Computers

Computer-based machine-tool control

The best place to inject a computer in numerical control is locally, not as a controller of many systems

An important advance in the philosophy of numerical control (NC) of machine tools took place during the early 1970s. That advance was the shift toward the use of computers instead of controller units in NC systems, and it produced both computer numerical control (CNC), in which a self-contained NC system for a single machine tool includes a dedicated computer processor controlled by stored instructions to perform some or all of the basic numerical control functions; and direct numerical control (DNC), which refers to a system of several machine tools directly controlled by a central computer.

One of the objectives of CNC and DNC systems is to replace as much of the conventional NC hardware with software as possible, and to simplify the remaining hardware. There are many ways in which functions can be shared between software and hardware in such systems, but all involve some hardware in the controller dedicated to the individual machine. This controller must contain at least the servo amplifier, the transducer circuits, and interface components. With both types of system, however, important economic considerations must be taken into account. Although the cost of a CNC system is expected eventually to fall below that of its conventional NC counterpart as minicomputers decrease in price, economics may pose an obstacle to widespread use of DNC.

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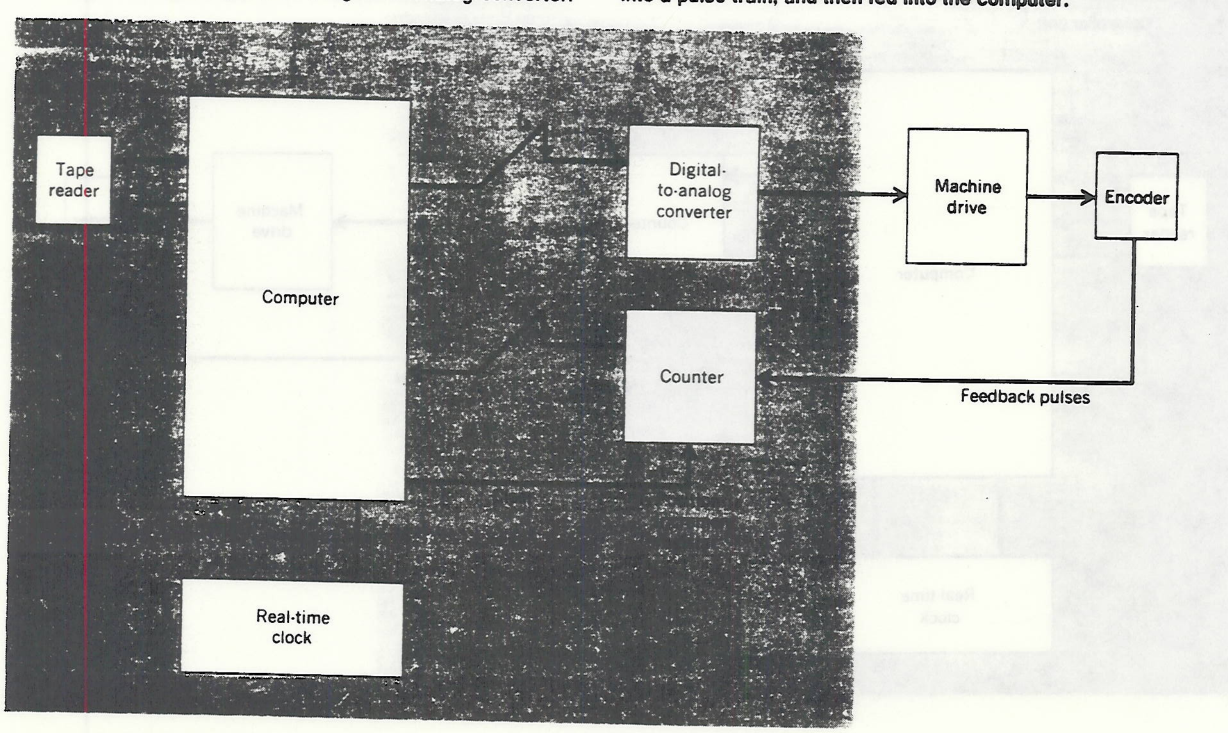
CNC boons

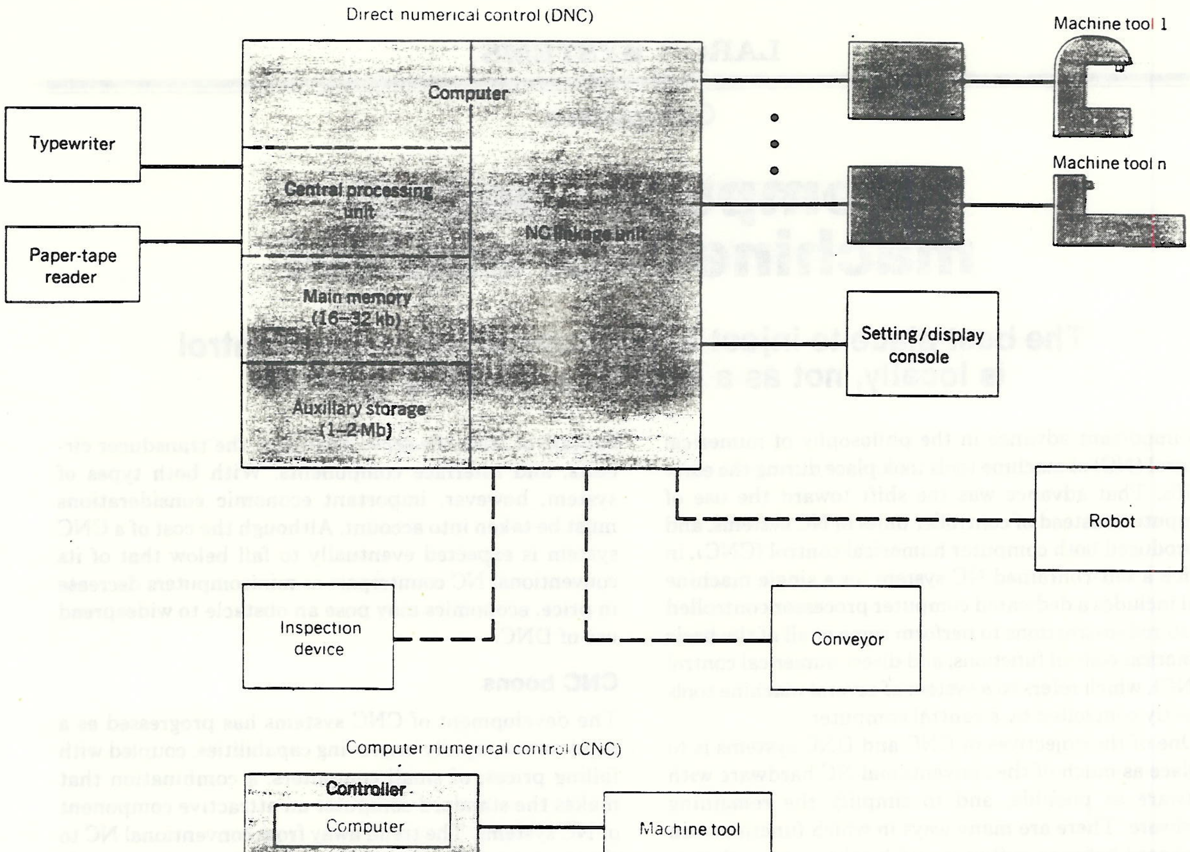
The development of CNC systems has progressed as a result of the rapidly improving capabilities, coupled with falling prices, of small computers, a combination that makes the standard computer an attractive component of NC systems. The trend away from conventional NC to the computer control system means a change from purely hardware-based NC to a software-based system, a change that will bring the user a number of advantages:

- An increase in flexibility.
- A reduction in hardware circuits and simplification of the remaining hardware, as well as the availability of

In an early-1970s model of a sampled-data CNC system, the computer monitors the feedback at constant time intervals (sampling frequency f_s), calculates the position error, and feeds it through its output register to a digital-to-analog converter.

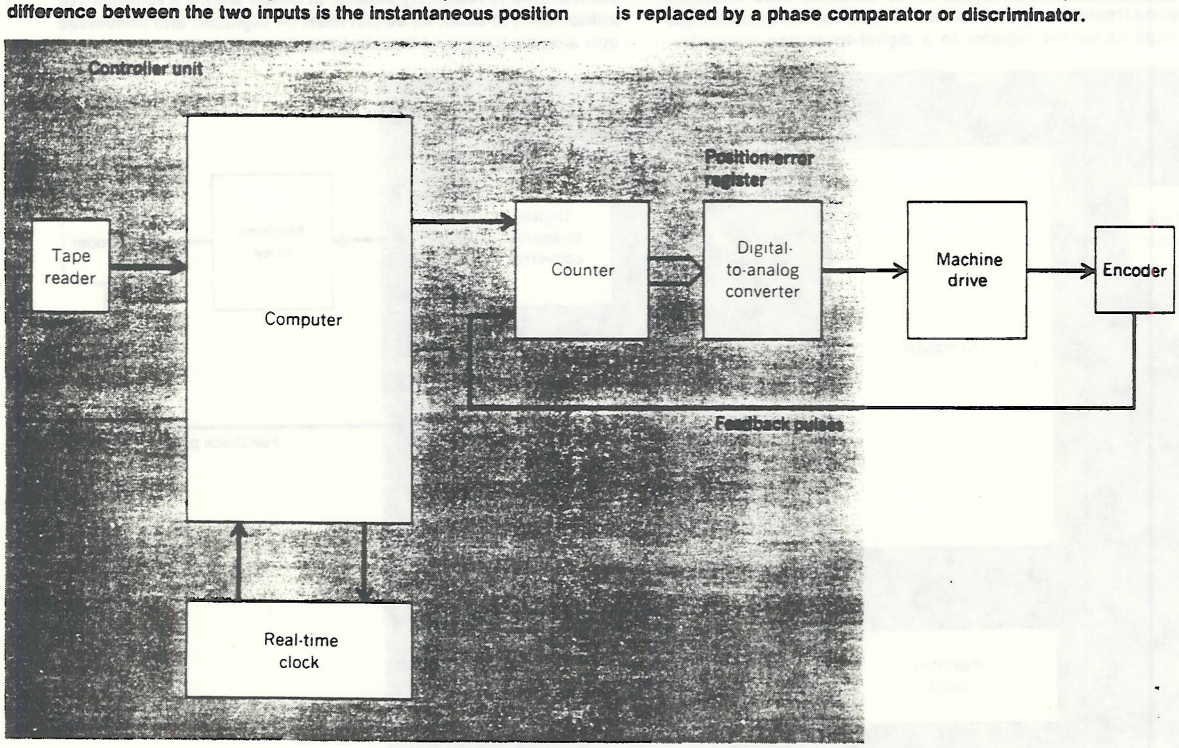
When a digital encoder is used as the feedback device, the control loop is relatively simple. In cases where a resolver (or inductosyn) is used, its output must be digitized and converted into a pulse train, and then fed into the computer.





In its basic configuration, Fujitsu Fanuc's direct numerical control system K includes several numerically controlled machine tools connected to a central computer. With the connection of additional components such as robots, conveyors, and inspection devices, the system can be expanded into a fully automated machining system. A generic description of a computer numerical control system for a single machine tool is included for comparison.

In one early single-axis CNC system, the counter is fed by a reference sequence of pulses from the computer and another pulse sequence from the digital encoder. The pulse-number difference between the two inputs is the instantaneous position error, which is fed to a digital-to-analog converter. The error signal is amplified and drives the machine in the direction of reduced error. If a resolver is the feedback device, the counter is replaced by a phase comparator or discriminator.



automatic diagnostic programs—and the need for fewer maintenance personnel.

- A reduction in inaccuracies in manufacturing due to a reduced use of the tape reader. (The data for manufacturing a part by a conventional NC machine tool are stored on a punched tape—the part-data tape. This tape is also called a "data program" or "object part program," with the term "part program" usually reserved for a program written in a specific code—the APT code.).
- An improvement in the possibilities for correcting errors in programming the machine to manufacture a specific part—the editing feature.
- The possibility of using the computer's peripheral equipment for debugging the edited part-data tape; e.g., a plotter or cathode-ray tube can be utilized for drawing the shape of the part.

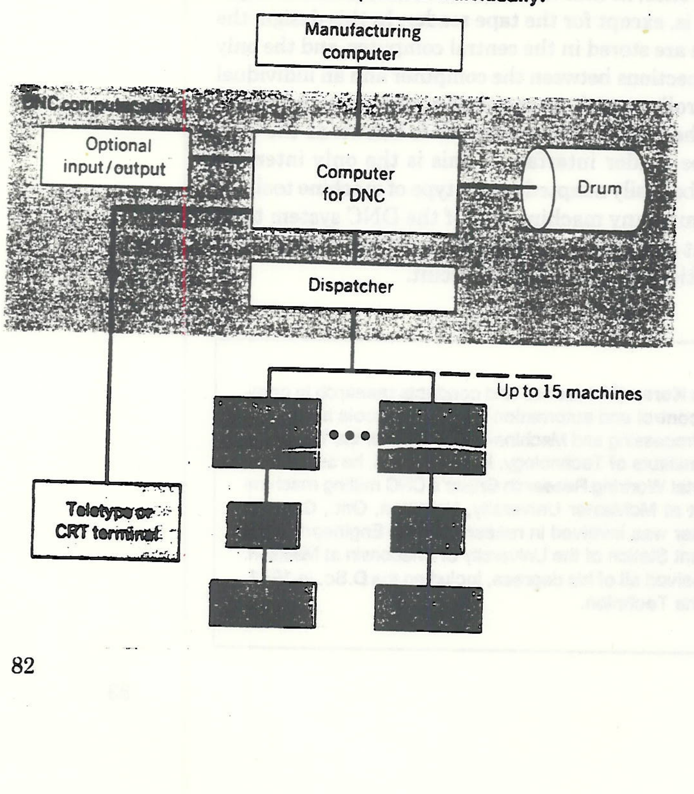
Let us elaborate on some of these features. For example, the improved flexibility and reduction in hardware of the CNC as compared with NC systems can be demonstrated by the way in which the systems are modified to suit specific needs. To alter a hardware-based system means rewiring, whereas a modification in a CNC system means reprogramming. In implementing the CNC concept, the control manufacturer can adapt a single design to many machine tools, with customizing implemented in easily changed software; the machine-tool builder can buy and service one control for an entire line of machine tools; and the user will end up with more features and options at lower cost.

The reduction in inaccuracies in the manufacturing process stems from the fact that, in many CNC systems, the part-data tape is read only once and then stored in the computer memory. When machining a part, the computer presents data in a format similar to that from the tape reader (but without pauses between blocks of information). This means that the part-data tape in such systems is used only once per manufaturing series, thus avoiding one of the biggest sources of error in NC systems.

In dealing with errors associated with the data on the tape, CNC systems offer the user an editing feature. (Errors of this type relate to mistakes in cutting conditions, such as speed and feed, in compensating for the size of the cutting tool, and in the dimensions of the part itself when they exceed permissible tolerances.) Since the part data in a CNC system are stored in the computer's memory, the data can easily be modified if necessary rather than having the tape reprocessed—a costly procedure that is followed in conventional NC systems. This editing feature is of particular importance in the manufacture of small series of products. By adding appropriate software, the corrected part data can be automatically punched on a tape, which can be kept for future use.

The peripheral equipment of a CNC system's computer can help the editing process in that the dimensional errors on the part-data tape can be sensed with the aid of a plotter or cathode-ray-tube display. A computer program, generally referred to as the "editor," allows communication between the part programmer and the stored part data through the keyboard of a teletypewriter. Prior to the production of a part, its edited part data must be proofed against illegal computer codes, radius errors in circular segments, and dimension differences in the part betweer the beginning and end of the manufacturing process. This check is generally provided by a sophisticated editor.

General Electric's CommanDir DNC system, although discontinued, may serve as an example of existing designs. The system, which was capable of simultaneously operating up to 15 conventional NC machine tools, included a small central processing unit with a large drum storage and a telecommunication printer. The heart of the processor and core memory subsystem was a general-purpose minicomputer whose core memory had a cycle time of 1 μs and a capacity that ranged from 16 to 64 kb. Matching information was supplied to each numerically controlled machine by a data dispatcher linked to the computer. Although the control system bypassed each tape reader, the machine tools could be operated individually.



CNC design concepts.

Although they offer their users a host of advantages as compared with conventional NC, CNC systems present a problem to their designers. This problem is related to the interpolation feature—an arrangement whereby the simultaneous movements along two or more axes are coordinated.

The main design problem with CNC (as well as with DNC) stems from the required maximum speed of the controlled axes of motion, a requirement that might lead to compromises as to the amount of conventional NC hardware to be replaced by software.

The interpolator output can be transmitted as a series or as a parallel command. In the series-command technique, for example, a pulse is supplied for each increment of axis travel. In an open-loop system with stepping motors as the drive elements, each command pulse causes a rotation by a single step. This method is very accurate but results in restrictions on the maximum feed rate. For example, in a three-axis CNC system with a 1-μs computer cycle time, this method allows a maximum feed rate of 5000 pulses per second. If the resolution of the system is 2.5×10^{-4} cm (10^{-4} inches), the maximum feed rate is 75 cm/min (30 in/min), a satisfactory rate for most metal-cutting applications.

In the early closed-loop CNC systems (see illustration on p. 80, bottom), the servo loops for velocity and position control remained in hardware, while the computer performed interpolation, feed-rate control, the decoding of the NC part data, and the distributing of these data among the axes of motion.

In the CNC systems of 1970, the interfacing point between hardware and software was shifted to the output of the position register (see illustration on p. 81). Because of the introduction of the sampling process in this type of system, lower loop gains had to be used for the position servo loop, a requirement that affected the transient response of the CNC configuration. On the other hand, this type of system offers the capability of a full diagnostic check by the built-in computer of its hardware and software, a feature considered by some manufacturers to be CNC's most important contribution.

The feed-rate control in CNC systems, including acceleration and deceleration, is carried out by software. Moreover, the position counters (which show the incremental distance to the next point) and the zero detecting circuit (a circuit that detects whether the machine is on target) are programmed in software as well. This is very simple in a system using resolvers (transducers of angular position) as the feedback elements, since, in this case, the reading of each position counter is reduced directly by the interpolator. When encoders are the feedback devices, the position counts are reduced, either by the software interpolator or by the encoder pulses. In the latter case, additional inputs to the computer are employed to feed the encoder pulses into the software counter, and the configuration shown on p. 81 might be used.

Microprocessors in NC

The biggest new force for change in the rapidly growing NC industry was the arrival of the microprocessor. The utilization of the microprocessor in NC equipment reflects the current trend of using software techniques to minimize or replace hardware, and will probably signify the NC trend of the late 1970s.

The use of microprocessors in NC systems provides a solution to the problems of cost and complexity. By employing microprocessors, the number of components in the CNC systems is reduced over that of hard-wired logic systems, which, in turn, results in higher reliability of microprocessor-based systems. Moreover, the microprocessor enables the design of a modular control, whereby each axis of operation of the machine tool requires only one printed circuit board. This scheme, which is also practicable with minicomputer-based systems, minimizes problems of complexity and maintenance.

The rate of penetration of the microprocessor to NC controllers is, however, slower than might be expected—the main reason being that the development of the microprocessor, as well as of the special instruments that are required to test it, is still underway. One aspect of this development involves improvement in the speed of microprocessor operation. For example, in the General Electric Mark Century 1050 system (the only system using a microprocessor by the end of 1974), hard-wired logic is employed to circumvent the slow-speed microprocessors in specialized calculations such as cutter compensation and circular interpolation. However, this solution is hardly in agreement with the main concept of a microprocessor-based system as being a self-contained system with minimum components.

To overcome the speed problem, most microprocessor manufacturers have settled on n-channel technology. This new generation of microprocessors, such as Motorola's MC 6800 and Intel's 8080, operates at high speed, with an instruction execution time ranging between 2 and 9 μs, or about ten times faster than early microprocessors. With this improvement in speed factor, the new generation of microprocessors appears powerful enough to be used in the new NC systems that will be introduced in the late 1970s. Another area where improvement is anticipated is in the microprocessor's instruction set, a development that is expected to increase the flexibility of future NC systems.

DNC: goal and problems

DNC systems operate in a time-shared mode. Each machine tool in a DNC system has its own program, with a supervisory program linking them and establishing any necessary priority. Usually, all NC part-data programs are kept in a large-capacity storage facility, such as a magnetic disk or drum. The supervisory program manages this storage and can take segments of desired NC data into the core storage of the computer.

The introduction of a DNC system in a manufacturing facility modifies the entire structure of the manufacturing cycle. DNC is a technique that allows machining processes to be fully integrated with other automation systems, with data files, and with management information systems. Since the control of machine tools alone has proved economically unsound, the aid to management might be considered as the most important advantage of a DNC system. DNC also reduces NC program processing costs.

However, there are other factors and problems that should be considered. For example, the lengthy cable runs needed for the transmission of the machine command data from a remotely located central computer to the individual machine control units of the DNC system strongly affect the initial investment in the system. System maintenance is another problem, inasmuch as the DNC system, including the central computer as well as the local controllers, is a special-purpose system. This means that software logic, timing problems, and interfacing vary from one system to another.

One of the major disadvantages of early DNC system design was that it was difficult to add or remove a conventional machine tool because such changes meant modifications of the machine's controller. These considerations are of great significance to most potential users, and so it is unlikely that such systems will become generally accepted. A new DNC system design, however, circumvents the last problem, as well as the economic and software ones, in that it leaves the conventional NC system as it is, except for the tape reader. In this design, the part data are stored in the central computer, and the only interconnections between the computer and an individual NC controller are those required to simulate the operation of the reader. This approach is known as the "behind-tape-reader interface." This is the only interface that can be easily adapted to any type of machine tool and that permits any machine tool of the DNC system to be taken out and used as a stand-alone NC machine just by the addition of a tape-reader circuit. ◆

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