messages.

In case of no errors, a paper tape is produced containing all necessary information to operate the controller which, in turn, operates the m/c tool. A special Plotting subroutine can be called, it causes a graph plotter to produce an image of the machine tool in its final shape.

Writing Post Processors:

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Post Processors are supplied by the m/c tool manufacturer for a particular type (or class) of machines. To write the post processor, it takes about 2-3 man months with experience in programming and m/c tool operation. To show the enormous amount of work involved in writing it, if we consider computer commands, a typical post processor includes from 8000 to 10000 commands on the average.

ECONOMIC ASPECTS OF NC

=====

In this section, I will analyse the cost of NC in comparison with conventional manual production and transfer line way of production.

We know that conventional manual production, numerical control and transfer lines each have different initial costs, i.e. preproduction costs. These costs include the costs of preperation, tools and fixtures and fixed overheads. The additional costs per piece, made up of labour costs, machine time costs and variable overheads, will be falling in the same order as the initial costs are rising. Thus there must be limits of batch sizes somewhere within which each method of production is more economic than the other two.

There limiting batch sizes can be found by plotting a graph in accordance with this figure:

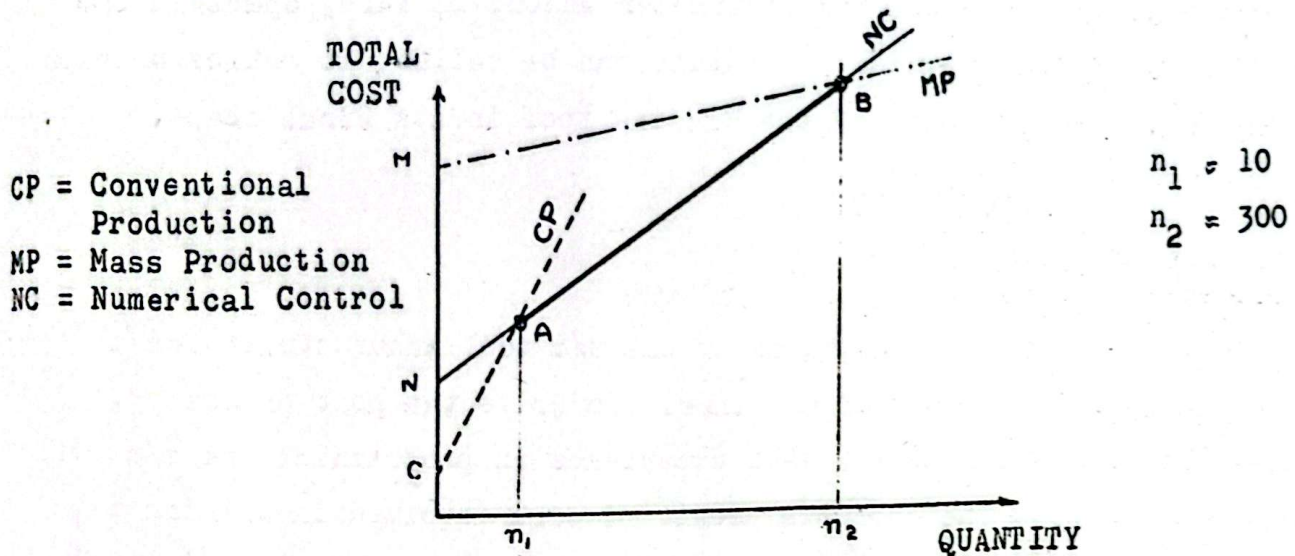


FIG. 9

When the initial costs plus the costs per piece are plotted against batch size, a straight line is obtained for any of the three production methods.

Points C, N & M indicate the initial costs for conventional Production, Numerical Control (comprising programming costs) & Mass Production (comprising tooling costs).

It can be seen that along the portion AB of NC line, NC is more economic than either of the other two methods.

The two break - even points 1 and 2 will determine the smallest batch n_1 and the largest batch n_2 respectively, for which NC can still be considered. Analysis of actual data available so far indicates that

$$\begin{aligned} n_1 &\approx 10 \\ n_2 &\approx 300 \end{aligned}$$

Those figures are not necessarily per batch, because most of the initial costs are in the preparation of the tape, which can be conveniently stored for repeated use.

The smaller numbers will generally apply where the workpieces are complicated and the larger numbers where the components are simple,

In general, NC machine tools can be looked upon as a bridge between manual and mass production and therefore have a very wide application potential. The accuracy and speed of NC machining adds a weighing factor to the importance of its implementation.

	CONVENTIONAL PRODUCTION	NUMERICAL CONTROL
DRILLING Holes In Condenser Tube Plates	2172 Hours	350 Hours
TIME FOR OPERA- TING a Drilling M/C	100 Time Units	40 Time Units
COST OF OPERAT'G Multi-Operation M/C	£ 150,000 per year	£ 111,600 per year (equiped with auto- matic tool changing)

NC AND MANPOWER

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NC implementation does not mean, for a single moment, to sack the old blocks and replace them by a class of intellectuals. Normally it is possible to train existing labour for the new duties. Machine operators find that the job is less tiring, as the monotony of repetitive mental and physical work has been removed. There is less scrap and more pride in work.

The handling of a NC machine is somehow similar to handle a car: it gives both satisfaction and status. The present production engineer is a good candidate for becoming a programming engineer and consultants should find no difficulty in establishing good relations with staff and labour.

INFLEUNCE OF NC ON:

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BETTER MAN HOUR UTILISATION

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The reduction of time taken by operators to obtain jigs and equipment from stores, coupled with savings on setting up times for each operation, gives greater productivity.

MACHINE OPERATOR

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The machine operator's responsibility for producing a correct batch of components is greatly reduced. Depending on the sophistication of the numerically controlled machine, feed rate, spindle speeds, depth of cut, tool selection, operation sequence and, in fact, complete machining times are nominated on the tape.

All operations are carried out in relation to one another. Previously, setting up of subsequent operations and locating in fixtures was done by the operator.

With this reduction in responsibility, reliability for the fewer functions still carried out by the operator is greatly increased.

SETTING TIMES

=====

All feed rates, spindle speeds, rapid traverse, machine cycles, stops and miscellaneous functions such as coolant 'on/off' are automatically set by the act of placing the tape on the tape deck.

On conventional machines, the machine operator or setter is responsible for all these functions.

REDUCTION OF SCRAP AND REJECTS

=====

Higher production standards and accuracies are now becoming quite common. Numerically controlled machines meet these requirements on a production basis and minimize human error which results in scrap and sometimes heavy rectification at the assembly stage. Existing plant does not incorporate built-in repeatability or all production elements and this is often the cause of a high scrap rate.

REDUCTION OF INSPECTION TIME

=====

Repeatability alone automatically saves a considerable amount of time. Only one inspection is necessary (instead of the usual check after each operation) and as the inspector's confidence in numerical control grows, this, too, is sometimes eliminated.

PRODUCTION RATES

=====

Fully programmed numerical control can often be well in excess of three times faster than manually operated machines - particularly when applied to conventional short run methods.

It also gives a consistent production rate and eliminates the majority of time lost through fatigue allowances and so on.

In short, the first component, the twentieth and the hundredth will be identical, and there will be no new learning period with a change of operator.

HANDLING COSTS

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Handling costs are reduced because all component operations are produced at the machine centre. Using conventional methods, operations on components are spread around the works in different machining sections and are therefore constantly being handled and transported.

SPACE UTILISATION

=====

Because a machining centre replaces several conventional machines, large savings are made on floor space. Only one area around the centre is necessary, compared with work areas around numerous machines when using conventional methods.

This results in savings in building costs, rates, heating and lighting. Further savings are made because less stores space is needed for tooling.

STOCKS AND WORK IN PROGRESS REDUCTIONS

=====

Economical batch sizes can be drastically reduced by as much as 5:1. This reduces stock and work in progress, freeing capital for other purposes.

Reduction of work in progress also reduces floor space required and internal transportation needs.

PAPER WORK REDUCTION

=====

Paperwork costs today are high. Numerical control reduces this because fewer drawings are necessary. Overheads are cut further by reduction in the number of process sheets, internal orders, job cards, and piecework calculations.

LEARNING CURVE

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When small quantities are repeated only two or three times a year, possible production times are never reached on conventional machines because the operator never reaches the stage in learning to get optimum results.

With a numerically controlled machine centre, the 'know how', operator rhythm and reflex action is in the tape. High production rates are therefore attained immediately.

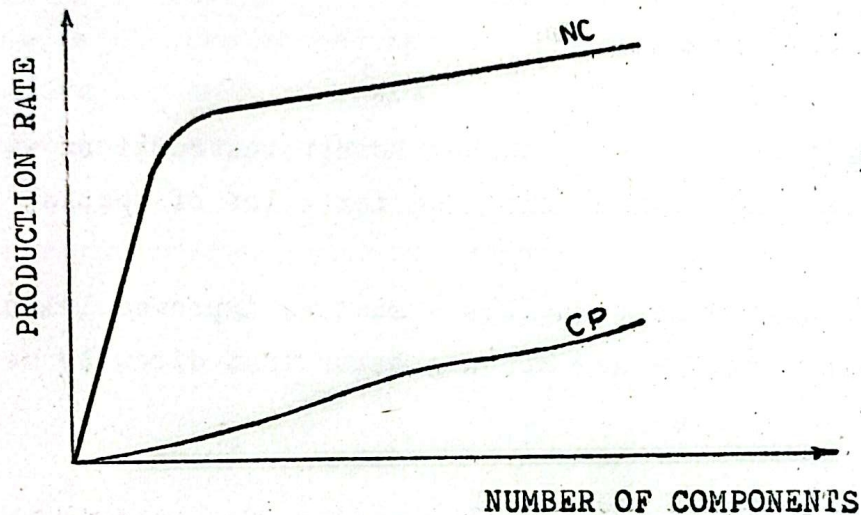


FIG. 10

COMPONENT PROGRESS FUNCTIONS

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Most machine shops are departmentalised: milling section, planing section, boring and drilling for instance. Progressing through this type of shop involves a progress man dealing with individual sections and a number of foremen or chargehands. This leads to difficulties in obtaining firm delivery dates for components making up a product.

With numerically controlled machining centres, where all operations on a component are completed at one time, progressing only involves one department and one supervisor.

COMPONENT INTERCHANGEABILITY

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Because of the inherent repeatability of numerically controlled machines, replaceable components - for spares - can be made in small batches without tooling.

REDUCTION OF LEAD IN TIMES

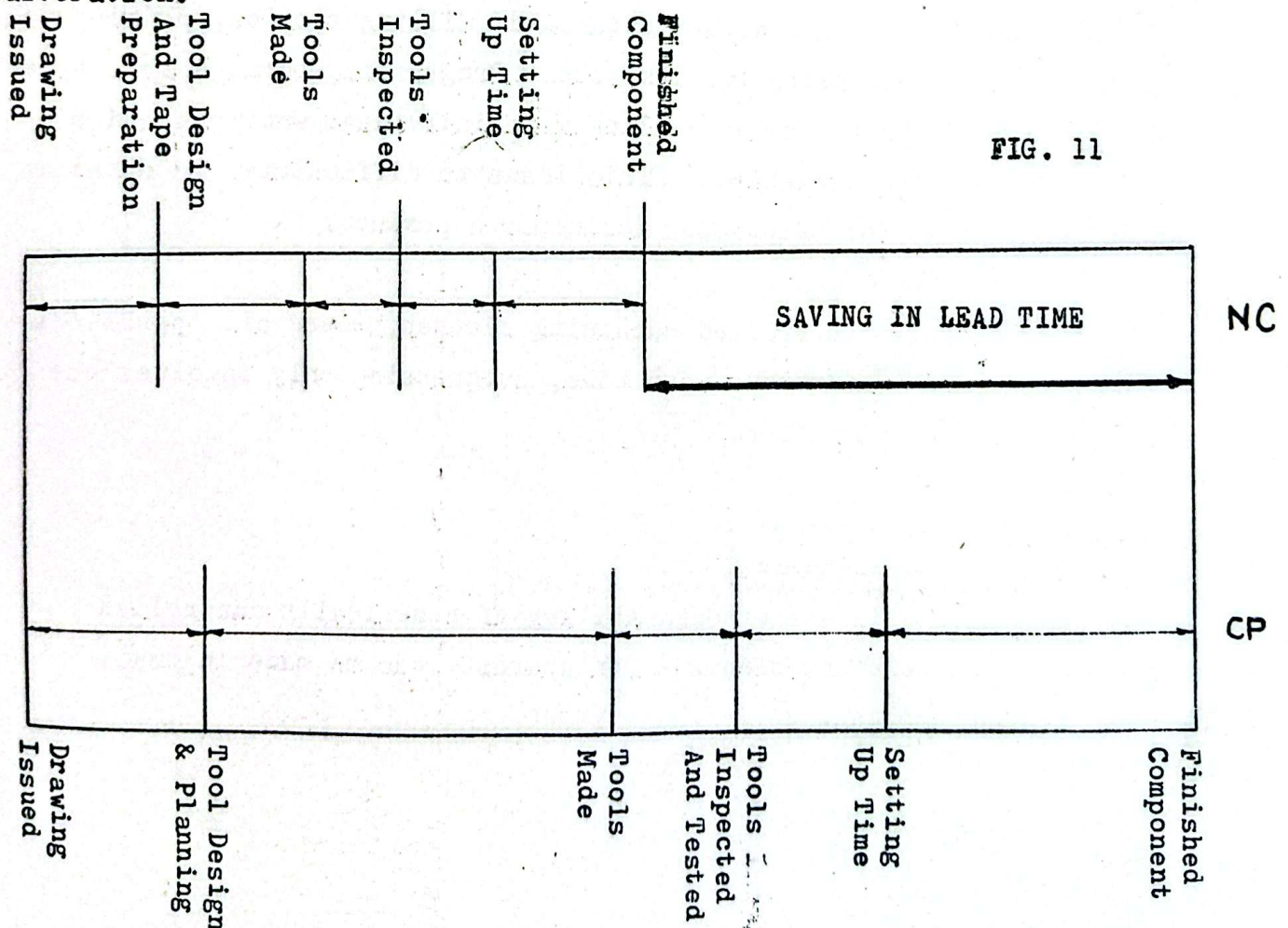
=====

Lead time is the time taken from issue of drawing from the drawing office to the actual cutting of metal. With numerical control, tooling is kept to a minimum and this makes the first major contribution to the reduction of lead in time.

Numerically controlled machines accept instructions with speed as well as accuracy and without the need for a lot of special tooling.

Other intangible cost savings - such as improved learning curve and reduced handling costs - are often greater than directly measurable savings.

Component modifications merely entail a few hours work on alteration of the tape compared with the long time delays with tooling redesign and alteration.



SHIFT WORKING

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With conventional machining, it is often difficult and sometimes impossible to use the two or three shift system economically on batch production. This is because of the necessity for duplication of setters or skilled operators and in many cases, the need to refer to such services as the drawing office, planning and rate fixing.

Numerical control obviates all of these.

