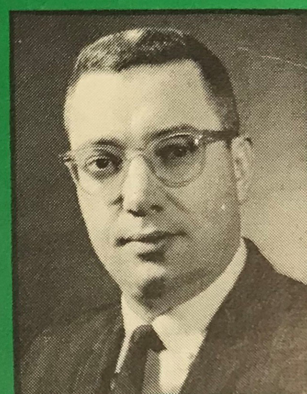
The Numerical Control Dimensioning System



First of a new vital four-part series on some of the working areas of N/C, based on training material developed and organized by Jack Moorhead of John A. Moorhead Associates, 759 River-view, Derby, Kansas, 67037, for the National Machine Tool Builders' Association and the American Machine Tool Distributors Assn.

First, let's lay the ground work for a fruitful N/C discussion by defining the process and the Cartesian Coordinate method of measurement on which N/C is based. Unless a few basic facts are clear, any further discussions tend to lead away and not toward understanding. Interestingly enough, one of the first hurdles to the widespread acceptance of N/C was a lack of comprehension about the concepts on which it is based. Persons not understanding the very logical foundations of N/C did not want to reveal their lack of knowledge by asking questions. Fortunately this has been largely overcome but a review is not out of order, so here it is.

By definition Numerical Control is the operation and control of a machine tool by numbers which are given to the tool through a control system and which direct some or all of the functions of any given machine. Normally at least two dimensional tool movements are so controlled although control may extend to as many as six dimensions and various auxiliary functions such as selection of tools, flow of coolant, direction and speed of spindle rotation, and even the turning off of the machine. The greatest emphasis, however, is devoted to the positioning of the spindle and workpiece in the proper relationship to each other to provide for accurate machining.

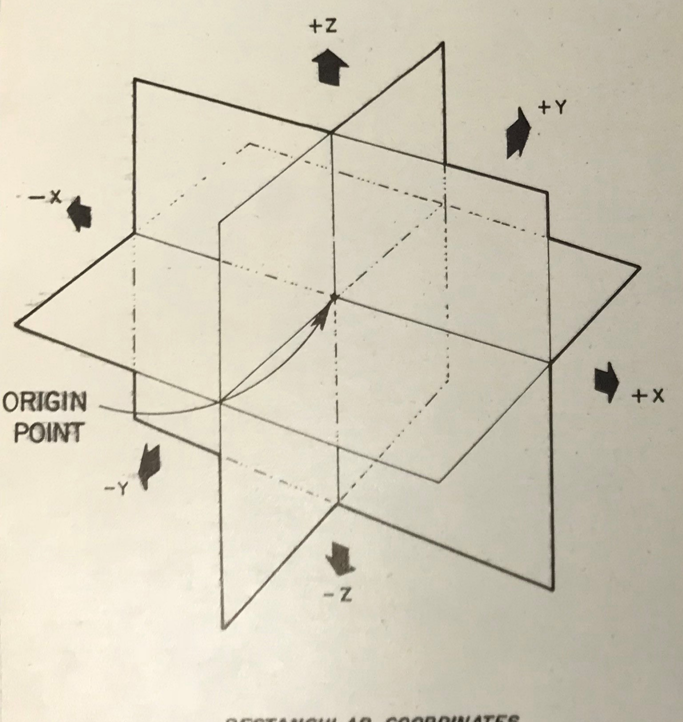


Fig. 1—The key to Numerical Control is the system of rectangular or Cartesian coordinates wherein any position can be described in terms of distance from an origin point along either two or three mutually perpendicular axes. Two dimensional coordinates are limited to flat surfaces while the three dimensional can describe and locate any point in space. Plus dimensions are to the right and up while the minus are to the left and down directions.

The units that control machine tools are predominently electronic although a number are either hydraulic or mechanical. We will not get into the make up of a control system as such. This is a specialized field in itself and not within the scope or objectives of this series. Variations of control design or type do not alter basic N/C concepts.

The medium by which numbers or numerical values, corresponding to either positions or commands, are in nearly all instances fed to the control unit is an eight channel perforated tape using a coding known as the Binary Coded Decimal. There are some control systems in use that are fed by the perforated tape using a straight binary coding, and there are also machines with control systems having either tabulating card or magnetic tape readers. Normally the perforated, or "punched" tape as it is more popularly called, is considered the standard but the other input types have certain advantages that seem to keep a certain number of them in use.

Actually, any concern about types of control systems and method of program input is in a sense a secondary issue in that operational variations may be involved, but in the main, neither the philosophy nor concepts show any significant alterations just because the program input is tape instead of tabulating cards or the control unit is electronic instead of mechanical or vise versa.

Cartesian Coordinates

If there is any single key that unlocks the door to understanding the N/C concept it is the diagram of Cartesian or rectangular Coordinates (Fig. 1) conceived by the French Philosopher and Mathematician, Rene Descartes. For in the Coordinates any absolute position can be described in terms of distance from a reference point along three mutually perpendicular axes. From this we get the term "three dimension," and the semi-mysterious term "fourth dimension," used in advanced science and by science fiction writers to connote the element of time, is a very fine tribute to the basic and fundamental three dimensions in the Cartesian mathematical developments.

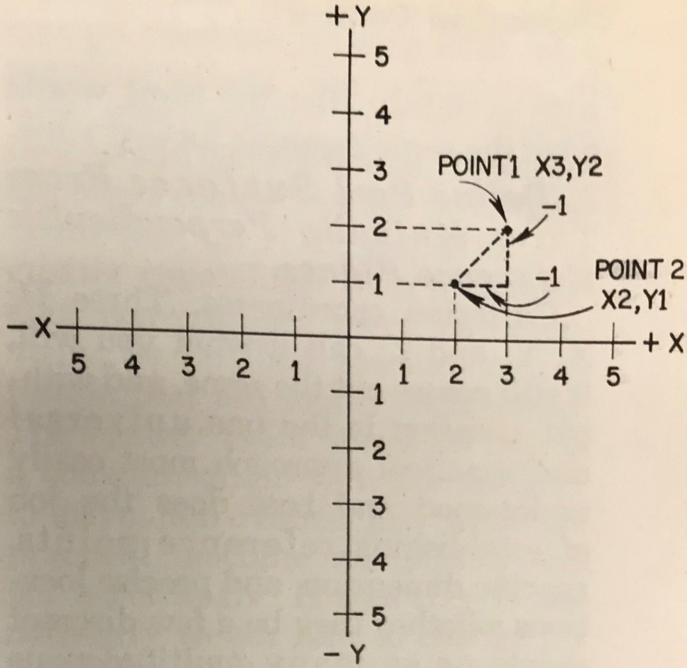


Fig. 2—Within the coordinate system, points or positions may be indicated by either an absolute or incremental method. Absolute positions are given in terms of distance from the origin of the coordinate axes. Incremental positions are given in terms of distance and direction from the preceeding point. In the above example, point one has a value of plus X 3, plus Y 2. Assume then the center of the cutter, or of the spindle, is located over point one. In the absolute mode the command would be to move the cutter to point two, plus X 2, plus Y 1. In the incremental mode the command would be in terms of direction and distance from point one, thus it would be minus X 1, minus Y 1.

Dimensioning Requirements

So much for the review. Knowing of course that the numerical inputs are largely dimensions from a fixed reference point, or at least a preceeding reference point within the scope of the coordinates, just why should there be any difficulties? Certainly what difficulties that have occurred have not been in the development of the N/C concept, but are basically a failure of all involved persons, including design engineers, programmers, draftsmen, and even machine setup men and operators to see in any given numerical value the same point of reference from which x, y, and z distances are measured. If we may paraphrase, "10 miles on a line due north from a fixed point in San Francisco does not describe the same location as a 10 miles on a line due north from a fixed point in New York City."

Seven Guideposts

What then are the steps being taken by N/C users to insure that the dimensioning language means precisely the same thing to the programmer as it does the design engineer, the draftsman and the setup man? Obviously not all these steps are being formally implemented in each and every plant. In a very small plant one person may be responsible for all functions from designing to programming and machine setup. In the very largest there will be specialists for each. But all must talk the same language, not just the same words, and proceed with certainty that the same words have the same meaning for everyone.

1. Define Part Surfaces From Three Mutually Perpendicular Reference Planes.

Cartesian coordinates; Three D; X, Y, and Z; call it what you will, it still comes out the same, and without question is the one universal mathematical approach most easily understood and best does the job of establishing reference points, specific dimension, and precise locations whether they be a few discreet points or so many multitudenous points in succession that in the final analysis a continuous cutter path is described.

There was that time when the world of N/C was young and everyone was learning, that programmers used to request that all drawings be made so they could be visualized in the first quadrant or the "all Plus" quadrant of the coordinate system. The idea was that there would be no minus dimensions. Then came the incremental methods of programming where the minus and plus signs did not indicate values but rather indicated travel direction along the axis. (Fig. 2). Close on the heels of this development came the floating zero, or zero shift, which meant the reference or origin point might be located in the middle of the part thus forcing minus designations to define locations to the left of and below the point of reference. The approach is more and more becoming "let's just all agree where the point of reference is located, regardless of the quadrant, so that we all have the same understanding."

2. Establish Reference Planes Along Part Surfaces Which Parallel the Machine Axes.

On a typical machine tool the table will comprise the XY plane and almost invariably the workpiece is loaded so that a flat surface is parallel to the table. Likewise a straight side on the workpiece will normally be parallel to the machine X or Y axis. The natural inclination of anyone would tend toward following the logic of parallel loading, so what has been the problem? It isn't so much a failure to establish references on the workpiece and machine that are parallel. More than likely the problem will turn out to be, "Which planes should be established as the reference?"

The problem arises when, in the design of a part, the designer establishes the reference plane, which in effect means he is loading the machine. It is the normal reaction of shop personnel to guard the prerogative of production and machining, and the design engineer doesn't want the task of determining machining sequences or machine loading.

What has been the answer? The workable approach seems to be a liaison between programming and designing at the time the piece part is ready to go to drafting. Here a mutually acceptable arrangement can be worked out to establish proper references for ease of programming and dimensioning while at the same time giving the programmer the prerogative of orienting it to the best possible machining attitude.

3. Dimension to Physical Points on the Part Surface.

Quality control people are the beneficiaries of this policy. As far as the *theory* of N/C is concerned, it makes little difference if the distances are measured from some point on the part surface or from outside the factory building. For machining it might be OK, but in checking there is no substitute for having the reference point on the part itself. The operator could also be the beneficiary of such a policy especially if he is asked to manually locate an initial hole or face on the part. Actually this policy or procedural step has nothing to do with Numerical Control; its just a point being charged to N/C to bring about better overall thinking into the general production process.

4. Allow for Concavity When Flatness Is Not Required on Surfaces Not Normal to Reference Planes.

Translation: On curved or sculptored surfaces it is virtually impossible with either a square or ball-nosed milling cutter to get a finished surface which for all practical purposes is perfectly smooth. There will be cusps and valleys. In theory, perfection could be obtained with enough machine passes but, as a practical aspect, the economics of both programming and machining time would be prohibitive. The trouble often comes because a designer heard that an N/C machine has greater capabilities than a comparable conventional piece of equipment. So he then specifies output results that are totally impractical. The answer again seems to rest in a communication with the designer to have him realize just what are practical machine capabilities and act accordingly. It usually is not necessary to ask him to change his basic design ideas but rather to be more practical in his thinking.

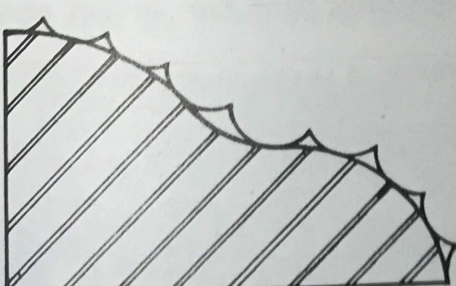
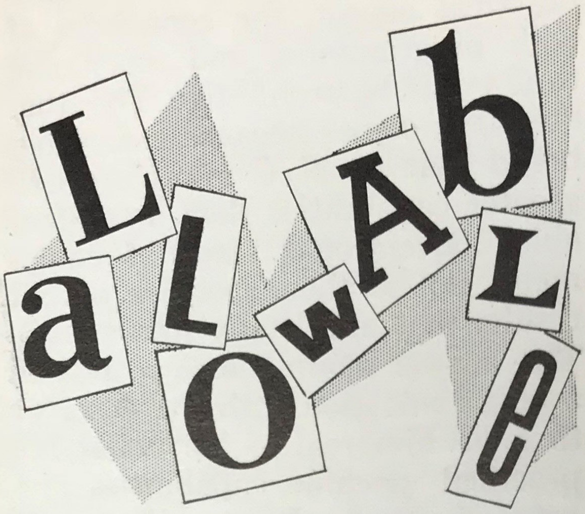


Fig. 3—When sculptoring a surface not parallel to one of the machine axes it becomes very difficult to get a perfectly smooth surface with either a ball nosed cutter or square end mill. Normally there will be cusps remaining which are then ground away. In planning such programs with a minimum of programming and machining time, the deepest part of the cut represents the finished dimension of the workpiece surface.

A straight line milling cut which is parallel to one of the major machine axes, and which is in effect, contouring the workpiece, will normally leave a fairly smooth surface. The above rule has its real application in the three dimensional sculptoring jobs such as sinking a die or mold for an automobile fender or contoured plastic furniture. One of the techniques used to do the job with a minimum of machine passes is to establish the maximum depth of cut, with whatever cutter is being used, as the finished dimension. Any remaining cusps are excess metal which will be ground away (Fig. 3). The entire work surface is covered with layout blue and ground down until only thin hairlines of blue remain to indicate the bottoms of the cutter path.

5. Determine Allowable Tolerances.

This statement applies in particular to the designer who is responsible for conceiving the workpiece,



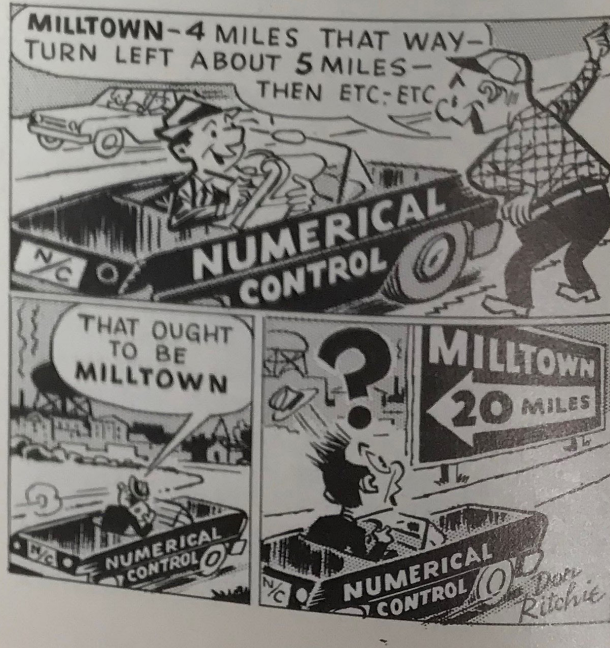
IS *NOT* ALLOWABLE

and especially if the designer, draftsman, programmer, set up man, and operator are all different individuals. Note the word *allowable*; it is very important. If the finished dimension allowable tolerances are not clearly stated at the time of workpiece design, each of the succeeding functions of drafting, programming, tool making, set up, or even operation may introduce their own interpretation of what is and what is not allowable. The final outcome will have passed through several opportunities for error introduction with little chance of tracing it back to a responsible source. If the designer initially established the allowable tolerances, the opportunity for error still exists, but there is a "master" source against which discrepancies can be verified.

Another observed difficulty has been that if allowable tolerances are not specified at the time of design development, drafting may establish a tolerance which is then narrowed by programming and further narrowed by tool design so in the end something that was quite reasonable will turn out to be prohibitively tight.

6. Dimension the Part So That Physical Shape Can Be Determined Without Calculations and Assumptions.

If the engineering drawing leaves any calculations or assumptions to be made by the part programmer, tool designer, tool fabricator, machine tool operator, or quality control inspector, the chance for errors are obvious. In spite of all that has been said about N/C control units and computers, the fact remains that they are not in any sense of the word "mechanical brains." If the wrong instructions are given to them, they will obediently and efficiently do the wrong things. If dimensions are assumed wrong and so programmed, neither a computer nor control system could care less. They will simply proceed in a most efficient manner with given instructions. When we hear of computers or control systems that can detect errors,



we are really talking about a set of conditions placed into either the computer or control system which will protect the programmer from himself by countermanding any bad instructions that could cause a collision or other serious consequence. But in no instance should we ever think of the computer/control developments as brains that are going to do basic thinking.

Thus if a design mistake is made, and they will be made, and if the dimension system is such that there can only be one place to question any dimensions, there then is only one place to go to rectify any errors. There is no merry-go-round between operators, tool designers, programmers, and quality men as to where and how the problem should be adjusted.

7. N/C Requires a Part Description From Which a Cutter Path Can Be Computed.

This seems so obvious that it would seem an exercise in redundity to state it, but there is more than meets the eye to this one. For example a programmer could ask a computer to calculate the point of tangency of two circles that are mistakenly drawn together but mathematically never meet. A control system may have three or four different capabilities for generating a circle path. In other words the methodology of programming must be compatible with the capabilities of the computer hardware assigned to generate the program and the control system expected to execute it. Taking it back one step, the programmer must have an accurate enough description of a part that he can describe it mathematically in terms acceptable to the control system either through a computer program or one made manually, if that be the case.

It will be noted that the recurring theme threading through these seven dimensioning requirements is a need for effective communication and basic understanding starting at the product designer right through to the final quality check inspector. They must all talk the same language with the same meaning implied in that language in order to secure the optimum results from N/C equipment. Undoubtedly in many installations many of these requirements will never be formally outlined but they will be implicit in a smooth flowing operation.

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NEXT MONTH

Next month the second article in this Numerical Control series will explore the all-important "Tool Design Requirements for Numerically Controlled Machine Tools." Watch for it!