Directorate of Intelligence

22382

CIA SOV 83-10061

Soviet Numerically Controlled Machine Tools: Problems and Prospects

A Research Paper

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SOV 83-10061
May 1983

Soviet Numerically Controlled Machine Tools: Problems and Prospects (U)

Summary

Information available as of 1 March 1983 was used in this report.

Beginning with the Eighth Five-Year Plan (1966-70), Moscow has attempted to place priority on accelerating the development of numerically controlled (NC) machine tools to increase productivity and to modernize its defense industries. It has met with some success as the number produced annually is now roughly equal to that of the United States. Soviet NC machine tool technology, however, is well behind that of the West, and most of the Soviet equipment is much less capable than that available in the West. The relative backwardness of the Soviet electronics and computer industry, insufficient numbers of trained NC computer programers, engineers, and machine tool operators, a bureaucratic system that discourages innovation, and a reduction in investment in the machine tool sector have retarded progress in Soviet NC machine tools. Consequently, the rapid gains in Western manufacturing productivity resulting from the introduction of NC machine tools in recent years have not been matched in the Soviet Union.

The USSR has resorted to large-scale imports to overcome shortcomings in domestic production of more advanced NC machine tools, and, for some types of NC equipment, imports now exceed domestic production. Although most Soviet NC machine tool and equipment purchases have been within COCOM guidelines, it is believed that sizable sales of embargoed equipment have been made. Mistaken judgments by licensing officials, misrepresentation by exporters, bona fide differences in interpreting COCOM definitions, and the willingness of some Western governments to permit the sale of embargoed equipment arising from differences with US interpretations on the strategic applications of the machinery in question have led to uneven controls on NC equipment going to the Soviet Union Much of the imported equipment has been allotted to the defense sector. Known applications include production of aircraft, tanks, ammunition, trucks, and ship propellers.

Although the Soviet Union now has one of the world's major machine tool research centers, a nationwide network of research institutes and design bureaus, and about 50 plants producing NC tool machinery, it will continue to lag behind the West for the foreseeable future. Dismantling of institutional roadblocks, changes in traditional manufacturing practices, and more discriminating allocation of scarce investment funds will be required to increase the output and quality of advanced machine tools and to use them more effectively. The record of the past suggests that success in resolving these problems will be limited, and the Soviet Union will continue to look to the West for NC machine tool technology.

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Background

The major innovation in manufacturing technology since World War II is the marriage of machine tools and electronics. The process by which this occurred involved changing from operating machine tools by hand to controlling the movements of the machines through a series of coded instructions transmitted electronically by a controller from directions contained on cards, tapes, or—more recently—directly from a computer.[1]

Numerically controlled machine tools are now widely used throughout the West, but Soviet industry has been much slower in adopting this new technology despite the advantages it offers in:

- Greater productivity through increased production rates and reduced scrap losses.
- Better quality control by reducing variations in the product caused by operator error.
- More flexibility in changing from the production of one product to that of another.
- Greater accuracy and the ability to machine more complex shapes—qualities particularly vital in the production of missile and aircraft systems

The pace at which the Soviet Union implements numerically controlled machine tools and other manufacturing technologies will have a major bearing on the success or failure of Soviet efforts to resolve the current economic problems through increased productivity. Moreover, the Soviet ability to match the West in the development and production of more complex weapon systems will depend in part on advances in such manufacturing technologies as NC machine tools. This study examines the Soviet development and production of NC machine tools and manufacturing systems, how Soviet industrial practices have affected the use of such systems, and the role of foreign technology and equipment in Soviet developments in this area.

[1] See appendix A for a more complete description of numerical control technology.

Soviet Strategy in the Development of NC Machine Tools

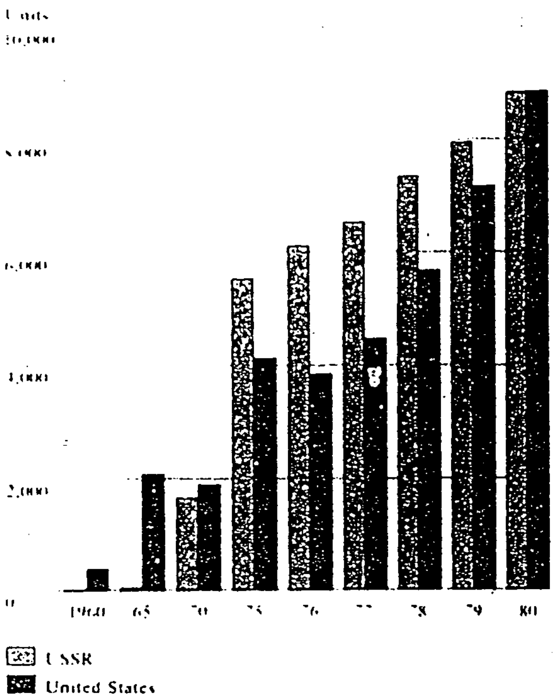
The Experimental Phase

Soviet development of NC machine tools started in 1949, shortly after work was initiated in the United States. By the mid-1950s, the Soviets reported the development of a prototype milling machine operated by an open-loop positioning system. The first prototypes appeared in 1958, four years after similar machines were produced in the United States, but the technical level was well below that attained by US and other Western machine tool manufacturers. By 1965, US production had increased to over 2,000 NC machine tools annually compared to 49 in the USSR (figure 1).

The relatively slow development of NC Soviet machine tool production before 1970 was the result of several factors. The Soviet electronics industry was backward, and this impeded the development of numerical control systems and their application to machine tools. Soviet machine tool builders frequently had to make their own controllers and other electrical equipment. Early Soviet NC machine tool builders thus concentrated on producing less sophisticated machines featuring open-loop controls. By contrast, the electronics industry in the West played a very prominent role both in the development of the control systems and in their application to machine tools.

Moreover, the Soviets followed certain traditional patterns in producing machine tools, which impeded the development of numerical control. They chose to develop control systems as accessories to existing machine tool prototypes, particularly lathes. The Soviet approach was aimed at eventual mass production of machine tools dedicated to one application for their entire lifetime. The West, by contrast, practiced

Figure 1
USSR and United States: Production of Numerically Controlled Machine Tools



Sources: Narodnoye khozyaystvo SSSR, statisticheskiy yezhegodnik; US Department of Commerce, Current Industrial Reports: Metalworking Machinery.

custom or batch production, in which engineering was concentrated on producing more complex machines designed specifically for numerical control and for performing a variety of machining tasks—a process better suited to long-range innovation.

A frequent complaint in the USSR was the absence of a single coordinating body for numerical control technology and the scattering of research and development among different organizations. The dispersal of research and development led to the creation of a number of noncompatible systems of numerical control and conflicts between the research organizations of various manufacturing plants.

By contrast, non-US Western machine tool manufacturers drew on one another's technology and on that of the United States, the most advanced in the numerical control field. Components such as controllers from one country could be fitted to the tools produced elsewhere. Finally, Western governments and private industry worked closely together to develop numerical control technology.

Series Production of NC Machine Tools
A major push to develop series production of NC machine tools in the USSR began with the Eighth Five-Year Plan (1966-70). Moscow appears to have followed a dual policy. To meet the needs of the aviation industry and other high-priority military users, the government called for the manufacture of high-precision machines used primarily for milling complex shapes. For the civilian sector, the major emphasis was to be placed on less complex control systems for efficient mass production of simpler tools, such as drilling and boring machines, lathes, and less complex milling machines.

Directives for accelerating the development and production of NC machine tools on a nationwide basis were issued by Moscow in April 1968. To implement the dual policy, the Ministry of Aviation Industry *(Aviaprom)* and the Ministry of the Machine Tool Building and Tooling Industry *(Minstankoprom)* were charged with the management of building these advanced tools.[3] Responsibility for designing and producing the control equipment was vested in the Ministry of Instrument Making, Means of Automation, and Control Systems *(Minpribor)*. The State Committee for Science and Technology (GKNT), with the participation of the relevant ministries, was delegated the responsibility of drawing up and approving a plan for

[3] See pp. 4-5 for a discussion of *Aviaprom*'s role in NC machine tool R&D and production

the coordination of R&D of unified systems employing numerical control for other types of equipment, such as metalforming, textile, woodworking, and printing machinery.

R&D was centralized in a network of design bureaus and research institutes set up under *Minstankoprom*. The Experimental Scientific Institute for Metalcutting Machine Tools (ENIMS), the Ministry's research arm, was expanded to include a number of regional branches. These research organizations interacted with specific plants and research organizations of other ministries for the purpose of developing new NC machine tool prototypes.

The Leningrad Electromechanical Plant (LEMZ), the primary manufacturer in the new specialized control systems branch of *Minpribor*, produced not only the early generation controllers for point-to-point machining, but newer systems as well for continuous-path cutting or contouring. Some control systems were also manufactured in smaller plants of *Minpribor*. The Ministry of the Electronics Industry (*Minelektronprom*) manufactured the electronic subassemblies, and ENIMS and other machine tool research organizations conducted R&D on machine tools supplied with controllers.

The USSR in the 1970s also set up a nationwide network of computer centers, which were to develop programs for the numerical controllers. Ten centers were established—nine for metalcutting machines and one for metalforming. Each center has been linked to the plants in its region by telephone and provides technical assistance to enterprises just starting machining with numerical control

The new policy also included a major program to import technology from Eastern Europe and the West. The USSR signed cooperation agreements with French, ι, and ; firms for production of control systems, and with its East European allies for joint R&D, production of machine tools and control systems, development of a single programing language, and an international programing network. Finally, the USSR imported large numbers of conventional and NC machine tools, mainly from the West, between 1970 and 1977

From the late 1960s to 1975, the USSR made rapid strides in producing NC machine tools. By 1971 Soviet annual output exceeded that of the United States. By 1975 about 30 Soviet enterprises, constituting a third of the plants in *Minstankoprom*, had shops producing this equipment. But most Soviet output was concentrated on 11 of the simpler type of standard models of NC lathes and milling, drilling, and boring machines. During 1971-75 the annual rate of growth of NC machine tool production averaged 27 percent, according to published Soviet statistics, but fell to 7 to 12 percent for the rest of the decade. The slower rate during 1976-80 reflected the cutback in investment of new plant and equipment for the machine tool industry as a whole, which the Minister of the Machine Tool Industry labeled "incomprehensible."

The program to expand numerical control was reinvigorated in conjunction with the 11th Five-Year Plan. In 1980 and 1981 alone, 13 additional plants began producing more complex NC metalcutting and metalforming equipment, including multispindle lathes, machining centers, grinders, profile milling machines, and press-forging equipment.

Not surprisingly, the Soviet inventory of NC machine tools produced in the 1970s mirrored the Soviet conventional machine tool stock.
estimated that 35 percent of the NC machine tools produced in the 1970s in the USSR were lathes, 28 percent drilling and boring, and 22 percent milling—by and large simpler, general purpose NC metalcutting tools adapted for use in the automotive, tractor, and agricultural machinery building sectors. The largest number of these machine tools were capable of only point-to-point positioning—open loop without feedback—with stepping motors and controls set by pushbuttons, plugboards, switches, or simplified cycles. Only the remaining 15 percent were advanced NC tools capable of multiaxis contouring, such as machining centers and complex milling machines.[1]

[1] See appendix A. (U)

Not until the end of the 1970s did the USSR also stress the development and production of NC metalforming equipment. Punch presses were among the first metalforming machine tools to be equipped with numerical control, and R&D facilities from 1976-80 produced 24 prototypes designed for various specialized operations, including hot and cold rolling of steel, ring rolling mills, and other forge-and-press equipment. In 1981 the total stock of forge-and-press machines in use in the USSR with numerical control was only 265, compared to an annual production of upward of 1,200 metalforming machines in the United States

The USSR is currently producing prototypes of computer-aided numerical control (CNC) and direct numerical control (DNC) machine tool systems. The only mention of tool machinery with CNC in the Soviet media relates to prototypes of a medium-size lathe, the 16K20T1, built with manual data input at the lathe manufacturing plant, Red Proletarian, in Moscow. There is also mention of copy grinders used for finishing turbine blade aerofoils being designed with DNC for use in a group setup operated by computer directly. The Moscow branch of ENIMS set up the first DNC system comprising 14 machine tools operated by computer in 1972-73, and it has since reported perfecting three additional prototypes of a "new generation" of DNC. [redacted] indicates that three additional systems are operating at the Red Proletariat and Ordzhonikidze machine tool plants in Moscow and at the Minsk Production Association for the Production of Automated Lines.

During the past decade, the USSR initiated a program to produce and use robots on a large scale. Soviet robotics technology, at least for industrial applications, apparently is not very advanced. The majority of the 2,000 robots that the Soviet Union manufactures annually are simple preprogramed machines used in work processing. Some complex individual robots have been developed for use in mining, servicing of nuclear reactors, and drilling in permafrost areas, but there is no solid evidence that the USSR is producing on a series basis servocontrolled robots capable of operating simultaneously on three different axes

Finally, the USSR, one of the leaders in the development and use of nontraditional metal-removing processes, including electrochemical machining (ECM), laser beams (EDM), and electron beams (EBM), has now applied numerical control to all three systems. Production in this area appears to be only pilot scale, however.

The Role of the Aviation Industry in the Development of NC Machine Tools

The Ministry of the Aviation Industry played an important part in the early development of NC machine tools, as did the aviation industry in the United States and other major Western industrial nations. As noted earlier, *Aviaprom* was chosen as coleader with *Minstankoprom* in 1968 to develop NC machine tool production. *Aviaprom* set up organizations that paralleled those of *Minstankoprom*. It had its own network of research organizations and design bureaus under the leadership of the Scientific Research Institute of Aviation Technology (NIIAT). Its chief branch was located in Moscow, with subordinate branches scattered around the country. According to [redacted] *Aviaprom* also had its own network of computer programing centers

Aviaprom also operates the Savyelovo Machine Tool Plant near Moscow, which apparently has manufactured the NC machine tools used in the aviation industry. The products of this plant include both metalcutting and metalforming tools, including state-of-the-art three-axis vertical mills, four- and five-axis planer milling machines, and machining centers.[4]

The importance of *Aviaprom* diminished, however, as NC technology became more widespread in the USSR in the 1970s. The output from *Aviaprom*'s Savyelovo plant obviously constituted a much smaller share of the NC machine tool inventory as the number of civilian plants producing advanced NC

[4] See appendix C for a description of these machine tools

machine tools with three or more axes increased to 13 and the total number of plants producing NC machine tools of all types reached 50.

Despite the privileged status of Soviet industries producing for the military sector—they are provided the best material and manpower resources—*Aviaprom* appears to have been no more successful in developing advanced tool machinery than its civilian counterparts. A recent Soviet monograph on advanced NC machine tools containing a discussion of Savyelovo and other evidence indicates that, in the 1970s, NC machine tool innovations proceeded at about the same pace in *Aviaprom* as in civilian industry. Early multiaxis NC milling machines built at Savyelovo were copied from models first produced at the Gor'kiy Milling Machine Tool Plant in the late 1960s and used widely in the civilian sector. Savyelovo's NC machine tools, like those in the civilian sector, were limited in the early 1970s to open-loop operation. As the technological level in the machine tool field improved and controllers with closed-loop capabilities came into production in the mid-1970s, Savyelovo, too, built more complex machines. These included plano-millers, machining centers, and movable gantries with three- to five-axis coordinate contouring path capabilities for milling large complex shapes made of high-strength steel or titanium alloys.

The same problems plagued both *Aviaprom* and *Minstankoprom* during the past decade:

- Managerial shortcomings such as the reluctance to install machine tools with numerical control.
- Slowness in the design and manufacture of prototypes.
- Technological shortcomings in the current generation of controllers, computers, and other electronic components, as well as shortages of machinery hardware.
- A lack of trained programers and service personnel.

[redacted] *Aviaprom*'s research arm, NIIAT, had to rely at times on civilian counterparts, such as the Odessa branch of ENIMS, to work out special machine tool-building projects. Finally, like the civilian sector, *Aviaprom* installed Western machinery to fill production gaps, improve machining quality, and hasten startup production.[1]

The Status of Multiaxis NC Machine Tools in the USSR

Production

Although the Soviets have progressed in NC technology, they are well behind the West in multiaxis machine tools operated by advanced controllers and computers (CNC). A small number of multiaxis NC machine tools were produced at seven plants between 1972 and 1977, but these machines required careful monitoring, lacked feedback systems, and were generally capable of achieving circular designs in cutting only through successive point-to-point movements around an arc—that is, "linear interpolation." Series production of NC machine tools capable of contouring on three or more axes continuously, and of controls suited for these advanced tools, was not fully under way until 1977. Since 1977, six more plants have been added (appendix B). Since 1972 the USSR has produced only about 1,400 machine tools capable of NC simultaneous contouring on three or more axes (see appendix B). The estimated annual production in the USSR in 1980 and 1981 was roughly 300 of these advanced machine tools compared to about 5,000 in the United States and more than 7,000 in Japan. Our estimates show that of the 20 models of multiaxis machines introduced in the USSR during 1972-77, only one-fifth were produced in the following five years in numbers larger than 20 per year by Soviet plants, and the remaining four-fifths continued to be produced at the rate of only 10 machines a year or less—rates far below those achieved in many Western industrial countries. Soviet technological lag in state-of-the-art machine tool production is most striking when comparing machining center output: in 1980 the USSR produced only 70 machining centers versus 2,100 in the United States and 5,200 in Japan.

[1] The technical features of this Western equipment are not known. Hence, it is not possible to establish whether the equipment was less advanced and therefore imported legally, or whether it was obtained in circumvention of COCOM embargo rules, since advanced NC tools may not be shipped to Soviet and East European military end-users. The machinery may also have been produced in and exported by Switzerland, Austria, or Sweden, which are not COCOM signatories

The USSR began series production of control units in the late 1960s. Although no figures are available on series production of controllers for less advanced NC machines, we estimate that in 1978 the annual Soviet output of three-axis control units was about 200 units. Output of four- and five-axis units was negligible. Annual production in the United States in 1977 was about 1,600 three-axis controllers and nearly 1,000 four- and five-axis units. Soviet controller production probably reached 300 units annually by 1981, concomitant with increased NC machine tool production.[a]

Factors Contributing to the Lag in Production of Multiaxis Numerically Controlled Machine Tools

The difficulties that the USSR has encountered to date in large-scale production of advanced NC machine tools stem from a number of factors—policy decisions beginning in the late 1960s, the technological backwardness of the country, and systemic features of the Soviet industrial system.

The Soviet Government's decision in the late 1960s to develop simpler prototypes and then mass-produce them, making incremental changes along the way, not only fitted in with the traditional approach to machine building in the USSR, but it also represented a response to doubts being voiced both in Eastern Europe and the West about the economic benefits of complex tools. A machining center, for example, could perform a large number of machining operations at one setting of the workpiece, but a number of these were relatively simple operations, such as drilling, which could be more economically done on a simpler and much cheaper machine.

Adapting numerical controls to basic models of general purpose conventional machine tools required simpler types of control such as open-loop systems and stepping motors and much less complex electronics design. This decision involved a willingness in the late 1960s to tolerate a level of accuracy in automated machining lower than that for US and British machines and to forgo the development of an infrastructure needed for series production of advanced machinery.

Technological Problems

When Western countries moved into series production of computer-aided and NC multiaxis tools in the 1970s, the USSR was unable to follow suit because of:

- Insufficient technological capability to produce controllers, feedback systems, and requisite computers.
- A shortage of programers and service personnel.
- The unavailability of precision-machined hardware needed for building these tools.

Controllers. The decision to concentrate on the production of simpler NC machine tools led to the widespread production of simpler open-loop control systems. These were generally mated to machines driven by electric or electrohydraulic stepping motors, employed less advanced solid-state circuitry based on transistors and semiconductor diodes, and generally handled only two-axis linear or circular positioning. In the late 1960s and early 1970s, the Soviets developed at least seven of these first-generation control systems.

When the USSR began series production of multiaxis tools capable of simultaneous contouring on three or more axes in the early 1970s (see appendix B), a new generation of controllers had to be developed. The N33 and N55 controllers, which met these requirements, were not produced until 1975 and 1977, respectively, and then only in very small quantities. These controllers had integrated circuits, like those in the West. By 1980 the USSR produced 15 models capable of multiaxis closed-loop contouring. By that time the demand for controllers began to exceed the supply. Since only the Leningrad Electromechanical Plant in the civilian sector was officially charged with controller production and was not meeting its production schedule, machine tool manufacturers in the USSR began making their own controllers.

[a] For an estimate of Soviet and US controller production

report that Soviet controllers suffer from numerous design and quality shortcomings, such as poor resistance to plant environment, improper tailoring to the requirements of the tools to which they were mated, inferior workmanship, and poor quality of the component parts. The controls are neither reliable nor durable; they are expected to function about 5,000 hours without repairs, but those used at the Sverdlov Machine-Building Association in Leningrad, for example, failed after 200 hours. Three full-time technicians were needed to service eight NC machine tools at the plant

Controllers also suffer from poor quality control and manufacturing practices. The Soviets do not use testing methods applied in the West to overcome "infant mortality," the period of early breakdowns of the equipment.[*] Their controllers appear to exceed the normal Western rate of 1.8 failures per year because multiaxis machines in the USSR are not used as intensively. Components are often damaged because of the heating and cooling periods associated with considerable machine tool downtime

Soviet controllers do not yet embody the advanced technology common to the West. The current generation of Soviet controllers lacks common Western features such as "nonvolatile" memory systems (magnetic core), semiconductor memory (integrated circuits), or bubble memory (a hybrid between magnetic and semiconductor systems)

The Soviets are still primarily adapting minicomputers rather than microprocessors to numerical control. Microprocessor production in the USSR, which began in 1980, is still only at the pilot plant production stage. Reports indicate that microprocessors are only now being designed into new products, and it will take a few years for series production to get under way. Even then, the Soviet machine tool builders will have to compete with other industries to obtain microprocessors for control units.

These problems with Soviet third-generation controllers, which are capable of medium-scale integration, suggest why the development in the USSR of the next generation of controllers—those that will have large-scale (LSI) or very-large-scale integration (VLSI) capabilities—is going to be difficult.[*] Such development needs to be accomplished, however, if the USSR is to expand its use of NC machine tools and incorporate them into groups of machines as in automated production or flexible machining systems.

Computers. Another factor contributing to the lag in production of advanced NC machine tools was Soviet backwardness in the technology, production, and delivery of computers in the 1970s. The Soviets expected to meet only a fifth of their domestic needs for minicomputers in the last half of the 1970s. The production of peripheral equipment was in even worse shape, as discs, line printers, and equipment for remote processing were in great scarcity

In contrast, during the 1970s computers in the West were rapidly applied to machine tools in three ways. First, small general purpose computers replaced some of the functions of conventional control systems in individual NC machines (CNC). Second, a central computer was used to feed programs directly and control a group of machine tools (DNC). Finally, computers were applied to control specially designed and integrated complex machining systems that often included robots.

Thus, while the majority of NC machine tools now being produced in the West are computer operated, only a fraction of the Soviet NC tool inventory has that capability. The shortage of minicomputers held back the integration of computers with NC tools. The older generation of Soviet computers, such as the Ural and Minsk series, were large and suited only to generating simple programs on two axes because of

[*] US producers of control units, such as Cincinnati Milacron, put the controllers through a careful program of testing, including the running of the machine and controller for 200 hours.

[*] The term "scale of integration" has a double meaning. On the one hand, it refers to strictly electronic functions. The scale of integration defines the number of components that have been integrated into one circuit in the controller. The larger the circuit, the more functions that can be handled. The range of functions that can be handled reflects on the range of capabilities of the tool to which a controller is attached. This leads to the second meaning, namely the complexity of the performance characteristics of the machine tool. An NC machine tool that is capable of only two-axis point-to-point open-loop movement has a control with low-scale integration. A machine tool capable of two- or three-axis closed-loop contouring capability has a controller with medium- to large-scale integration.

their limited memory capacity. Generally, at least 32,000 addressable units of memory (32K) are needed to write a contouring program for three or more axes. The M-6000 series, a minicomputer introduced in the early 1970s and still widely used, has 32K total memory, which enables it to guide machines with three axes. But because not all of this memory is usable—a portion of the memory is used simply to operate the computer—the computer is generally employed with machine tools functioning with medium- rather than large-scale integration.

The modernization of numerical control systems has been held back also because of shortages in trained personnel for maintenance and repair of control and computer equipment and the complexities of programing machine tools—a difficult and time-consuming operation at the early stages of the development of advanced numerical control. In the early 1970s, a Soviet writer estimated that 50 hours were required to prepare a program of average complexity, while each machine tool in use in small- or medium-batch production needed 200 programs on the average. As late as 1973, most Soviet NC machines were still being programed by hand, although computers were in wide use in the West. To overcome these difficulties, the Soviets set up regional computer centers, as noted above. The Soviets also failed to create a general programing language, such as the Automatically Programed Tool, or APT, developed in the 1960s in the United States

Hardware. There have been serious problems in producing and obtaining hardware components for advanced NC machine tools. So widespread has this problem been that it was readily admitted in a machine tool symposium in the USSR in 1981 that half of the Soviet machining centers with numerical controls are equipped with imported components. The shortage of these components resulted from a production system that was historically slow to respond on its own to innovation and from the government's failure to plan for the manufacture of such components

Motors are a case in point. The decision to concentrate on mass production of standard general purpose machine tools fitted with numerical control also meant mass production of simpler forms of control, electronics, and drives. Open-loop systems, characteristic of these simpler NC machine tools, required a simpler drive such as electrohydraulic stepping motors.[10] These were built in two plants. The introduction of machining centers and other multiaxis contouring machines after 1972 required the more sophisticated servomotors, which can be integrated with feedback systems.[11] There is still a great shortage of these—the first major plant for servomotor manufacture is still under construction. The Soviets also neglected to establish a regular source for producing permanent magnets, a key component in these motors. Action on another key component, thyristors, was taken only in 1981, when four plants were assigned to manufacture them.

The Soviets have also encountered difficulties in the series production of subcomponents for feedback devices, such as transducers and resolvers, without which closed-loop machine tool operations are impossible. The failure to provide for production of these key components, which have been imported, resulted from the original decision by the Soviet Government to concentrate initially on large-scale production of the simpler, open-loop type of NC machine tools. Nor did the USSR centrally organize the production of lead screws with bearings, or "ballscrews," a central component guiding the movements of machine parts along each of the major axes in NC tools. Currently only one plant produces ballscrews for all of the USSR. a, the key machines used in this plant to manufacture this component were imported from the West because the Soviets lacked the precision equipment required to machine these components

[10] Stepping motors move the equipment they control in discrete increments from start to a fixed stop position. There is no correction possible in the movements.

[11] Servomotors are small or large direct-current high-torque motors with thyristors—that is, silicon rectifiers—which, according to command, change the speed of motors or reverse the motor action in accordance with instructions coming from the feedback system. This enables the machine to make tool positioning more accurate.

Finally, manufacturing shortcomings that have in the past affected the reliability of conventional machine tools are plaguing the advanced tools as well. These include:

- Improperly stress-relieved castings, which can cause a machine tool base to warp or buckle.
- Improperly hardened slides, which can wear rapidly and unevenly and cause a rapid loss in accuracy after only several months of use.
- The traditional low quality of cutting tools that last, on the average, about one-fourth as long as their Western counterparts.

Other Factors Impeding NC Machine Tool Production

The participants of a conference held at Ivanovo in the fall of 1981 on machine tool modernization agreed that additional funds were needed within the machine-building field for manufacturing of advanced tools, despite Moscow's edicts calling for greater machine tool modernization. Moreover, A. G. Aganbegyan, a prominent Soviet economist and chairman of this conference, urged shortly afterward in an article in *Pravda* that additional investment be shifted at the national level away from such sectors as chemicals, metallurgy, timber, coal, and land reclamation and into machine tool modernization, on the grounds that the benefit from such funds would be greater for these fields if they were put into technologically improved and cost-saving machinery

Although these recommendations stemmed in part from the vested interests of these "modernizers," it is equally true that progress in modernizing machinery and in acquiring the requisite capital and institutional support was held back by powerful interests who wished to maintain the traditional strategy of producing large quantities of conventional tooling. The director of Gosplan's machine tool department, L. N. Snovskiy, pointed out at the conference that Gosplan had planned to double investment in machine tool modernization during the 11th Five-Year Plan period. He claimed, however, that pressures for maintaining the traditional system were greater and more widespread than those for innovation.

In the USSR, production of advanced NC machine tools was also impeded by the absence of a large-scale base of product specialization. In the West, machine toolbuilding is carried out by a large network of independent firms devoted solely to the production of machine tools and backed by a vast network of independent firms furnishing specialized parts and components. In the USSR, machine tools are produced in a variety of multipurpose plants, less than half of which specialize in machine tool production. When even a major producer of NC machine tools such as Leningrad's Red Proletarian Plant must use some of its resources to produce thousands of mowers, plants for whom machine tool building is a sideline can hardly be expected to have the expertise and interest in tackling advanced NC machine tool production.

Another factor impeding innovation has been the separation in the USSR between toolbuilders and the manufacturers of electronics and other components. Computer and control system development and the building of actual machines are usually closely linked in the United States.[12] In the USSR, production of machinery and components has been parceled out among four different ministries, with *Minstankoprom* being responsible for building the machinery, *Minpribor* for control systems, *Minelektronprom* for electrical subassemblies, *Minelektrotekhprom* for drive systems such as motors, and other manufacturers for various hardware items. Many problems in advanced multiaxis tool production have resulted from this division of labor, including constant breakdowns in production schedules, design shortcomings, and the development of systems unsuited to shop floor conditions.

Moreover, established budgetary practices at the plant level, including incentives, have proved disruptive to tool modernization. Plant managers continue to

[12] In the United States, despite the fact that some multipurpose corporations such as General Electric, Bendix, and Allen Bradley supply US tool manufacturers with a considerable portion of their electronics and control equipment, a number of leading American machine tool manufacturers, such as Cincinnati Milacron, Giddings and Lewis, and Warner and Swasey, have their own specialized control systems manufacturing divisions. These produce instruments for their own use and for sale. American machine tool firms have played an active role in the development of control units and the adaptation of computers to machinery

concentrate on meeting quantitative output goals set by the central planning authorities, and these goals are more easily met by keeping older models in production. This in turn discourages modernization. Even Moscow's efforts to create a new incentive structure, including special awards for innovation, have not been effective. Indeed, since such awards make up only 15 percent of a factory manager's budget, they are clearly not enough to provide a real incentive to innovate or to deviate from standard management practices

The high cost of electronic equipment in the USSR also has served as a deterrent to product innovation. In the West, electronic components are mass-produced, and the cost of computers and controllers has fallen drastically over the past two decades. Reports indicate that in the USSR the price of computers for machine tools continues to be very high, hovering around 100,000 rubles (approximately $140,000 at the official exchange rate).[a] Controllers also continue to be very expensive. As reported recently by the chief of Vladimir Machine Tool Plant's design bureau, his institution in 1978 purchased a Razmer-4 control system for 120,000 rubles. The system is currently still selling for 108,000 rubles. In the United States, the cost of a computer-aided NC multiaxis tool breaks down into 15 percent for the control package including computer; 15 percent for the drive package, including motor and feedback systems; and 70 percent for the machine itself. The electronic components in comparable Soviet machine tools, however, constitute more than half of the total cost.

Faced with such problems, only the occasional manager would seize the initiative and undertake production of NC tools, especially of the more complex types. [ ] Those who were charged with innovation often delayed NC tool building, stretching out the production of first prototypes over half a decade or more. Some suspended work on advanced tool development or production to meet their regular production quota of conventional tools. Plants that had already spent years developing multiaxis prototypes sometimes refused to go into series production because of difficulties in operating and programing the tools, and the prolonged costs associated with these efforts. Others began series production but produced far fewer than necessary for cost effectiveness.

The Role of Foreign Technology

The USSR resorted to large-scale imports during the 1970s to speed up development and production of NC machine tools. By decade's end, the annual value of Soviet imports was three times greater than at the beginning.

These imports served a number of functions in both the defense and civilian sectors. At the beginning of the 1970s, research organizations such as ENIMS purchased foreign tools for testing and evaluating this equipment—in some cases for deciding on models for future purchases from abroad. Machines and their components were also imported for reverse engineering. The Soviets found, however, that reverse engineering of multiaxis NC machine tools was not practicable, given the complexity of the machinery's hydraulic and electronic systems

The failure to produce controllers in large enough quantities for NC machine tools with three or more axes led to sharp increases in imports not only of control equipment, but also of NC tools and to extensive efforts to acquire NC production technology from the West. Machines, controllers, and other components were purchased to aid production directly when:

- Equipment that was needed for startup purposes could not be obtained from domestic sources.
- The limited use of the equipment made it inefficient to develop and manufacture such machine tools domestically.
- Similar models produced domestically were in short supply and could not be obtained in time to meet production schedules.
- Similar machinery was available in the USSR but did not have the requisite quality

[a] Average exchange rate in 198[illegible]

Table 1
Soviet Imports of Machine Tools From the West by Country, 1970-81 [a, b]

Million US $ (except where noted)

	1970	1975	1977	1978	1979	1980	1981	Totals 1970-80	Share for 1970-80 (percent)
Total	**77.3**	**192.3**	**357.5**	**453.0**	**706.6**	**487.5**	**385.3**	**3,567.8**	**100.0**
West Germany	20.6	72.4	172.4	199.0	357.9	240.1	181.3	1,618.9	45.5
Switzerland	16.2	33.7	56.6	52.1	66.4	69.8	47.3	490.2	13.7
Japan	5.3	7.3	28.7	67.8	86.0	53.2	39.3	347.4	9.7
Italy	14.1	10.9	44.1	23.1	39.0	37.5	23.2	262.6	7.4
France	7.5	17.9	12.1	20.4	49.9	43.6	36.8	263.0	7.4
United Kingdom	10.8	20.5	3.5	41.8	42.5	15.6	9.4	193.6	5.4
Austria	0.6	5.6	33.5	34.6	37.0	11.0	16.7	176.2	4.9
United States	1.9 [c]	13.3	1.8	11.5	14.9	5.0	21.5	136.3	3.8
Sweden	0.3 [d]	10.2	2.6	1.9	6.0	8.2	7.5	62.3	1.7
Belgium	NA	0.5 [d]	2.2	0.8	7.0	3.5	2.3	17.3	0.5

[a] Metalcutting and metalforming machine tools.
[b] Data have been converted using average official exchange rates for each of the years.
[c] Metalforming equipment only.
[d] Metalcutting tools only.

Sources: Vneshnyaya torgovlya SSSR, 1970-81, Statisticheskiy obzor (Moscow: 1970-81).

The USSR also has engaged in cooperative production with foreign manufacturers. They sometimes help directly in improving Soviet-manufactured machinery or issue licenses that enable the Soviets to produce the machines, equipped with key foreign-made parts, for resale abroad in Western markets. Cooperative arrangements have helped Soviet designers and engineers obtain Western know-how and keep Soviet manufacturers abreast of Western innovations and standards.

Imports of Multiaxis NC Machine Tools From the West

Western Europe supplied more than four-fifths of the USSR's non-Communist imports of machine tools; during the 1970s, nearly half originated in West Germany. Japan was also a major supplier, while the United States accounted for a relatively small share of the total (table 1).

COCOM controls on sales to Communist countries of continuous-path NC machine tools with three or more axes and very-high-precision machine tools kept Soviet imports lower than they might otherwise have been. (These commodities are defined as "strategic.") Following some relaxation in embargo controls in 1976-77, however, Soviet imports of NC machine tools surged, rising from 17 percent in 1975 to nearly a third of the total metalcutting machine tool imports from the West in 1980.[a] Almost half of the advanced tool imports, by value, were machining centers.

Austria, Switzerland, and Sweden—not members of COCOM—have been important suppliers of advanced tools and control equipment. They produce

[a] Numerical control was not applied widely in the West to metalforming equipment until the late 1970s. Thus, conventional metalcutting and metalforming tools made up the major share of Soviet tool machinery imports during the decade.

electronic equipment, such as controllers and CNC continuous-path NC machine tools with three or more axes, in large numbers. The USSR has also made R&D arrangements with these countries, the most recent being a joint Soviet-Swiss machine tool working group to improve Soviet NC machine tools using Soviet electronics and computers. Information on Soviet imports of advanced tools from non-COCOM nations is sketchy, but considerable amounts of advanced equipment, probably including some exceeding COCOM guidelines, have been imported from these countries. The Swiss, the leader among the non-COCOM nations in the production of multiaxis tools, ship half of their total machine tool exports to the USSR. During 1970-80, Switzerland, Austria, and Sweden ranked as the second-, seventh-, and ninth-largest Western exporters of machine tools to the USSR.

Although most Soviet machine tool and equipment purchases from COCOM countries were within COCOM guidelines, sizable sales of embargoed equipment may have passed through COCOM because of mistaken judgments on the equipment by licensing officials, misrepresentation of their products by exporters, bona fide differences in interpreting COCOM definitions in the least restrictive sense, and, finally, the willingness of some Western governments to permit the sale of embargoed equipment arising from differences with US interpretations on the strategic applications of the machinery in question.

Thus, the Soviets have been getting help where their technology lag is most pronounced. As early as 1967, the USSR bought 300 NC machine tools from Alcatel Company of France. Since then there has been a steady stream of Western technological assistance in the development and, to some extent, in the production of such advanced NC equipment as machining centers. In the early 1970s, the Soviets acquired manufacturing know-how from Fujitsu of Japan for the production of stepping motors. Since then many agreements have been signed providing technology for mating numerical controls with machine tools, the preparation of NC program tapes, the computerization of the tools, and feedback and measuring systems. Recently a number of agreements have been signed that extend numerical control technology to other conventional machine tools in fields such as blanking presses, plasma-arc welding, casting, plating, and power generation (table 2).

How important advanced Western machine tools are to the Soviets may be inferred from a comparison of imports with domestic production. For example, the USSR, which has been a major buyer of machining centers from Western Europe and Japan, acquired 286 units during 1976-81 from Japan alone—more than the total Soviet domestic production during the same period (table 3).

Military Applications of Imported Western NC Machine Tools

[redacted] indicates that such procurement has been carried out by the Soviets since the early 1960s. Some known examples include:

- Four heavy-duty NC machining centers, probably for tank turret machining, were delivered in 1981 [redacted]
- Propeller shops of several Soviet naval shipyards including Severodvinsk submarine plant purchased computerized lathes, NC milling machines, and profilers [redacted]
- A high-precision, 230-inch NC gear-cutting machine [redacted] for use in manufacturing nuclear submarine reduction gears was delivered to the Soviet Union in 1968.
- [redacted] NC chemical milling machines for production of helicopter rotor blades probably have been installed in helicopter manufacturing plant 387 near Kazan, RSFSR.

Table 2

Table 2

[redacted]

- Spot-welding robot [redacted] and gear-cutting machines and computer-aided assembly tool [redacted] were installed in the 1970s in three Soviet truck plants that produce both civil and military vehicles.[a]

- Automatic machine tool [redacted] were installed in the Kalinin Plant, Leningrad, in 1976 for the production of artillery warhead cases.

- An unidentified NC machine tool [redacted] was reportedly employed to produce parts for the SU-25 bomber at Tbilisi Airframe Plant 31.

Imports of Multiaxis NC Machine Tools From Eastern Europe

Eastern Europe has been a less important source of Soviet imports of NC multiaxis machine tools than the West. That area also fell behind the West in the last decade in developing NC machine tool technology, although East German numerical control technology, which was the most advanced in Eastern Europe, did not lag much behind that of the West in the 1960s. East Germany produced its first NC machine tool prototypes in 1964, and by 1970 it was exporting 80 percent of its NC tools to the USSR. During 1971-72, the East Germans sold the USSR almost 300 NC machine tools, although these were hard-wired, point-to-point types. They opened a machinery center at the Red Proletarian Machine Tool Plant in Moscow to familiarize the Soviets with the operation of East German NC tools and to train Soviet technicians in maintenance and programing. Moreover, East Germany also engaged in the early 1970s in prototype production of advanced machine tools such as machining centers and systems of aggregated machine tools (FMS). In the 1970s, however, East Germany failed to move into series production of multiaxis NC machine tools and FMS. Although it is not entirely clear why this happened, excessive concentration on exporting early-generation NC machine tools to the USSR and Eastern Europe probably played an important role.[b]

[a] See [redacted]

[b] In 1979, for example, East Germany sent half of its total machine tool output to the USSR.

Table 3
Volume of Japanese Exports of Machine Tools to the USSR, 1976-81 [a]

Units

	1976	1977	1978	1979	1980	1981	Total
Machining centers	2	17	62	50	76	79	286
NC-operated lathes	2	6	65	8	32	3	116
NC milling machines	0	7	0	3	14	10	34
Profile milling machines	0	54	0	0	4	0	58
NC boring machines	0	4	12	6	2	2	26

[a] Source: Japanese Ministry of Finance customs clearance trade data.

A serious effort appears to be under way in Eastern Europe to close the technological gap. These countries currently have 10 or fewer multiaxis NC models each in production, including machining centers. About half of these are estimated to be operated by computer. Series production of controllers has now started in East Germany, Czechoslovakia, Hungary, Poland, Romania, and possibly Bulgaria. [ ] the Hungarians are emerging with the most sophisticated programing and graphics modeling in Eastern Europe, and Hungary, Czechoslovakia, and East Germany have produced prototypes of flexible machining systems (FMS)

East Europeans are major suppliers of conventional machine tools to the USSR—providing more than 60 percent of all Soviet machine tool imports—and the USSR may be preparing them to become a major source of advanced NC machine tools as well. In 1971 a plan was initiated for joint Soviet/East European R&D, programing, and production of machine tools and control systems. In 1979, Hungary, Poland, and East Germany revealed plans for exporting substantial numbers of microcomputers to the USSR. Bulgaria has begun to export software, computers, and peripherals, such as tapes and discs. Romania is said to be shipping some three-axis machine tools that have mechanical components and software imported from the West. The USSR and Bulgaria signed an agreement [ ] for cooperation on advanced tool manufacture. Bulgaria, which has received extended help from Japanese and Western manufacturers, has also agreed to ship more than 200 robots annually to the USSR.

Outlook

Modernization of the machine tool sector is essential for Soviet industrial growth, because machine tool quality is critical to the manufacture of complex machinery needed to increase productivity in Soviet industry. The USSR has had difficulty, however, in utilizing this new technology, and has lagged severely in moving from early vintage NC tools to advanced computer-operated multiaxis machine tools now common in the West. Excessive concentration on mass production of simple general purpose tools fitted with less complex control systems as add-ons, the backwardness of the Soviet electronics and computer industries, the rigidities of the Soviet industrial system, insufficient numbers of trained machine tool operators, engineers, and programers, and, more recently, slowing investment growth have all impeded innovation

The USSR now has one of the world's major centers for research on machine tools, a nationwide network of research institutes and design bureaus, and about 50 plants producing NC machine tools. Metalcutting and metalforming tools and nontraditional metal removing equipment (electrochemical, laser, and electron-beam machining) are being fitted with numerical control. Some upgrading of the Soviet machine tool inventory should be accomplished in the long run, but, in the critical period of the 1980s, improvements are unlikely to come quickly enough to be an important factor in raising Soviet industrial productivity. Since the late 1970s, the production of conventional tools, still the backbone of the industry, has fallen largely because in 1979 investment funds for the machine tool sector were cut 26 percent below that originally planned. Although NC tool production was not affected by the cut, 7- to 12-percent annual growth during 1976-85 appears insufficient to take up the slack. The 1985 goal of producing 5,000 advanced multiaxis tools—up more than 12 times from the current production of about 400—is unattainable.

Short on both conventional and advanced tooling, the USSR may be required to rely as heavily on imports as it did in the 1970s. How much imports are constrained by hard currency availability or by COCOM controls is difficult to judge. Imports will not be a cure-all, however. Dismantling of institutional roadblocks, changes in traditional manufacturing practices, and more discriminating allocation of scarce investment funds also will be required to increase the output of advanced machine tools and to use them more effectively in increasing productivity. The past record suggests that successes in modernizing the machine tool industry will be limited.

Appendix A

Numerical Control Manufacturing Technology

Machine tools may be categorized as numerically controlled (NC) types and conventional machines. Conventional machine tools are those that are not NC equipped and are controlled by an operator. NC machines are equipped with a control system that operates the machine by means of numerically coded programs fed into the system in the form of punched tape, the playback of prerecorded operating programs, or a computer.

The steps in preparing and operating an NC machine tool are as follows. A part programer, after studying engineering drawings of the parts that need to be fashioned, visualizes the machine operations required to machine the workpiece. A program is prepared and "typed" onto a tape or card (or, in the latest generation of tools, into a computer). The program is then machine scanned and converted into machine tool movements by the control unit or controller (figure 2). Controllers may handle perforated tape, magnetic tape, tabulating cards, or even signals that are sent directly from computer logic or computer peripheral equipment such as disk or drum storage.

Numerical control programing falls into two classes or systems. The simpler method, usually used in drilling or boring machines, is point to point or positioning. The programed commands place the spindle, tool, or table in specific positions and the tool then drills or bores, for example. The tool does not touch the workpiece while moving between positions. Also, the tool generally moves along only one or two axes (figure 3).

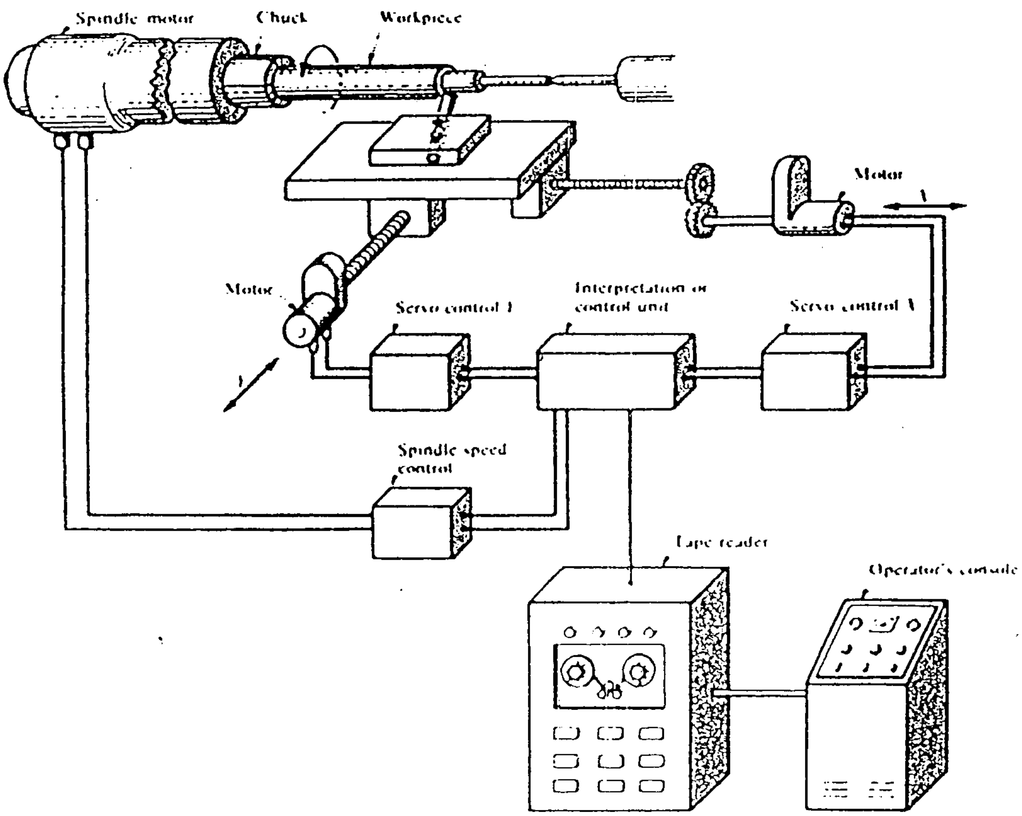
The more complex system involves continuous path or contouring, a method used in milling, turning, and grinding machines. In this method the cutting tool moves along the surface of the workpiece, cutting the metal into either straight or complex, or even asymmetrical, shapes. These movements are designated as interpolation, and labeled as linear (straightline machining), circular (curved machining), or parabolic (free-form machining used in shaping molds or in sculpturing dies).

The control units may be constructed for either open-loop or closed-loop operation. A closed-loop system, as shown in figure 3, is essentially a method for checking the operations of the machine tool and correcting deficiencies. The movement of the tool table or cutting tool is monitored through a feedback unit, which may be electronic, mechanical, or optical. As shown in the illustration, a gauge such as a transducer or inductosyn indicates the position the machine table, slide, or tool has reached in response to the tape or computer demand and reports this finding back to the control unit, which then continually compares these signals with those given in the original command. The controller then gives new signals compensating for any inaccuracies in movement, stopping the correcting motion when input and feedback signals are the same. Such measuring systems are essential where great accuracy is required.

On the other hand, an open-loop system does not have a feedback mechanism (see figure 2). Machines with open-loop systems are simpler in construction and require less electronic circuitry. As a result, they cost less, are cheaper to produce and repair, and require less sophisticated control mechanisms, gauges, and drive motors.

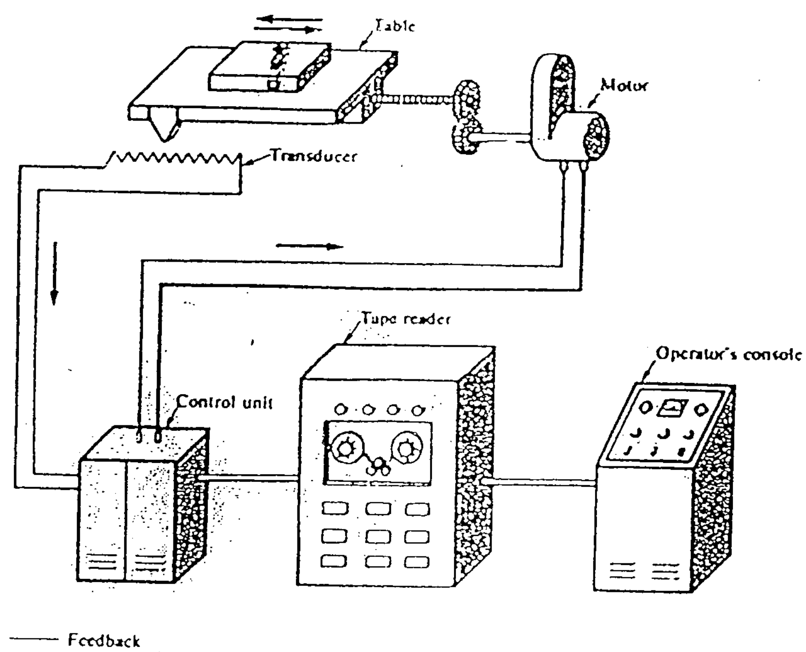
The features discussed so far are characteristic of the first two generations of NC machine tools. Generally speaking, these tools rely on hard-wired control systems in which the configuration of the electronic circuitry determines the range of control functions that can be performed.

Figure 2
Two-Axis, Open-Loop Numerically Controlled System



Socket

Figure 3
One-Axis, Closed-Loop Numerically Controlled System



Recent advances in computer technology brought about by the use of integrated circuits (ICs) have given rise to cheap and reliable small computers. This has led to a convergence of machine tool and computing technologies. In computer numerical control (CNC), a small computer is substituted for the command portions of a single machine tool's control system. The computer, which is cheaper to use than a conventional NC system, can assume many more functions than previous NC command systems, including: program storage selection and verification; feed and speed-rate calculations; and correction of errors caused by tool wear or machine deflection.

Computers also make possible direct numerical control (DNC), the operation of a group of NC machine tools and robots directly from a single, central large-scale computer. DNC is frequently used in the tool machinery working in an aggregate system such as a transfer line or a flexible machining system.

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Appendix B

Soviet Multiaxis NC Machine Tools: Types and Estimated Output, 1972-81

Model Number	Type of Machine	Manufacturer	Year Reported in Production	Estimated Production, 1972-81	NC Unit [a]	Interpolation	Control Loop
Three-axis contouring							
6R13F3	Vertical milling	Gor'kiy	1972 1975	65 150	2PT-71/3 N332M	Linear Linear/circular	Open Closed
6R13RF3	Vertical milling (with turret)	Gor'kiy	1973 1974	40 130	2PT-71/3 N331M	Linear Linear/circular	Open Open
6520F3	Vertical milling	L'vov	1973 1974	40 130	2PT-71/3 N331M	Linear Linear/circular	Open Open
P6520F3	Vertical milling	L'vov	1975	65	2PT-71/3	Linear	Open
1U6520F3	Vertical milling	L'vov	1975	65	N331M	Linear/circular	Open
6520PF3	Vertical milling (with turret)	L'vov	1975	65	N331M	Linear/circular	Open
LF270F3	Vertical milling	L'vov	1975	65	N331M	Linear/circular	Open
LF260F3	Vertical milling	L'vov	1975	60	N331M	Linear/circular	Open
LF260MF3	Vertical milling (machining center)	L'vov	1975 1980	40 5	N331M N332M	Linear/circular Linear/circular	Open Closed
MA755MF3	Vertical milling	Stankokon-struktsiya	1976	25	N552	Linear/circular	Closed
6305FA	Planer milling	Gor'kiy	1977	25	N551	Linear/circular	Open
6B443GF3	Horizontal milling	Leningrad [b]	1977	25	N552	Linear/circular	Closed
6B444F3	Horizontal milling	Leningrad	1977	25	N552	Linear/circular	Closed
6B445F3	Horizontal milling	Leningrad	1977	25	N552	Linear/circular	Closed
IR500MP4	Machining center (drill, mill, bore horizontally)	Ivanovo	1976	25	NA	Linear/circular	Closed
IR800MF4	Machining center (drill, mill, bore horizontally)	Ivanovo	1978	Fewer than 5	NA	Linear/circular	Closed
IR500PMF4	Machining center (drill, mill, bore horizontally)	Ivanovo	1979	5	NA	Linear/circular	Closed
6560MF3	Machining center (drill, mill, bore vertically)	Ulyanovsk	1978	25	NA	Linear/circular	Closed
6M610F3	Planer milling	Minsk	1978	20	NA	Linear/circular	Closed
4532F3	Vertical milling (profiling)	Kirovakan	1978	10	NA	Linear/circular	Closed
MA2611PMF4	Horizontal milling	Stankokon-struktsiya	1978	20	NA	Linear/circular	Closed

Soviet Multiaxis NC Machine Tools: Types and Estimated Output, 1972-81 (continued)

Model Number	Type of Machine	Manufacturer	Year Reported in Production	Estimated Production, 1972-81	NC Unit [a]	Interpolation	Control Loop
1516F3	Vertical turning (with turret)	Krasnodar	1978	20	NA	Linear/circular	Closed
LR336F3	Horizontal milling	Leningrad [b]	1979	25	N552M	Linear/circular	Closed
6620MF4	Machining center (drill, mill, bore vertically)	Ulyanovsk	1979	10	N552	Linear/circular	Closed
6540F3	Machining center (drill, mill, bore horizontally)	Ulyanovsk	1981	Fewer than 5	N552	Linear/circular	Closed
2204VMF4	Machining center (drill, mill, bore horizontally)	Odessa	1981	Fewer than 5	Razmer-4	Linear/circular	Closed
2254VMF2	Machining center (drill, mill, bore vertically)	Odessa	1981	Fewer than 5	Razmer-4	Linear/circular	Closed
Four-axis contouring							
2623PF4	Horizontal milling (machining center)	Leningrad	1977	35	N552	Linear/circular	Closed
			1980	5	N552	Linear/circular	Closed
6902PMF2	Machining center (drill, mill, bore horizontally)	Vilnius	1978	20	NA	Linear/circular	Closed
6904VMF2	Machining center (drill, mill, bore horizontally)	Odessa	1978	25	NA	Linear/circular	Closed
KU352	Horizontal milling	Kolomensk	1980	Fewer than 5	N552	Linear/circular	Closed
Five-axis contouring							
GF1860	Planer milling	Gor'kiy	1977	25	N552	Linear/circular	Closed
KM350	Vertical milling	Kolomensk	1980	Fewer than 5	N552	Linear/circular	Closed
KU351	Vertical milling	Kolomensk	1980	Fewer than 5	N552	Linear/circular	Closed
IR1600MF4	Machining center (drill, mill, bore horizontally)	Ivanovo	1980	Fewer than 5	NA	Linear/circular	Closed
IR320MF4	Machining center (drill, mill, bore horizontally)	Ivanovo	1981	5	NA	Linear/circular	Closed

[a] The controllers listed here are manufactured in the USSR and represent three generations of numerical control units: the first-generation 2PT-71/3 (open looped and capable of linear interpolation only); second-generation N331 (open looped) and N332 (closed looped and capable of circular interpolation); and the most recent N551, N552, and Razmer-4, which control machining up to five axes.

[b] The machine tools from Leningrad were manufactured by plants in the Sverdlov Machine Tool Building Association.

Appendix C

Representative Soviet NC Machine Tools

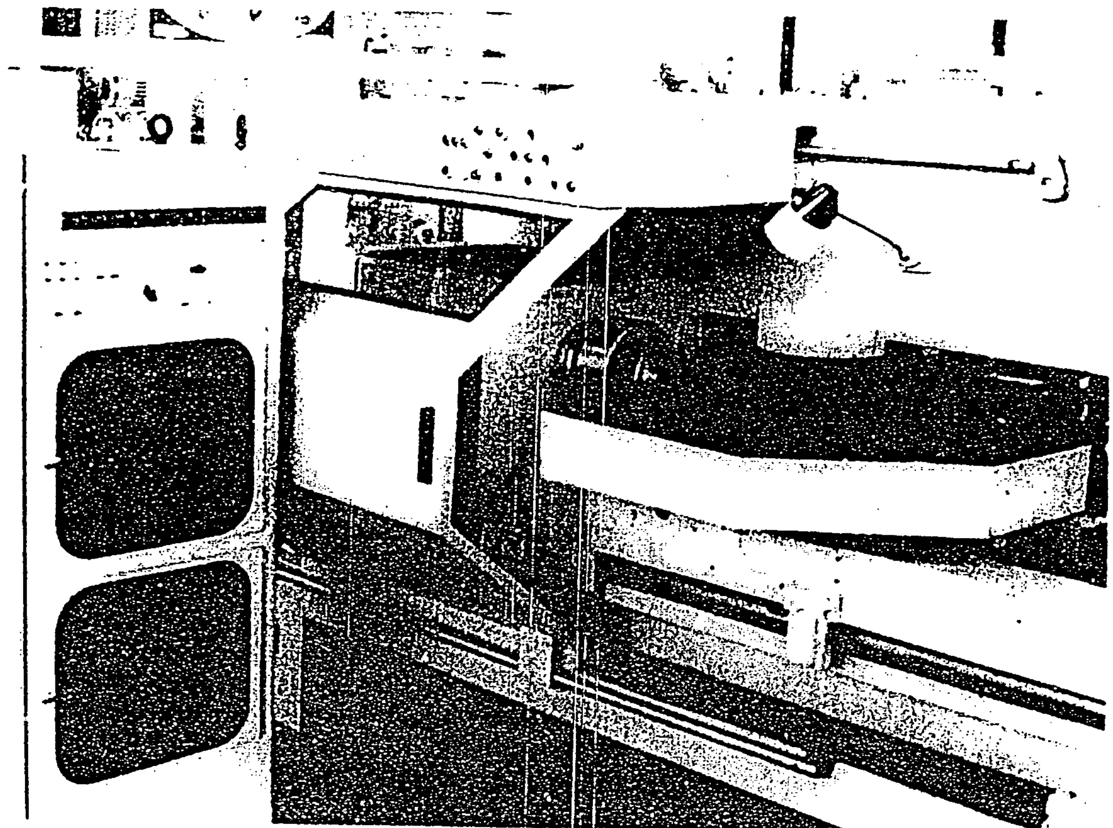

Figure 4

Numerically Controlled Lathe
Red Proletarian Machine Tool Plant, Moscow

The Red Proletarian Plant, one of the largest lathe manufacturers in the world, built its first numerically controlled engine lathe in 1966. The 16K20F3 NC lathe shown here was developed from the general purpose engine lathe 16K20, the basic model for 40 varieties of medium-size lathes intended chiefly for batch production. The 16K20F3 is a horizontal engine lathe capable of contouring simultaneously on two axes and operated with an eight-channel punched tape. Tools are clamped in a horizontal six-station turret for shaft and chucking work. A version is also manufactured with the tool holder in a vertical position rather than in a horizontal position. The machine is currently operated by a Soviet controller, the N22-1M, which has only an open-loop capability

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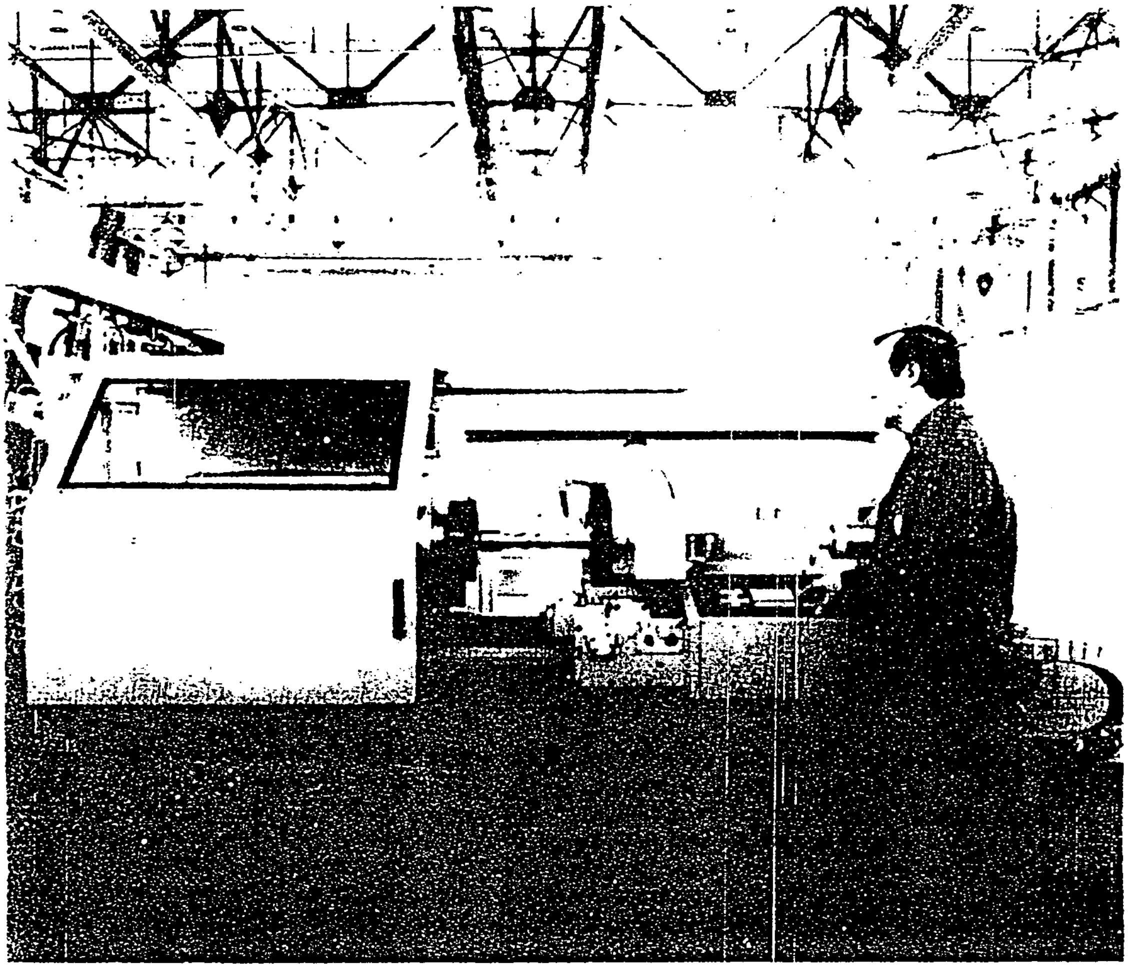


Figure 5

Computer-Aided Numerically Controlled Lathe
Red Proletarian Machine Tool Plant

This is the first variant of Red Proletarian's general purpose engine lathe to operate by computer-aided numerical control (CNC). The Soviets displayed this first prototype, the 16K20T1 CNC Lathe, at the Leipzig Fair in 1981. A number of machining programs have been stored in the memory of the computer, and the operator selects the appropriate program directly on the control panel at the front of the machine. Only a few machines of this type have been produced to date, including one delivered to OY Kone[illegible] Company of Finland.

[illegible]

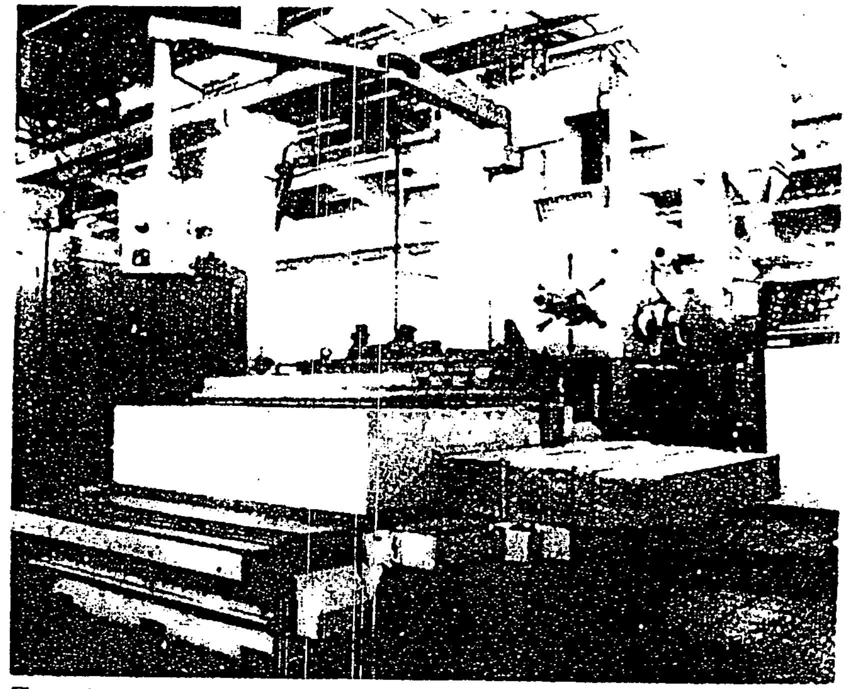
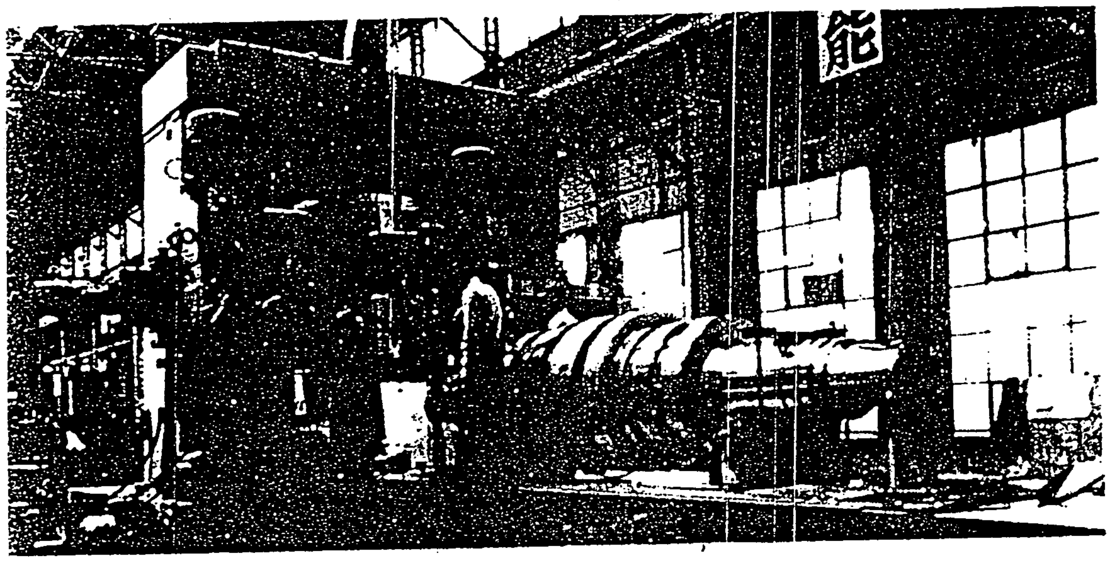


Figure 6

Numerically Controlled Drilling Machine Tool
Stankokonstruktsiya Plant, Moscow

Drilling and boring machine tools have also been fitted with NC for batch or series production. This machine is a horizontal drilling machine — the 2A622F2 — built at the Stankokonstruktsiya Plant that serves ENIMS, the central research institution of the Soviet machine tool industry. The machine was purchased in 1977 by the French firm Alcatel and outfitted with Western numerical controls. The USSR also builds vertical drilling machines with multiple spindle heads designed for simultaneous machining of several holes in one or more parts. (U)

Stankoimport Review



gure 7

laner Milling Machine
irov Machine Tool Plant, Minsk

is machine tool is part of a series of large planer-milling achines that are a specialty of the Kirov Machine Tool Plant in insk. The machine, the 6M610F1, receives its name from its semblance to a planer. The workpiece, which rests on the table, is d against two vertical rotating cutters at the appropriate speed. hese machines are designed for milling large workpieces requir-g heavy stock removal and contouring. This particular machine not NC, but the plant produces a line of planer-millers with ngle cutting heads, such as the 6M610F3, that are operated by

[illegible]

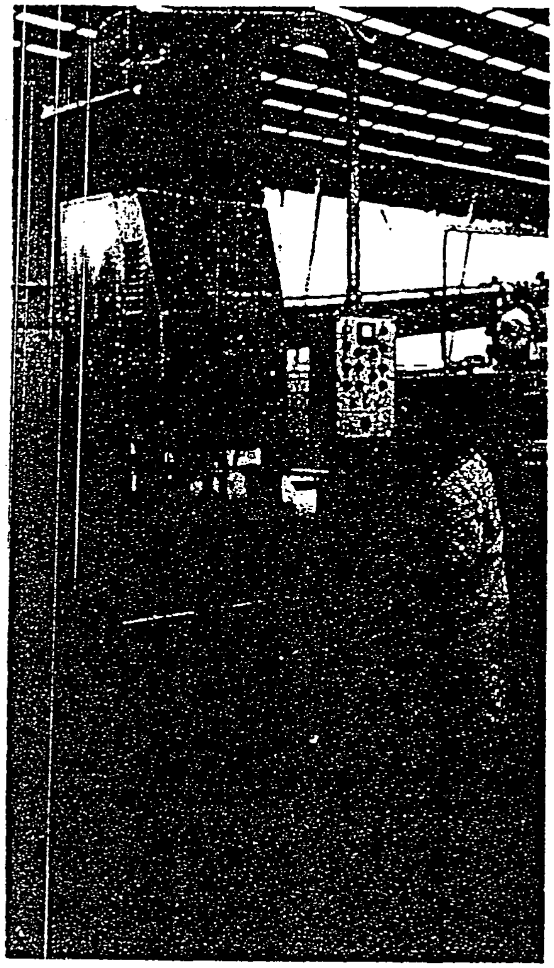


Figure 8

Numerically Controlled Profile Grinder Designed by ENIMS, Moscow

In manufacturing, grinding refers to the removal of metal by a rotating abrasive wheel. In this model, the MA396F3 profile grinder, the wheel is attached to, and spins around on, a vertical spindle. The wheel can grind interior and exterior surfaces of hollow or solid parts. The use of numerical control enables the wheel to cut or polish not only straight, but also complex, curved surfaces.

[illegible]

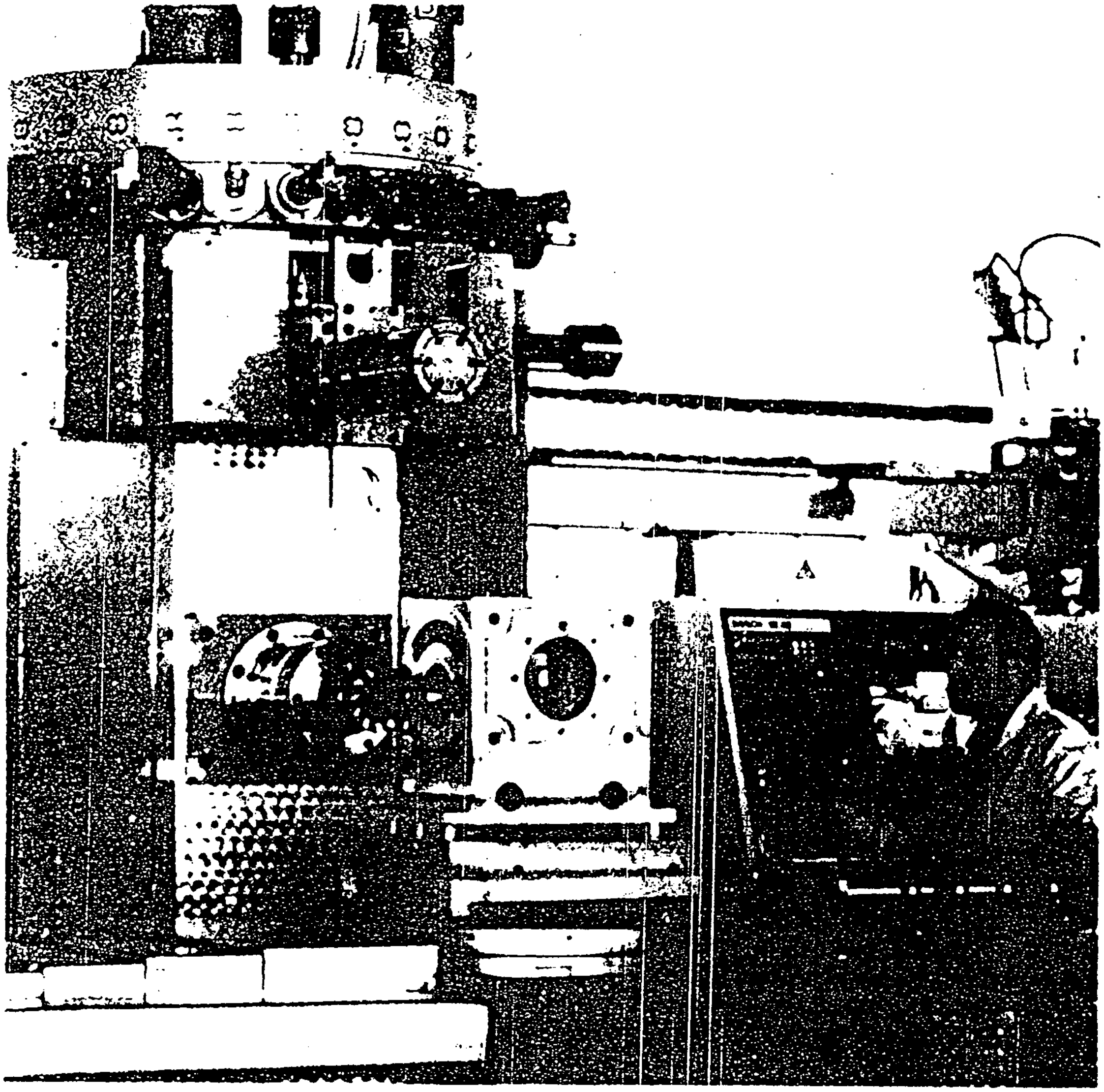


Figure 9

Numerically Controlled Machining Center
Ivanovo Machine Tool Plant

The machining center is a [illegible] integrated system with [illegible] more [illegible] attached in a toolholder. The tool changer can insert any of these tools into the spindle and the machine can then drill, mill, bore, or thread a workpiece—operations that in the past had to be performed on two or three different machines. The operation of a machining center thus saves labor and time. Machining centers in both the USSR and the West are capable of [illegible] continuous [illegible]. The IR-500MF4 is the basic model produced at the Ivanovo Plant. Note that the controller is from Bosch, [illegible] West Germany. [illegible]

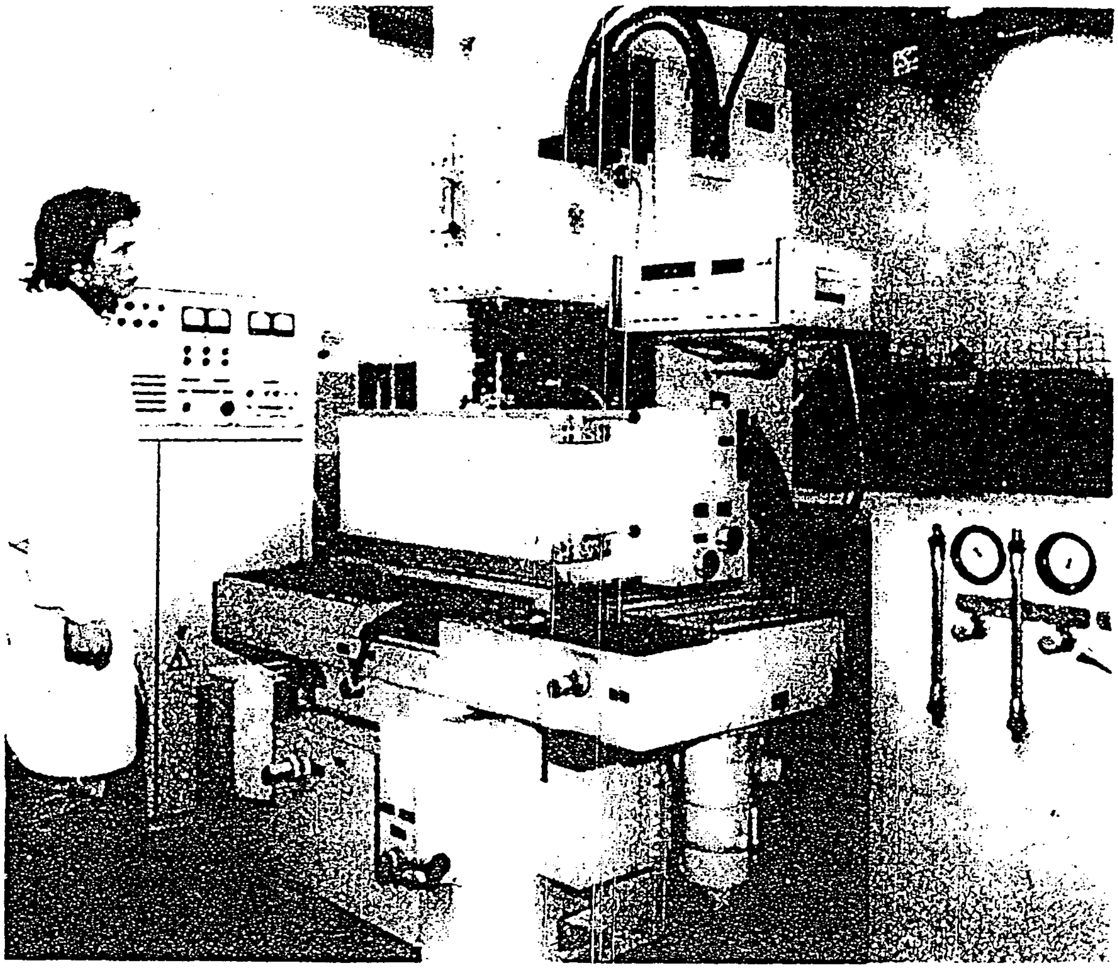


Figure 10

Numerically Controlled Spark-Erosion Jig-Boring Machine Dzerzhinskiy Machine Tool Factory, Kaunas

The USSR has also adapted NC to tools used for nontraditional machining. This includes precision machines such as the 4D722AF3, a spark-erosion jig-boring machine tool whose three-axis NC contouring capability enables it to machine-finish complex shapes, such as those of dies and molds made of conductive material, as well as heat-resistant high-alloy and hardened tool steels. The tool is part of a jig-boring series produced at the Dzerzhinskiy Machine Tool Plant in Kaunas. The Soviet Lithuanian machine tool industry has become an important producer of precision and specialized small metalworking machinery

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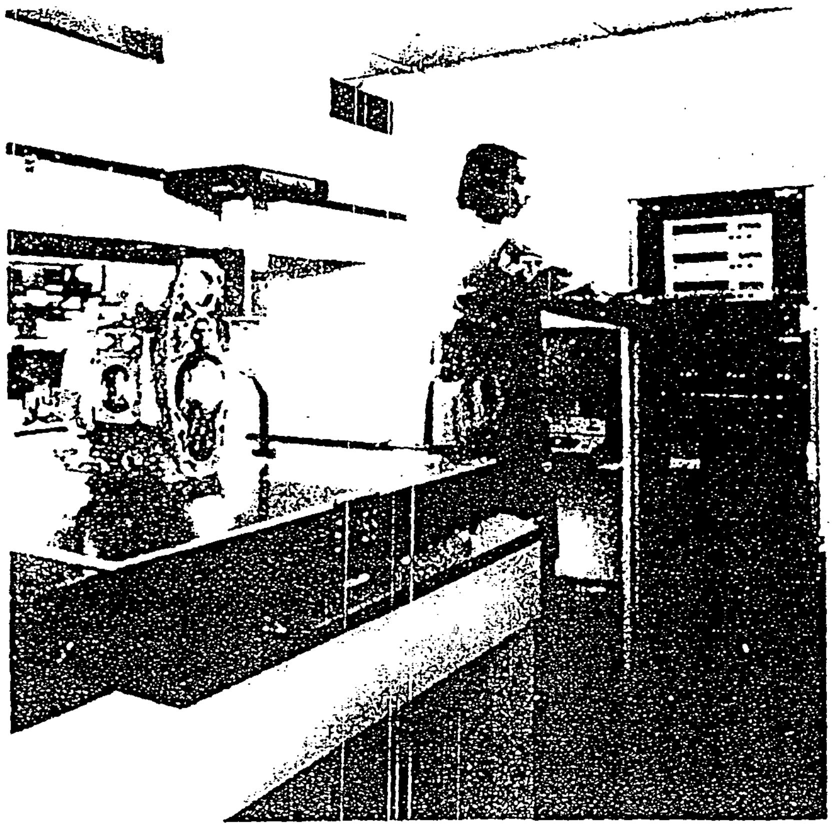

Figure 11

Coordinating Measuring Machine
Vilnius Division, ENIMS

The USSR not only has begun to manufacture electronic components for NC tools, but has applied NC to devices for measuring parts. One such device, now in prototype production, is the BE-155 coordinate measuring machine. This CNC multiaxis machine can check complex machine housing parts such as the one pictured. Its control system incorporates a minicomputer, which enables the data and the corrections to be fed back directly into an automated production system. These prototypes were designed and built in Lithuania, a center for precision machining in the USSR.

Figure 12

Numerically Controlled Forge and Press Equipment

The USSR has begun to develop numerical control with forge-press equipment. The upper photo shows the IB2114P sheetfolding press, intended for bending sheets up to a thickness of 2.5 mm and a width of 2 meters. The lower photo shows the K0122P NC turret-type multiple-punch press, equipped with a turret holding up to 28 punching tools for making holes of various sizes and shapes.

[illegible]