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NUMERICAL CONTROL SERIES

CONCEPTS OF NC

by

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INTRODUCTION

This article is the second in a series devoted to the NC field. In the previous article, I have tried to introduce, in a very simple & general way, NC basic features and overall construction of NC systems.

To gain perspective on the role of m/c'g,* it is necessary to review several important topics such as the various methods by which parts are m/c'd, this leads to classification of NC into Point-To-Point m/c's and continuous path m/c's.

Discussion of the various national definitions for the axes of motion shows the possibility of confusions to arise, an example of a neutral system gives an outlet from such dilemmas. Steps towards a unified international systems are also mentioned.

The capabilities of NC m/c's will be expressed as a function of the no. of axes of motion available on each. Examples of parts to be m/c'd on each type are also given.

Realising the importance of the control tapes as a basic feature of NC, a control tape is shown with different binary representations.

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* m/c'g = machining

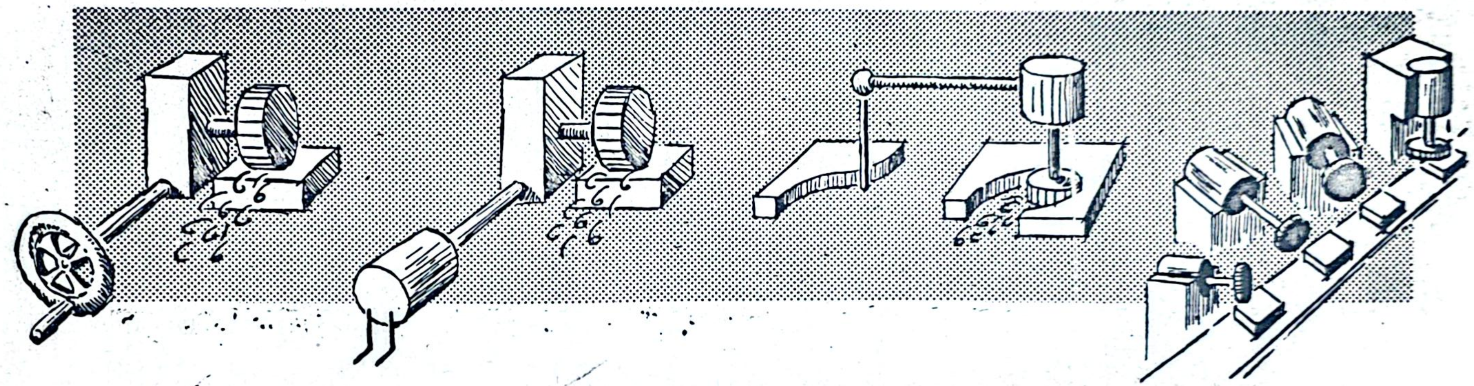
WAYS TO CONTROL CUTTING TOOLS:

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) TRACER 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.



MANUAL CONTROL

NUMERICAL CONTROL

TRACER CONTROL

TRANSFER LINE

FIGURE I CUTTING TOOLS WAYS OF OPERATION

1) MANUAL CONTROL:

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

Advantages: Low equipment and tool costs

Disadvantages:

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

Role In Industry:

- 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:

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 coodrinate motions of two leadscrews.

Advantages:

- Complex contours can be generated
- Machines can be equiped for rapid production

Disadvantages:

- Guiding devices may be expensive and difficult to produce.

Role In Industry:

- 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:

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

Advantages:

- Rapid Production
- Repetitive Accuracy
- Low Labor Costs

Disadvantages:

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

4) NUMERICAL CONTROL:

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:

- 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:

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

Role In Industry:

- 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.

ADVANTAGES OF TRACER CONTROL VS. THOSE OF NC

TRACER CONTROL	NUMERICAL CONTROL
	NC Tape costs less than templates or models for tracing
Basic Machinery are less costly than those needed for NC	
More economical, in general, where models can be built easily and where large numbers of parts are required	
	Some configurations may be too complex, even for tracer equipment, and must by cut by NC

Out of those four ways of control, we will be discussing Numerical Control in more detail.

BASIC TYPES OF NUMERICALLY CONTROLLED MACHINES:

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

I- CONTINUOUS-PATH NC

This type is based on SYNCHRONIZED SERVOMOTORS. In such cases, the motors can be coodrinated 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

II- POINT-TO-POINT NC

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:

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:

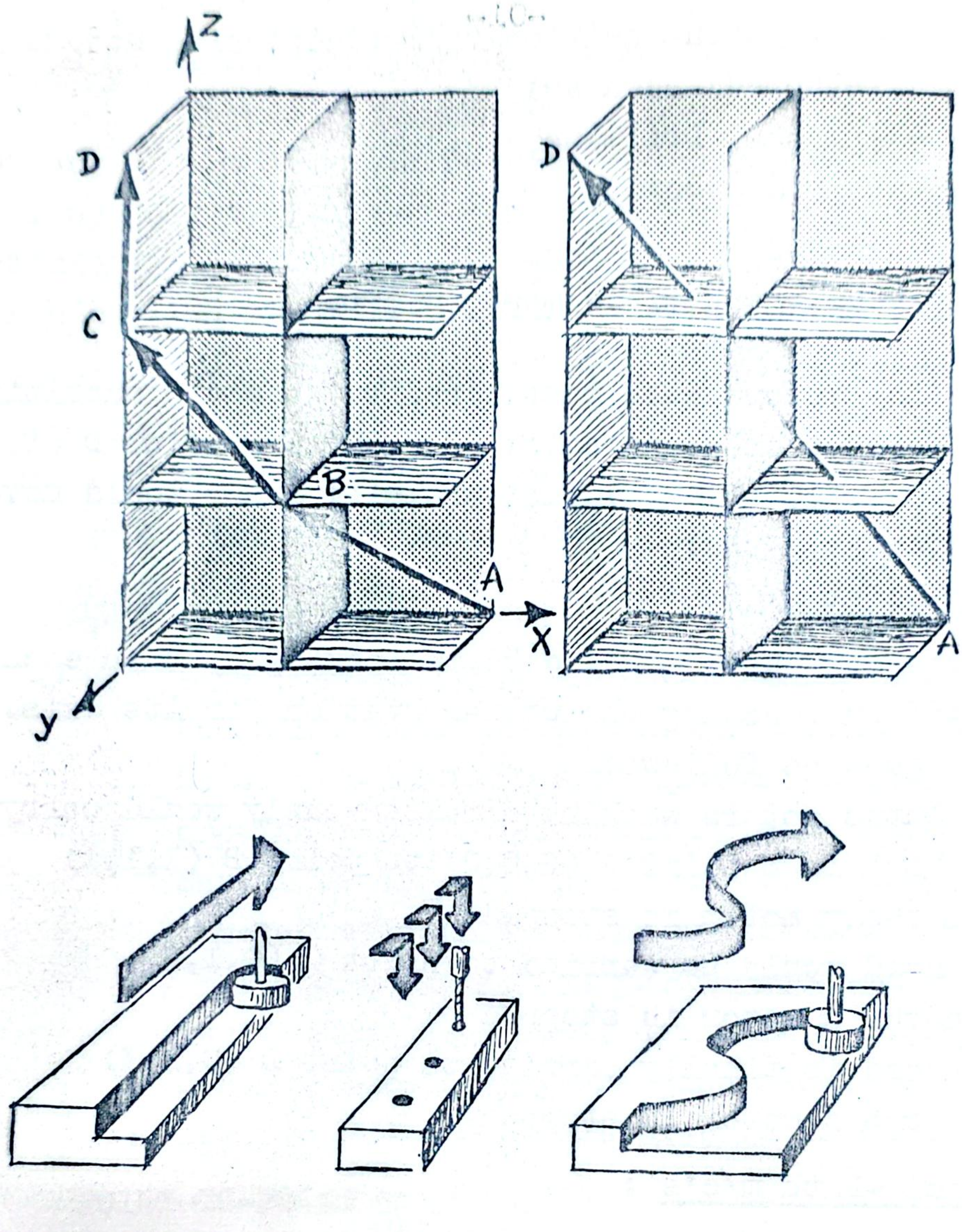
<u>For Point-To-Point m/c's</u> :

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.

<u>For Continuous -Path m/c's</u> :

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



POINT TO POINT CONTINUOUS PATH

FIG. 2 TYPES OF NC

INFLUENCE OF NC ON PART DESIGN

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 for the m/c shop. Fewer design promises are needed since complex shapes are easily specified and produced. It is now often more economical to sculpture 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. Examples and more detailed information will be illustrated later on. For the moment, we will discuss the role of each type of NC

POINT-TO-POINT machining provides no new fundamental capabilities in the design of parts, except in encouraging the use of one-piece, heavily machined components in place of assemblies. It may affect design exactly in the same way as anything that lowers costs, cuts lead time and speeds production may do. In general, a human operator can do anything that a point-to-point machine can do, but not as fast or as accurately.

CONTINUOUS-PATH machining is the type of NC that has greatly affected design. It provides the contouring ability of NC m/c tools and has made it feasible to utilize precisely defined, intricate shapes.

Continuous-Path machines do things that NO HUMAN OPERATOR (or even tracer-controlled m/c's) CAN DUPLICATE

Continuous-Path m/c's also have Point-To-Point capability.

NATIONAL DEFINITIONS FOR AXIS OF MOTION FOR NUMERICALLY CONTROLLED M/C TOOLS:

There are three different definitions for the axis and motions nomenclature for NC m/c tools, they are: American, Japanese, German. As a result of the trivial difference between the three systems, any other m/c tool manufacturer or user which does not belong to any of those countries is liable to face a considerable confusion. Therefore, I will try to present, in brief, the basic differences when applying definitions to three axis machining situations. Also, what a typical user (NEL*) has decided to consider from those definitions to adopt his NC situations.

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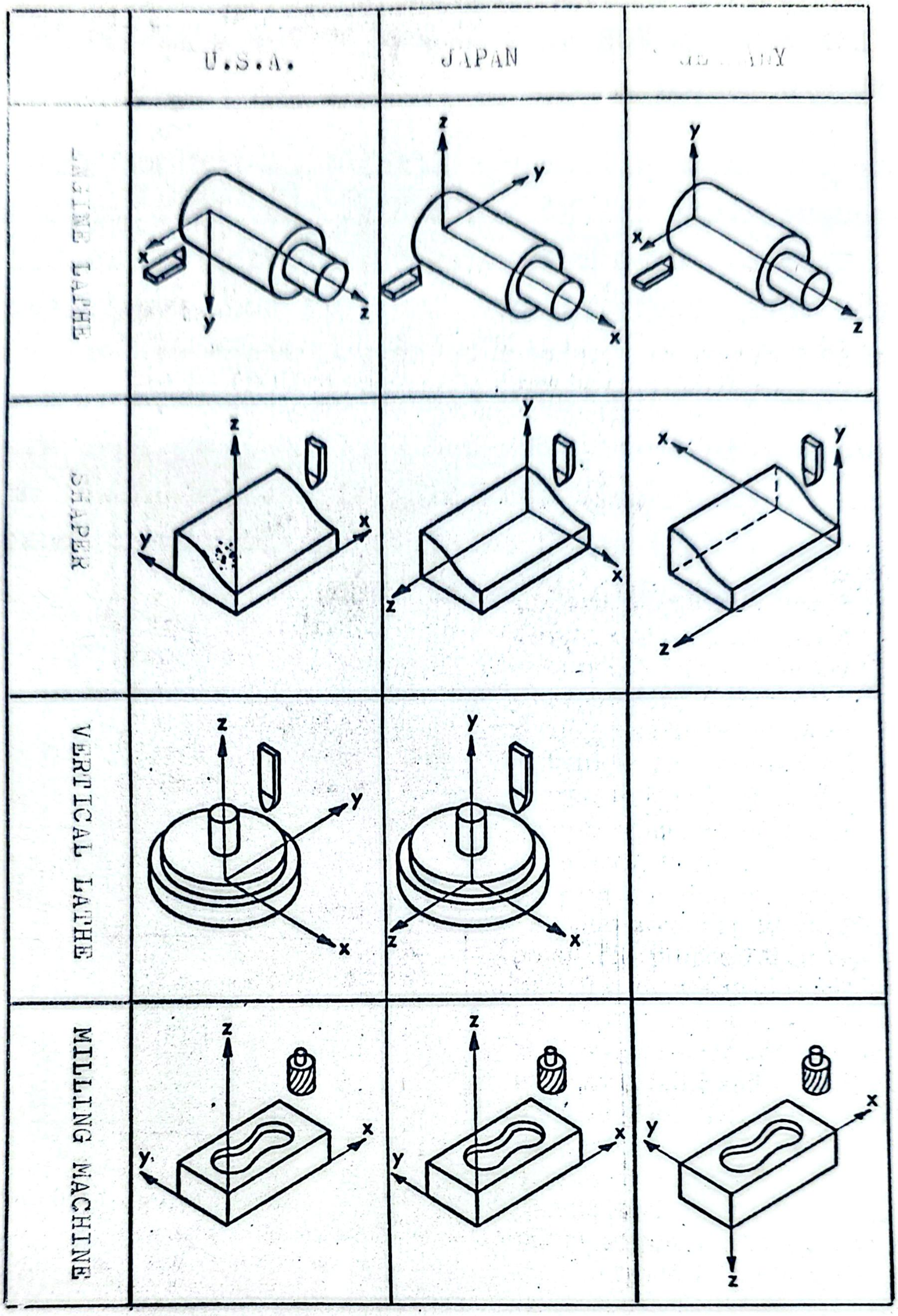


FIG.3 DIFFERENT NATIONAL SYSTEMS

	U.S.A.	JAPAN	GERMANY
Definition Of Axis	Use the right-hand coordinate rule to define the X & Y axis from the Z axis		Use the left-hand rule
Direction Of The XY Plane	the XY plane is perpindicular to the principal spindle axis	the XY plane is parallel to the plane defining the characteristic profile of the w/p *	
Principal Spindle Axis	The principal spindle axis of the m/c is always the Z axis (irrespective of the type of m/c)	The principal spindle axis varies from m/c to m/c;e.g: • For a center lathe:the X • For a vertical lathe:the Y • For a boring mill: the Y • For a milling m/c: the Z	The principal spindle axis varies from m/c to m/c

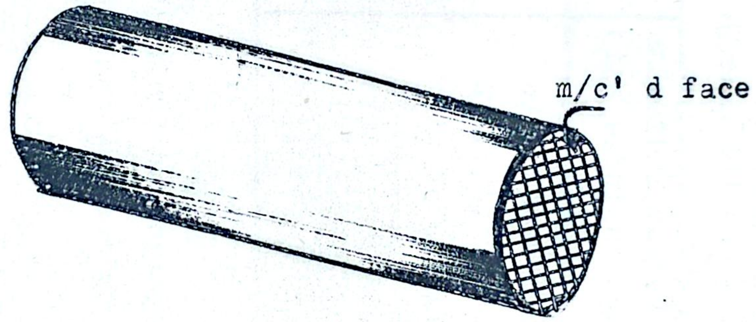
* The germans have recently amended their standard to make an exception of m/c's with rotating w/p's, such as a lathe, by designating the Z coordinate as the direction of the rotary axis.

Some serious disadvantages arise from those principles of designation in various systems. For example, as a result of designating the axes of a m/c so that XY plane contains the characteristic profile of the w/p (as the Japanese and German standards do) results in :

- In case of MILLING, it could only apply to two-dimensional work, since on three-dimensional work characteristic profiles could also be in the XZ and YZ planes.
- Confusing changes in axis designation according to the type of m/c used, for example in the Japanese standard:
  - The principal spindle axis of a centre lathe is the X axis
  - ,, ,, ,, ,, a vertical ,, ,, ,, Y axis
  - ,, ,, ,, ,, a boring mill ,, ,, Y axis
  - ,, ,, ,, ,, a milling m/c ,, ,, Z axis

ILLUSTRATIVE EXAMPLE

Consider the case of m/c'g* the end face of a round billet of material:



<u>ON A TURRET LATHE</u>: The m/c'd face would be in the YZ plane

<u>ON A TEE-LATHE or A VERTICAL BORER</u>: The m/c'd face would be in the XZ plane

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* m/c'g = machining

ON A HORIZONTAL or VERTICAL MILLING M/C:

The m/c'd face would be in the XY plane

ON A PLANER or SHAPER:

The m/c'd face would be in the XZ plane

Generally speaking, the program for NC would have to be re-written if the job was transferred from one type of m/c to another.

ADVANTAGES OF THE AMERICAN STANDARD:

In the American standard, as previously mentioned, the principle spindle axis is always the Z axis, irrespective of the type of m/c. This convention is the easiest to understand and commit to memory, as well as being the most consistent from the point of view of the PART PROGRAMMER concerned with programming various m/c's.

On applying this convention in machining the face of the billet, the cut would take place parallel to the XY plane on either of the following m/c's:

- A turret lathe
- A vertical or horizontal miller

Furthermore, since the standard lays down that on a non-spindle m/c the Z axis is perpendicular to the workholding surface, the same applies if the face is machined on a planer or shaper.

SCHEMATIC DRAWINGS AS A GUIDE:

To overcome the problem of framing definitive rulings that will cover the wide divergence of types of m/c's to which NC is or may be applied to, it is proposed that schematic drawings of each type of m/c should help as a precise guide.

These drawings should indicate by letters and arrows the numerically controlled motions.

The American standard already includes such drawings . Beside showing some of the typical m/c's, the drawings also include individual m/c's* such as:

- Giddings & Lewis m/c's
- Cincimatic m/c's
- The five-axis Milwankee-Matic m/c's
- The five-axis Sundstrand m/c's
- The Hughes-Burkhardt & Weber MT3 m/c's

The standard also included:

- Drafting m/c's
- Filament winding m/c's
- Inspection m/c's
- Welders
- Flame cutting m/c's
- Turret presses

Some m/c's are omitted because no confusion is liable to arise with their use, those are such as:

- Jig Borers
- Drills

NEL CONSIDERATIONS:

We will consider only one problem and discuss it in more detail, let us see how the NEL have resolved the question of the X axis.

NEL is critical of the designation of the X axis. The experts there suggest that the only way to avoid misinterpretations is to give separate definitions for signs of axis motions on each of the main m/c families. Those definitions originate from a main one, which is:

The X axis of motion is horizontal and parallel to the

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* m/c's = machines

workholding surface, and is the principal axis of motion in the positioning plane of tool or workpiece.

For different families of m/c's, signs are suggested as follows:

For M/C'S WITH ROTATING W/P'S* AND NON-ROTATING TOOLS

A) **With A Horizontal Axis:** (LATHES)

The positive X motion is corresponding to the motion of a tool receding from the axis of revolution, thus adopting the concept of the X axis being positive in both directions from the spindle center. On all other m/c's (with a horizontal axis) positive X is to be to the right looking from spindle to W/P

B) **With A Vertical Axis:** (BORING MILLS)

Those m/c's would have the X axis parallel to the cross slide, and positive when the tool is receding from the axis of revolution.

For M/C'S WITH NON-ROTATING W/P'S AND ROTATING TOOLS:

A) **With A Vertical Axis:** (MILLING M/C'S)

Those m/c's would have the X axis parallel to the table slide.

For M/C'S WITH NON-ROTATING W/P'S AND NON-ROTATING TOOLS:

(PLANERS AND SHAPERS)

For those m/c's, the X axis would be parallel to, and positive in the principal direction of cutting.

For M/C'S WITH ROTATING W/P'S AND ROTATING TOOLS:

(CYLINDRICAL AND INTERNAL GRINDERS)

Those m/c's were not included.

Concerning schematic drawings, the NEL have prepared a set of drawings embodying their own suggestions.

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* W/P'S = Workpieces

TOWARDS AN INTERNATIONAL STANDARD

International agreement is being sought to arrive at a universal definition for the axis and motion nomenclature for NC m/c tools. But to find a rational system that will cover all the possible types of m/c to which NC could be applied is proving no easy task. A committee of the ISO* is examining the possibilities of establishing an internationally acceptable standard.

For the purpose of illustration, one of the ISO proposals:

- Lays down rules for the designation of primary and secondary rotary motions
- Lays down rules for secondary (and even tertiary) motions parallel and non-parallel to the main axis, here it enters into the realm of multi-axis, multi-spindle (and sometimes multi-way) m/c's. Many such m/c's have their own individual configurations and it would seem virtually impossible to frame general rules that would indisputably identify all motions without reference to individual models.
- Stipulates (for example) that when there are several spindles, one should be selected as the principal one. This seems to leave the selection of the Z axis of, for instance, a three-way m/c'g centre to the programmer's personal choice.
- Stipulates that if linear motions exist which may not, or are not, parallel to X,Y,Z they may be designated V, W, P, Q, or R as is most convenient. This provision again seems to allow choice.

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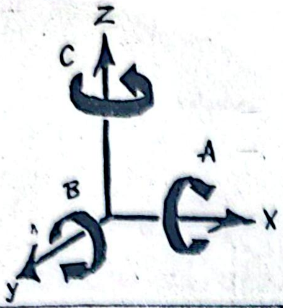
* International Standardization Organization

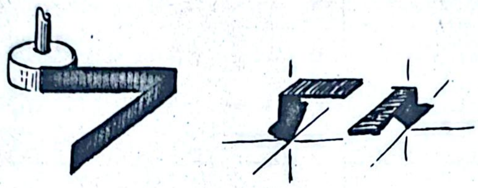
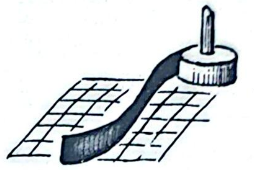
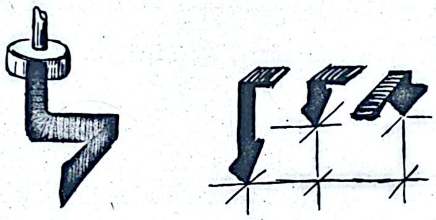
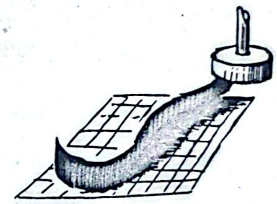
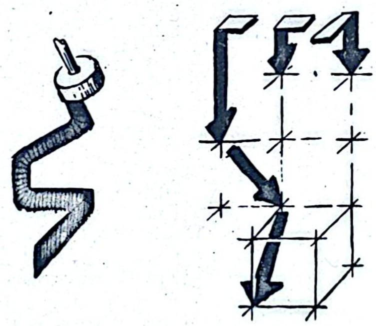
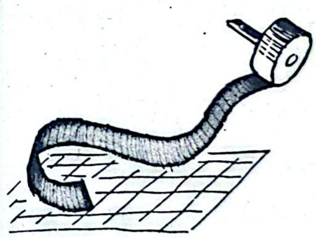
CLASSIFICATION OF NC ACCORDING TO THE NUMBER OF AXES AVAILABLE FOR CUTTER MOTION:

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 coodrinates 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.

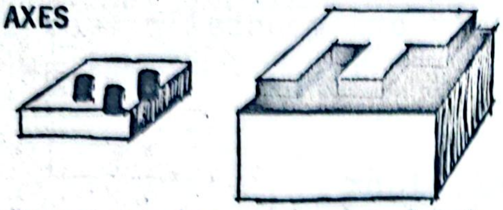
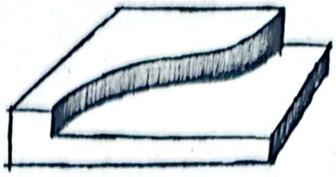
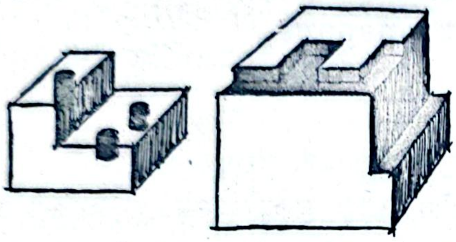
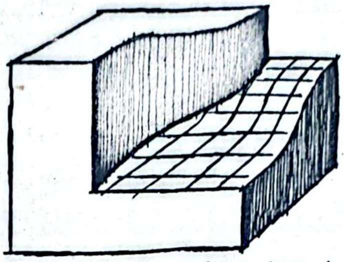
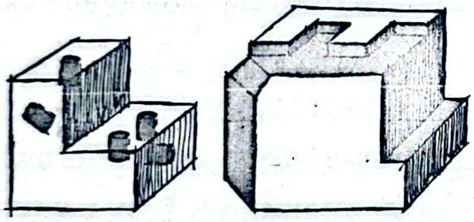
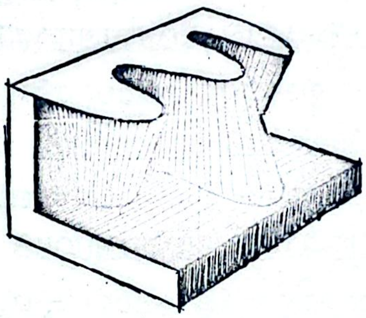
GROUP A of sketches illustrates three different cases each with different no.of axis

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 : DIFFERENT NO. OF AXIS AVALIABLE FOR NC M/C' G

POINT TO POINT	CONTINUOUS PATH
TWO AXES  Straight-line cuts on a plane, or holes of equal depth drilled (or bored, tapped, etc.) anywhere on a surface.	 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 : WHAT NC CAN DO IN DIFFERENT CASES

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

POINT-TO-POINT AREA

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

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)

NC TAPES:

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. This will be extensively explained on dealing with post-processors.

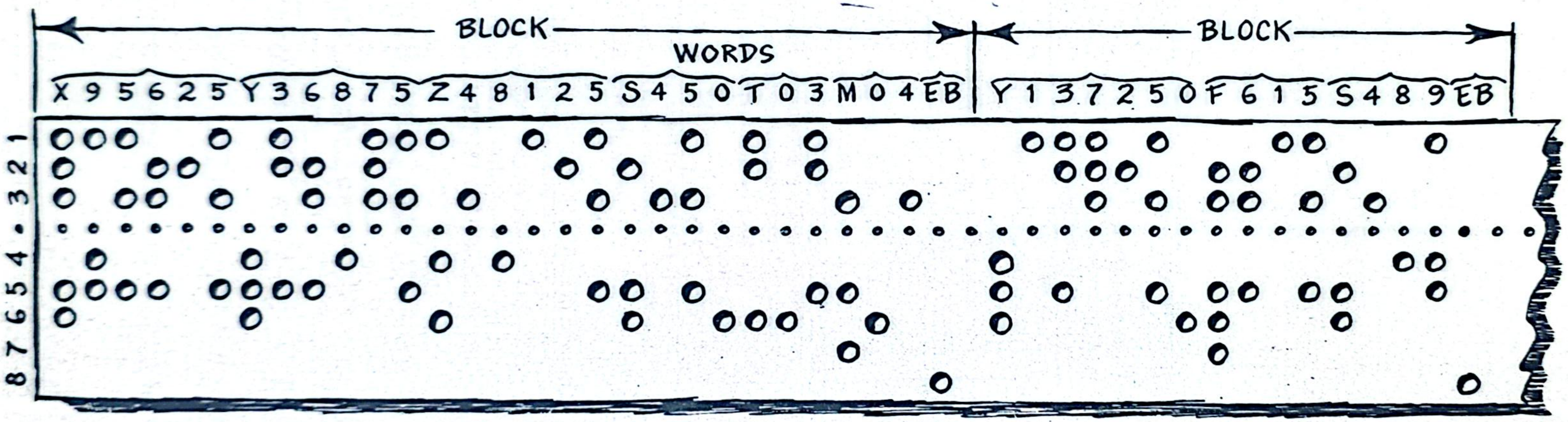
On the tape, blocks are separated by an end of block notation. The following tape shows an example of a tape from Dynapath Tape Preparation Manual (Bendix Industrial Controls Div., Detroit, Mich., USA)

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

A TYPICAL NC TAPE

On the tape,each data block consists of words,with each word being made up of both alphabetic and numerical characters to designate information such as X-axis position, Y-axis position, Z-axis position,feed,speed,tool or auxilaries.

On the following page,two blocks in the word-adress format is illustrated together with an example of the Programmer's Process sheet.



PROGRAMMER'S PROCESS SHEET

X AXIS	Y AXIS	Z AXIS	FEED	SPEED	TOOL	AUX
9.5625	3.6875	4.8125		45	03	04
	13.7250		615	489		