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NUMERICAL CONTROL FABRICATION: ITS NATURE AND APPLICATION

Numerical control is a tool that frees the craftsman from the mechanical control of equipment in much the same way that the calculator and computer freed the engineer from the burden of manual calculations. This article presents background information that describes the nature of numerical control and highlights several applications of numerical control fabrication at APL.

INTRODUCTION

In order to understand the application of numerical control and computer numerical control fabrication, it is valuable to review the nature of these processes that have become so commonplace in metalworking facilities.

Numerical control is the operation of a machine by a series of coded instructions comprised of alphanumeric characters. The instructions are translated into electrical pulses or other output signals that activate motors and other devices to control a machine. For machine tools, numerical control commands range from positive positioning of the spindle in relation to the workpiece, to auxiliary functions such as selecting a tool station or a turret, or controlling the speed and direction of spindle rotation. Numerical control commands can include functions such as coolant control, dimension sensing, and tolerance verification. The commands, compiled and logically organized to direct a machine tool in a specific task, comprise a numerical control part program. The program, once developed, can be stored and executed at a later time to obtain exactly the same results as the first time it was used.

The program is executed by feeding the data into a machine control unit. A common medium for data transfer is punched paper tape, the method used at APL. Early machine control units for numerical control were hard-wired units where all the features of the controller had circuits that were developed for their execution. There was limited flexibility or ability to modify features and no editing capability for the program at the machine control unit. As computer technology developed and microcomputer capabilities became less costly and more tolerant of fabrication environments, computer numerical control equipment became the standard in the fabrication industry. Today, the terms have blended until they are almost interchangeable in usage, with numerical control being the generic term for both.

THE NATURE OF THE PROCESS

Numerical control is revolutionary because the responsibility for controlling a machine is now shared between a craftman's skill and the documentation of the machine's motions and functions needed to fabricate a workpiece contained in the numerical control program.

It is important to understand that numerical control is a concept of machine control, not a manufacturing method. While it is important to understand what numerical control is, it is equally critical to understand what it is not. Numerical control is not an electronic brain; not even computer numerical control at the current state of technology can approach the capabilities of the human brain. Numerical control cannot think, evaluate, judge, discern, or show any true adaptability. It is possible, with advanced computer numerical control, to have predetermined logic trees or alternatives that allow incorrect instructions or unplanned occurrences such as tool breakage to cause machine actions to override the program instructions. The basic process, however, remains that of (a) a programmer developing instructions that are encoded and (b) the machine control unit executing them.

A numerical control machine tool has design parameters that determine its capabilities; adding numerical control will not provide machining capabilities that are not already present. The fact that a numerical control is installed on a machine with a 7-horsepower spindle in no way changes the spindle's capability to drive a cutting tool. When properly applied, however, numerical control will permit greater efficiency in using that spindle by machining during a greater percentage of the fabrication cycle. This holds true for other machine capabilities. For example, if the maximum table travel is 30 inches, numerical control will not electronically provide a 40-inch travel range, but numerical control will allow more efficient use of the 30-inch movement.

A fundamental requirement of numerical control is the ability to communicate in the language of the machine control unit. A machine control unit can only process or act on certain limited symbolic codes that have specific meanings. The programmer must understand the codes and their precise meaning to the machine control unit and then must limit communication to that framework. Creative thinking to use the full capability of a machine and the machine control unit and learning how to communicate (encode effectively) in the machine control unit's language comprise the art of effective numerical control.

There are several reasons why numerical control equipment is effective in all fabrication environments, including both the high volume of industry and the low volume of the experimental environment at APL.

With numerical control, multifunctional machines become more practical. A machining center, for example, can mill, drill, and bore. Most of the installed equipment has multiple tools stored on the machine, ready for automatic insertion in the machine spindle as required to perform multiple operations with only one setup of the workpiece. The average part does not have to be transferred between machines for different processes, which reduces the cycle time for the fabrication of the part, an extremely critical consideration at APL.

Numerical control can produce a part at a consistent rate of speed. In conventional machining, it has been observed that the rate at which the machinist removes material decreases as the part draws closer to completion. This is a reaction to the realization that an error at a late point in the fabrication process will void all previous activity. With numerical control machining, the program can be verified graphically on a cathode ray tube at the controller and can then be machined in metal at a constant rate, because the program has been verified before the first cutting tool has touched the material.

In a numerical control program, the experience and judgment of the craftsman are preserved indefinitely, allowing the program to be used repeatedly with identical and predictable results. Numerical control should be viewed as an extension, not a replacement, of the craftsman. Numerical control serves as a catalyst that relieves the craftsman of the responsibility for turning handles and moving a workpiece and allows him to apply his true skill: the determination of the fabrication process.

TYPES OF NUMERICAL CONTROL PROGRAMMING

Just as computers have evolved from the vacuum tube mainframe to the powerful personal computer, an analogous evolution is taking place in the related area of numerical control programming. There are now multiple appropriate methods for developing numerical control programs. APL is developing the capabilities for using the most appropriate and cost-effective method for each project; three modes of programming are used to provide the appropriate level of sophistication required to fabricate a part (Fig. 1).

The most sophisticated programming mode at APL uses computer-aided design, an interactive graphics system that can display color geometry and toolpaths in three dimensions. The complexity of the geometry can range from simple straight lines and arcs to complex curves and surfaces. The numerical control capabilities of the computer-aided design system include profiling, automatic pocketing, point-to-point milling, surface milling, drilling, tapping, and various turning and punching operations.

There are three advantages in using the computer-aided design system for numerical control programming. The first is the ability to program the machine to cut difficult shapes and contours without performing manual calculations. The programmer can display three-dimensional part geometry at any desired viewing angle. He can then interactively drive a graphically displayed tool along that geometry. The second advantage is that the programmer can verify the toolpath by simply displaying the tool following the geometry. All necessary geometry and toolpaths are displayed as they are defined. The third and primary advantage is that the part geometry has been defined for the programmer, who has direct access to the computer-aided design engineering

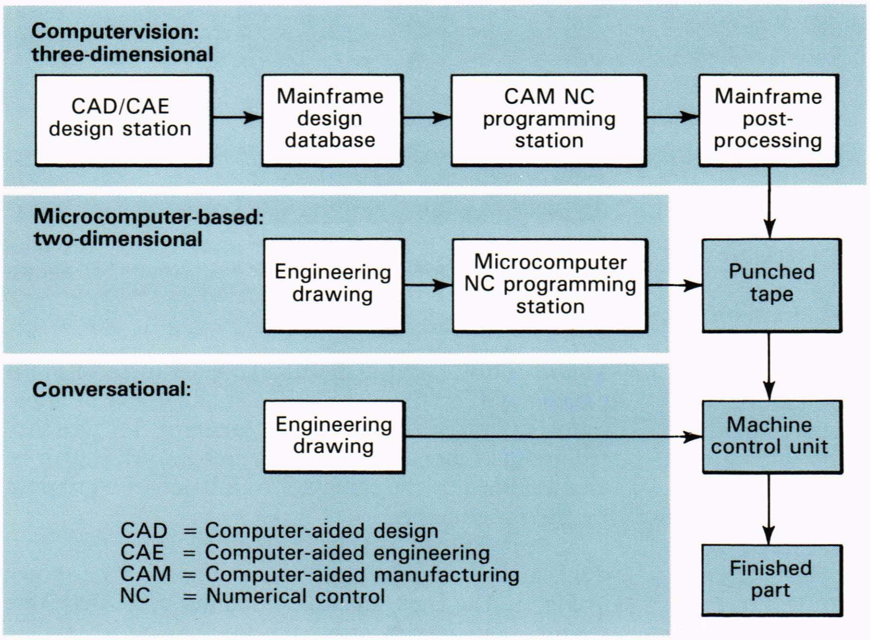

Figure 1—The three methods of numerical control programming used at APL.

drawing created by the designer. These advantages allow the programmer to do complex work more quickly and reliably.

The types of work on which computer-aided design capability is of greatest benefit include (a) complex curves, such as a series of tangent arcs or a spline curve (which is commonly seen on hydrodynamic outlines), (b) complex surfaces that may have control in two directions and require three- or four-axis machining operations (e.g., flow nozzles and vortexes used in propulsion systems), (c) intricate pockets with islands at varying depths (commonly found on many custom-designed electronics housings), (d) parts with multiple holes that are not in any particular pattern, and (e) round parts that have complex curved shapes.

At a lower level of sophistication is the two-dimensional programming microcomputer-based workstation. This is cost effective for the programming of parts that have not been designed on a computer-aided design system, thereby eliminating the potential to use geometry developed in the design process. Much of the hardware fabricated at APL is designed using conventional engineering and drafting activities. For this type of hardware, given that the shapes are not extremely complex, a two-dimensional system is appropriate for developing the numerical control programs to fabricate the part.

The third type of programming, which is relatively new, is conversational programming. In a conversational mode, the machinist programs the part at the machine control unit on the shop floor. Controllers for machine tools have developed to the point where a machinist may be machining one part using a partition of the controller memory while he is programming and observing the next part to be fabricated on a color graphics display.

Conversational programming is often appropriate where extremely complex fixturing will be required. The communication of that complex fixturing from a programmer to a machinist would involve additional expense and time that are not necessary with conversational programming. It is also an appropriate method of programming when the required fabrication is less complex (e.g., the machining of connector slots in an existing cover, or the drilling and tapping of a bolt hole pattern).

NUMERICAL CONTROL APPLICATION AT APL

Numerical control provides the ability to achieve configurations that are not possible with manual machining methods and to achieve economics in fabrication that accrue from exact and rapid duplication of multiple parts.

The recent fabrication of a component casting mold illustrates the ability to machine a part that would not be possible manually. It required the machining of a "cornu bend" (a bend with a centerline that is a third-order curve) with a circular cross-section tolerance of 0.003-inch while generating a nonconstant radius bend. Figure 2 illustrates the radii of the cornu bend. The milling required the fabrication of a custom two-flute cutter (Fig. 3), which was then used on a Cincinnati Milacron 10VC vertical machining center to perform the machining (Fig. 4). Mold halves are an excellent application of numerical control programming, because they require the fabrication of mirror images, which can be accomplished by the computer translation of a program by the programmer.

An example of economy resulting from the rapid duplication of multiple parts is the antenna base shown in Fig. 5. The eight antenna mounting bases that were required were fabricated by conversational programming

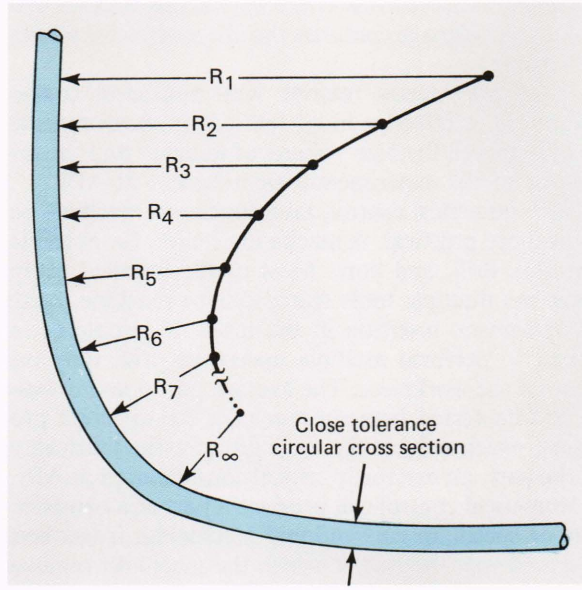

Figure 2—The radii of the cornu bend. The mold required fabrications of a continuously varying radius while maintaining cross-section circularity.

Figure 3—A tool and cutter grinder with a custom two-flute cutter he fabricated in order to machine the mold half shown on his left.

Figure 4—An experimental machinist using the custom cutter in the Cincinnati 10VC numerical control vertical machining center to machine the cornu-bend mold half.

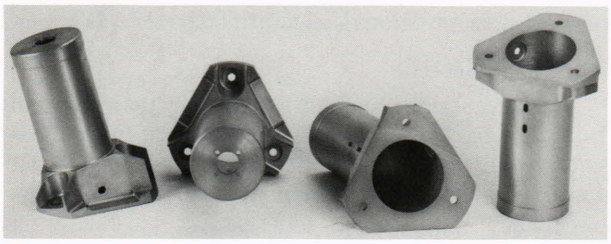

Figure 5—Multiple views of an antenna base machined on a Deckel FP3 numerical control using conversational programming. Overall height is approximately 6 inches.

on a Deckel FP3 numerical control horizontal/vertical mill (Fig. 6). Conversational programming was appropriate because of the complex fixturing required to fabricate the part. The actual fabrication time was about 30 percent less than what would have been required using conventional methods. Also, all parts were identical and were inspected with no noted defects. The zero defect rate is a component of the cost-effectiveness of numerical control machining that is often overlooked. The ability to prove a program graphically on a controller or computer-aided design station before actually machining the material almost eliminates the scrapping of a complex and expensive part.

An example of the effectiveness of numerical control in the sheet metal fabrication area is the chassis shown in Fig. 7, first in the flat before forming and then as a formed chassis, that was fabricated on the Amada-Pega turret punch (Fig. 8). The chassis illustrates another advantage of rapid numerical control fabrication: the simplification of a structure. Traditional manual fabrication would have required seven separate pieces to fabricate the chassis. The base chassis would have cutouts for the ventilation areas, which would have been filled with a section of perforated metal held in a frame. The use of numerical control to rapidly punch the ventilation pattern, as well as the required forming and mounting cutouts, resulted in a saving in the total cost of over 75 percent in the fabrication of one chassis.

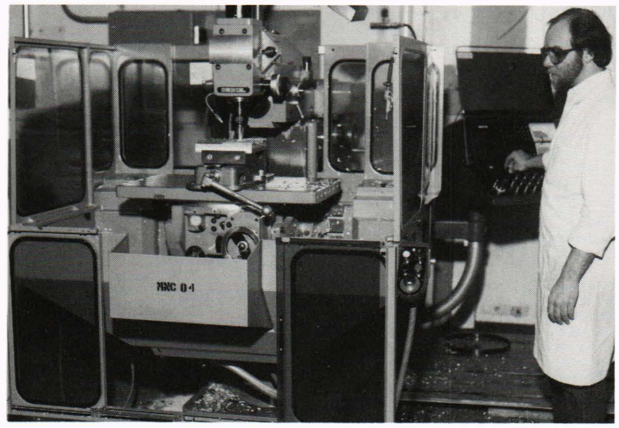

Figure 6—An experimental machinist operating the Deckel FP3 numerical control horizontal/vertical milling machine that was used to machine the antenna base.

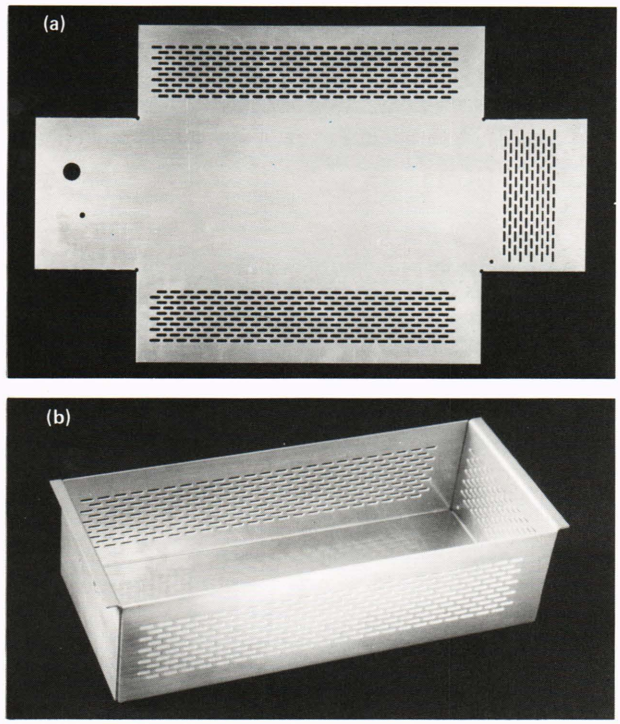

Figure 7—Chassis fabricated on a numerical control Amada-Pega turret punch. (a) Before forming and (b) after forming.

FUTURE TRENDS

Future trends in numerical control cluster in three major areas: interfaces, machine control units, and applications. The area of interfaces is undergoing rapid development as alternatives to traditional punched paper tape are developed. Direct numerical control, which is a hardwired link between a programming computer and a machine control unit, is being replaced by distributed numerical control. With distributed numerical control, the geometry of the numerical control program, known as cutter location or centerline data, is distributed via hardware to a minicomputer-based unit, where it is post-processed (the centerline data are converted into ma-

Figure 8—An experimental sheet metal worker operating a numerical control Amada-Pega turret punch.

chine-control code) and subsequently sent via hard-wired interface to the desired machine control unit. Distributed numerical control can be thought of as a local area network for machine control data. Distributed numerical control provides increased flexibility in machine selection, allowing the fabrication area to be responsive to changing priorities and conditions. A distributed numerical control system is planned for installation at APL by the third quarter of 1987.

Machine control units are providing an increasing number of capabilities that previously were available only on mainframe-based numerical control programming systems. The machine control units currently installed and scheduled for installation at APL are state-of-the-art units that provide full-color graphics, toolpath simulation, macro-based programming capabilities, and large memory capacities for utility subroutines. Future machine control unit development will be in the areas of increased processing capability (in terms of speed and memory capacity), enhanced user friendliness, and internal post-processing capabilities.

The application of numerical control equipment in all fabrication environments will continue to expand and replace conventional manual equipment. The equipping of numerical control machinery with electronic handwheels and assistance macros to control machine movement will allow the craftsman to simulate traditional manual skills on numerical control-capable equipment.

CONCLUSION

Numerical control is a tool that frees the craftsman from the mechanical control of equipment in much the same way that the calculator and computer freed the engineer from the burden of manual calculations. The paybacks are similar, the increase in satisfaction is comparable, and the outlook for the future is just as bright.

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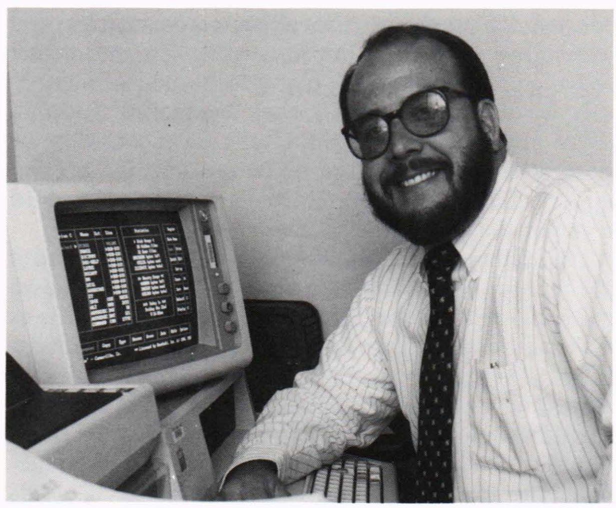

MICHAEL L. HAGLER was born in Buffalo in 1947. He received a B.A. in economics from the State University of New York at Buffalo in 1970 and has completed course work toward a B.S. in mechanical engineering at the University of Kentucky. He is a master's degree candidate in the G.W.C. Whiting School of Engineering. Mr. Hagler has worked for General Electric and TRW in manufacturing and materials management, including responsibility for the design and development of computerized tracking and scheduling systems for production environments, and as a member of a design team that developed and implemented one of the first successful materials requirements planning systems.

Since joining APL in 1984, Mr. Hagler has served on the staff of the Design and Fabrication Branch Office, where he was responsible for the development of fiscal and workload projection reporting systems and of a scheduling system for numerical control fabrication. He now supervises the Mechanical Fabrication Group. He is a Fellow of the American Production and Inventory Control Society and a member of the Society of Manufacturing Engineers.