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18 March 1980

East Europe Report

SCIENTIFIC AFFAIRS

(FOUO 4/80)

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CZECHOSLOVAKIA

IMPACT OF NC, MICROPROCESSOR TECHNOLOGY ON MACHINE TOOL INDUSTRY

Digital Semiconductor Technology

Prague STROJIRENSKA VYROBA in Czech No 8, Aug 79 pp 633-639

[Article by Ivan Krsiak, Research Institute for Machine Tools and Machining Processes, Prague: "Progress in Digital Microelectronics and Its Impact on Machine Tools Automation"(part 1)]

[Text] For the past 20 years numerically controlled (NC) machines have been used for the automation of small-scale and intermediate-scale mass production. But up until recently NC machines accounted for only a small percentage of the total output of machine tools. But in conjunction with the strides that have been made in the development and application of microprocessor technology we are now witnessing a real boom in the production and installation of NC machines. It is to be expected that during the 1980's the application of microprocessors will play a crucial role in determining the technical quality, utility and marketability of most machine tools.

This three-part article is intended to serve as an introductory discussion of the development of digital microelectronics and their impact on the automation of machine tools. In part one we will be talking about current trends in the development of digital semiconductor technology with special reference to microprocessors and memory units. Part two will give an account of the impact of this technology on the machine tools industry, and part three will be devoted to a discussion of the current state-of-the art in the development of CNC systems and microprocessors in the CEMA countries and the CSSR.

The Development of Digital Semiconductor Technology

The development of semiconductor technology got under way in 1948 when the three inventors Shockley, Bardeen and Brattain published their findings on the theory and design of the type-A transistor. This work laid the groundwork for the development of transistors, which eventually replaced the vacuum electron tube. The results of research work in the field of solid-state physics and the opportunities opened up by developments in precision mechanics, optics and photochemistry paved the way for the transition to a new and qualitatively higher stage in the field of electronics, i.e., the emergence of the science of microelectronics. The first digital integrated circuits were introduced in 1961. These circuits combined several transistors (now numbering in the thousands) on a single silicon chip. The discovery of the multiemitter transistor structure in 1965 and its use in the design of TTL-type integrated circuits opened the way for the rapid development of the microelectronics field and led to the production of increasingly more complex integrated circuits. While the SSI (small-scale integration) integrated circuits developed during the period 1965-1970 made it possible to mount, say, a counter or adder on a single board, the development of MSI (medium-scale integration) circuits made it possible to mount a simplified processor on a single board. LSI (large-scale integration) circuits, which went into production starting in 1974, make it possible to mount an entire computer, including a microprocessor, memory unit and input/output circuits, on the same board. Current development work has brought things to the point where it is possible to incorporate all of these circuits into a single integrated circuit, the so-called single-chip microcomputer. These efforts have culminated in the development of VLSI (very-large-scale integration) circuits.

The growth in the scale of circuit integration together with the refinements that have been made in the physical properties of integrated circuits is illustrated in Table 1.

Table 1. Advances in the Level of Integration of Digital Circuits

	1950–1965	1965–1970	1970–1974	1974–1978	další vývoj
1) Stupeň integrace	diskretní součástky 5)	SSI	MSI	LSI	VLSI
2) Počet tranzistorů 3) Plocha čipu 4) Součástka	6) odpory kondenzátory diody tranzistory	7) 10–100 1–2 mm^2 hradla invertory klopné obvody zesilovače	8) 100–1000 5–10 mm^2 čítače registry 4-bitová sčítačka	9) 1000–10 000 20–40 mm^2 mikroprocesory LSI paměti	10) > 10 000 > 50 mm^2 mikropočítače

Key:
1) Scale of integration
2) Number of transistors
3) Surface area of chip
4) Component
5) Discrete components
6) resistors, capacitors, diodes, transistors
7) gates, inverters, flip-flop circuits, amplifiers
8) counters, registers, 4-bit adders
9) microprocessors, LSI memory units
10) microcomputers

These rapid strides that were made in the development of semiconductor technology are largely attributable to the development of the technology required for the production of integrated circuits. Table 2 gives a comparative breakdown of the characteristics of the most important technologies developed in recent years.

Table 2. Quality Ratings of the Characteristics of the Most Important Technologies Used in the Production of Integrated Circuits

	7) Technologie					
	8) bipolární			9) unipolární		
1) Vlastnost	TTL	ECL	I²L	P-MOS	N-MOS	C-MOS
Hustota integrace 2)	3	4	2	2	1	2
Rychlost 3)	2	1	2	4	3	3
Spotřeba energie 4)	3	4	2	2	2	1
Odolnost proti rušení 5)	3	4	3	2	2	1
Výrobní náklady 6)	3	3	2	1	2	2

1 velmi dobré 10)
2 dobré 11)
3 uspokojivé 12)
4 špatné 13)

TTL = Tranzistor – Tranzistor – Logic
ECL = Emitter Coupled Logic
I²L = Integrated Injection Logic
P-MOS = P – Channel MOS
N-MOS = N – Channel MOS
C-MOS = Complementary MOS

Key:

1) Characteristic
2) Integration density
3) Speed
4) Energy consumption
5) Reliability
6) Production costs
7) Technology
8) bipolar
9) unipolar
10) 1 -- very good
11) 2 -- good
12) 3 -- satisfactory
13) 4 -- poor

Depending on the transistors that are used, the production technologies are classified basically as being either bipolar (TTL, ECL, I^2L) or unipolar (PMOS, NMOS, CMOS). While in the case of bipolar transistors the current is shared by carriers of both polarities (negative electrons and positive holes), in unipolar transistors the current is generated by charges of only one polarity (positive holes in PMOS and faster negative electrons in NMOS). Bipolar integrated circuits are characterized by a higher function performance speed, whereas unipolar MOS circuits can be manufactured more easily and permit extremely high integration densities. In most cases LSI circuits (microprocessors, RAM and ROM memory units and input-output circuits) are still being manufactured by means of the PMOS and NMOS technology, and in this connection the NMOS technology is now most prevalent due to its higher speed of function.

The CMOS technology, as a special case represented by the combination of the PMOS and NMOS technologies, is marked by a high interference resistance rating and by an extremely low power consumption rate, even though relatively few LSI circuits are now being produced using this technology.

The most advanced technology cited in Table 2 is the I^2L technology, which combines the advantages of the TTL (high speed) and MOS (easier production and high integration density) technologies and which is therefore considered to be very promising.

The increased density of integration has been accompanied by faster functional speeds, a development which is mainly attributable to the reduction of parasite capacities and the shortening of signal paths as a result of the smaller geometric dimensions of the component parts. Given the smaller dimensions of transistors and their connecting wires, the size and width of which now vary on the order of micromillimeters, light diffraction problems now have to be taken into account during exposure. This is why exposure to electron or X-ray beams is now being used more and more frequently for the production of VLSI circuits. Beam lithography is making it possible to manufacture structures that are smaller than 1 micromillimeter. It goes without saying that the transition from photolithography to beam lithography will force components manufacturers to make considerable capital outlays amounting to millions of U.S. dollars.

Since the development of integrated circuit production technologies has been accompanied by a steady increase in chip surface area, it can reasonably be expected that the predictions will come true which hold that by 1980 the density of integration per chip will amount to 10^6 transistors, by 1990--10^8 transistors per chip, and by 2000--10^{10} transistors per chip. In the future this scale of integration will make it possible to design complex computational and control systems which by virtue of the functions they can perform will begin to approximate the complexity of the functions performed by the human brain. Even though we do not necessarily agree with these bold predictions, it is certainly to be expected that in the not too distant future it will be possible to construct an entire control system for a machine-tool consisting of a few command-controlled integrated circuits supplemented by appropriate control and readout elements.

In the next section of this article we will give a more detailed description of the two most important categories of LSI and VLSI circuits, i.e., memory units and microprocessors.

Memory Units

The first breakthrough involved the integration of more than 1,000 transistors on a single silicon chip in memory circuits (see Figure 1) with uniform structures and requiring relatively few housing leads. This resulted in the development of the first random access memory units (RAM) which were manufactured according to either unipolar or bipolar engineering designs. One disadvantage of the RAM memory unit is that information is lost when the power feed is shut off. A little bit later on static memory units (ROM-read-only memories) were developed with an unalterable data store which can only be read, but these memory units did not lose recorded information when the power is removed from the system. For this reason ROM-type memories are used as memories for discrete and unalterable control programs, while RAM-type memories are used as memories for the storage of data which needs to be altered. In the control systems of machine tools RAM memories are used, for example, to insert programs for the kinds of pieces to be machined, for tool adjustment values, for starting-point adjustments, and so on, while ROM memories are used to set up control programs for system operating modes, for determining the way in which workpiece machining programs are to be edited, for position plotting, for controlling feed drive, and so on.

Every RAM memory consists of a series of individual memory elements which assume a position of either logic-0 or logic-1. Depending on the design used, memories are distinguished by the time it takes to access information and by the density of memory-element integration, which in 1978 reached the point of 64k memory word locations (1k=1,024). The evolution of access time, integration density and relative costs per memory bit is described in Figures 2, 3 and 4.

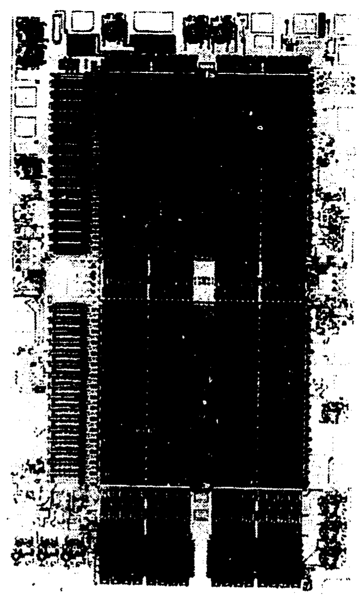
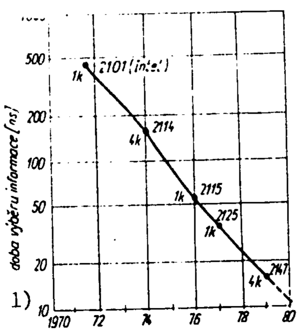
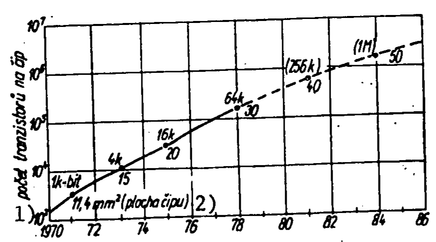


Figure 1. Chip microstructure of an Intel 2107 dynamic RAM memory with a capacity of 4,096 x 1 bit. In 1974 this memory virtually brought the era of ferrite memories to an end.



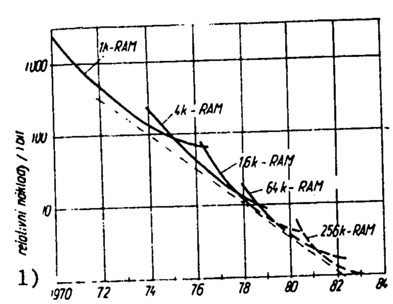
Key: 1) data access time [ns]

Figure 2. Evolution of data access time in static RAM memories



Key: 1) number of transistors per chip
2) (chip surface area)

Figure 3. Evolution of integration density in dynamic memories



Key: relative costs per bit

Figure 4. Evolution of relative costs per bit of memory unit capacity

RAM memory units are classified as being either static or dynamic memories. While the memory element of a static memory unit consists of at least two transistors, which form a flip-flop circuit (normally comprising 4 transistors and 2 resistors or 6 transistors), all that is needed to create a dynamic memory is a single transistor which is energized by a charged or discharged capacitor. For this reason, a dynamic memory unit is characterized by a higher degree of integration density and a lower power consumption rate; but one disadvantage of these kinds of memory units is that they have to be periodically refreshed in order to retain information stored in the capacitor (e.g., every 2 ms).

RAM-type CMOS memory units have recently appeared on the market that have extremely low power input requirements (usually on the order of microamperes per memory element). In the event of a power loss these memory units can be energized by batteries which can compensate for a power outage over a period of several days without any loss of recorded information.

ROM memory units are programmed by the manufacturer to suit the application needs of the customer during the actual production process (as a rule by using the so-called final mask). Programmable ROM memory units can be programmed one time by the user, e.g., by "blowing" the bridge link in a given memory element by means of current impulses of sufficient magnitude. Both types of memory units cannot be reprogrammed.

In order to be able to do this it is necessary to have an Erasable Programmable Read Only Memory unit (EPROM) whose information content can be erased, after the link is placed into an open condition, by means of ultraviolet light irradiation within a few minutes and then reprogrammed.

The use of an ROM memory unit is advisable only when a larger number of pieces (more than 1,000) are being produced, for only then does it become economical to fabricate the relatively expensive mask which is used to determine the amount of information to be recorded.

When a smaller number of pieces are being produced it becomes convenient to use PROM or, more often, EPROM memory units, whose principal advantages are related to the alleviation of the programming workload.

An innovation in the field of static memory units is represented by the development of Electrically Alterable PROM memory units (EAPROM), which without being removed from the board can be first erased and then reprogrammed by means of an electric signal. The entire function lasts just a few ms. Insofar as the user is not concerned about this relatively long time span, EAPROM memories combine the advantages of RAM and ROM memory units (the feasibility of on-board reprogramming and the retention of information in the event of a power loss).

As is shown by Figures 2, 3 and 4 the evolution of semiconductor memory circuits is headed toward a further increase in integration density and, therefore, toward an improvement in their parameters. In 1978 the VLSI threshold was crossed with the development of a dynamic RAM memory unit with a capacity of 64k bits (the Texas Instruments TMS 4164 memory). Using this memory unit it is possible to mount an operational memory with a storage capacity of 1MB (8 x 10^6 bits) on a single circuit board costing anywhere from 20,000 to 28,000 dollars. In order to build an operational memory unit with this capacity rating it was necessary up until very recently to make room, say, in an IBM 360 computer for several ferrite-core memory boxes with substantially inferior functional properties.

Microprocessors

In the wake of the successes that were scored in the development of technologies for the production of semiconductor memories leading manufacturers were attracted by the idea of starting with the large-scale integration of arithmetic and control circuits which heretofore had been realized in the form of small- and medium-scale integration circuits in the central processing units of computers.

The first microprocessor was developed in 1971 as a byproduct of the unsuccessful development of a circuit for computer imaging units. It was at that time that the still not-so-well-known firm Intel introduced the world's first four-bit microprocessor onto the market. Since 1971 the development of microprocessors has moved ahead by leaps and bounds, many new manufacturers have entered the market, new technologies have been developed, and word-position length has been lengthened from 4 to 16 bits, even though the Intel firm still outranks all other manufacturers as the world's leading producer in this field.

The development of microprocessors was made possible above all by the development of new MOS-type technologies which are needed for the production of high-capacity semiconductor memory circuits and more complex types of calculators. It was on this basis that it proved to be possible to design a universal computing system which affords a broader range of application potential than even the most refined calculator. In the case of microprocessors it proved to be possible to transfer the basic operational principles of relatively larger computers onto the small surface area of a silicon chip no larger than several square millimeters. But at this point it needs to be pointed out that there is a major difference between a microprocessor and a microcomputer. A microprocessor (see Figure 5) is merely the primary unit of a microcomputer that is incapable of functioning as an independent unit. It takes the place of what is known as the central processing unit (CPU) in computers. They always contain an arithmetic logic unit, various working registers and control circuits (see Figure 6). A microcomputer on the other hand is a complete computing system which can perform predetermined (programmed) functions such as numerical calculations, control calculations and so on. A microcomputer

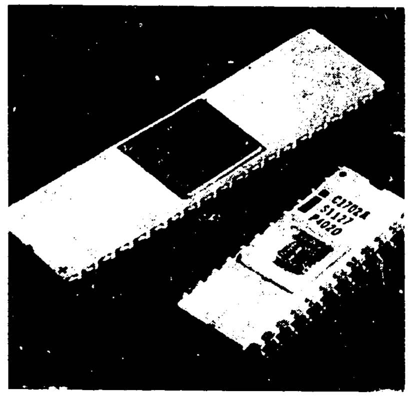
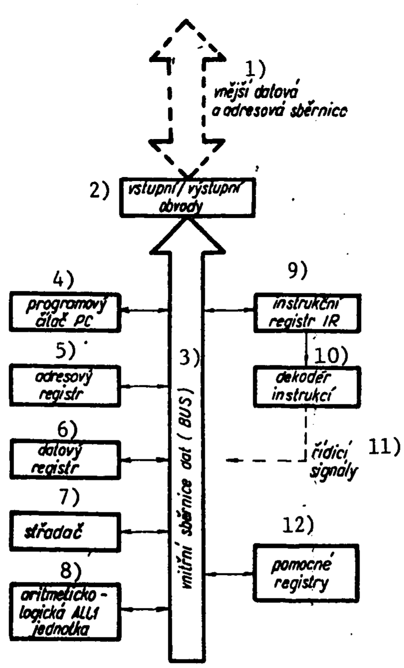


Figure 5.



Key:
1) outside data and address buses
2) input-output circuits
3) inside data bus
4) program counter
5) address reigster
6) data register
7) accumulator
8) arithmetic-logic unit
9) instruction register
10) instruction decoder
11) control signals
12) auxiliary registers

Figure 6. General scheme of a microprocessor

is a combination of subassemblies consisting of the microprocessor, memory unit, control circuits for the synchronization and generation of control signals (the read-write memory and peripheral equipment), input-output circuits for entering data into the system and retrieving data from the system, and interrupt circuits that enable the microprocessor to be controlled from the outside when necessary (see Figure 7).

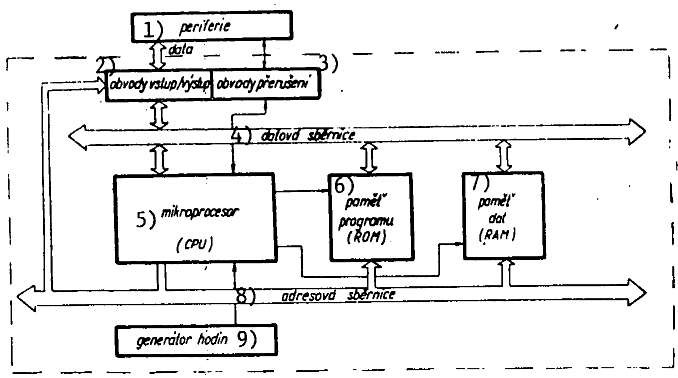


Figure 7. General scheme of a microcomputer

Key:
1) peripherals
2) input-output circuits
3) interrupt circuits
4) data bus
5) microprocessor (CPU)
6) program memory (ROM)
7) data memory (RAM)
8) address bus
9) clock pulse generator

The operation of a microprocessor is determined by a sequence of instructions which comprise the program. The instructions of a given program are entered consecutively into the ROM memory from a selected address so that the lowest address contains the first instruction which is the first to be executed, while the higher addresses contain the following instructions. At the start of every program the address of the first instruction is placed into the program counter (PC). The microprocessor retrieves the instruction from the memory and places it into the instruction register (IR). The instruction decoder decodes the instruction and then executes it. Even before the completion of any instruction phase the microprocessor increments the PC (i.e., it increases its information content by 1) and thereby locates the address for the next instruction. This sequential retrieval of instructions can be interrupted by a special jump instruction whereby the microprocessor replaces the PC information content with the address contained in the jump instruction. In this way the ROM instruction jumps over to another section of the memory unit.

The PMOS technology was used to produce the first 4-bit and the later 8-bit microprocessors (e.g., the Intel 4004 and 8008). These microprocessors are characterized by an instruction-cycle period (the time it takes to retrieve and execute instructions) ranging between 10 and 30 microseconds, a housing with less than 20 outlets, and a not overly refined set of elements comprising the microcomputer hardware.

The second-generation microprocessors are distinguished by the use of the NMOS technology. Typical representatives of this generation are the 8-bit Intel 8080 and Motorola 6800 microprocessors introduced in 1974. Second-generation microprocessors have a more advanced structure and, correspondingly, housings with 40 outlets. The second-generation microprocessors represent a major step forward in terms of operational speed, functional properties, differential circuits and the refinement of software. The instruction-cycle time amounts to about 2 microseconds. The structure of the Intel 8080A microprocessor is shown in Figure 9.

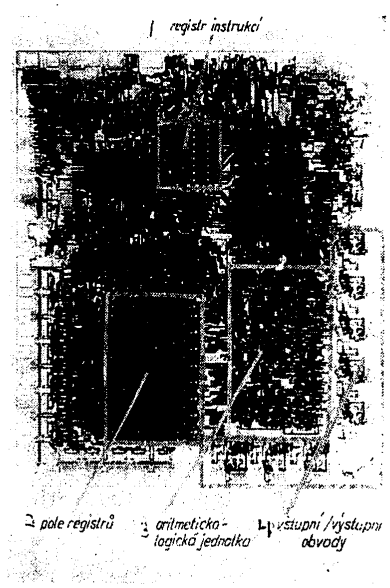


Figure 9. Microstructure of the Intel 8080A microprocessor. There are more than 5,000 transistors on this one chip.

Key: 1) instruction register
2) registers field
3) ALU
4) I/O circuits

In the course of executing instructions the microprocessor uses additional registers (data and address registers) or the so-called accumulator and the arithmetic-logic unit (ALU). The accumulator is a central register in which one of the ALU operands is always stored and which usually also records the result of an operation.

The arithmetic-logic unit performs all arithmetic and logic operations (addition and subtraction in binary or decimal arithmetic, rotations, moves, and so on). The address register holds the address of the memory location of the RAM memory or the address of the input or output port of the peripheral equipment. This means that the address register contains the address of the location inside the microprocessor which is designated by a given instruction for the processing of data. Finally, the data register provides for the temporary memory storage of data thereby eliminating unnecessary contact with the main memory and speeding up the operation of the microcomputer.

Connection between the individual registers of the microprocessor and the ALU is accomplished by the internal data bus. The number of carriers on a bus exactly matches the number of bits contained in one microprocessor word. The number of bits in a word is usually 4, 8 or 16. The microprocessor is linked to the other microprocessor circuits by means of an input-output circuit which is connected to an external bidirectional data bus. Some older types of microprocessors use this bus to transmit the addresses of memory units or external devices, but the newer microprocessors with 40 outlets have an address bus with a separate outlet.

Even though the history of the production of microprocessors only spans a period of 6 years, some authors have already identified three separate generation classes in their development based on the technologies used for their manufacture. The evolutionary stages in the development of microprocessors is shown in Figure 8.

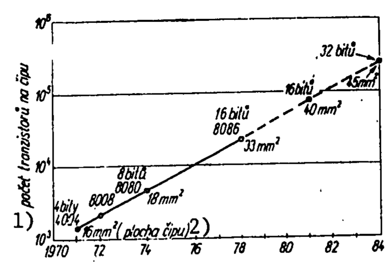


Figure 8. Evolutionary stages in the development of microprocessors

Key: 1) number of transistors per chip
2) (chip surface area)

In 1975 the Intel firm introduced the bipolar "bit-slice" microprocessor series 3000. This paved the way for the development of a special category of multichip microprocessors. In view of the fact that the bipolar technology does not permit a very high integration density, the bipolar microprocessors consist of two or four 2- or 4-bit slices which by means of a cascading arrangement can be used to assemble a microprocessor of indeterminate word length. The larger number of integrated circuits is offset by the extremely high speed at which operations can be performed, since the instruction-cycle time of these microprocessors drops to a level as low as 100 nanoseconds. Not even the fastest minicomputer could possibly match this speed of operation. The further development of the I 3000 bipolar microprocessor system is also under way in Czechoslovakia at the TESLA n.p. [national enterprise] in Roznov.

The professional literature indicates that at the present time there are more than 50 manufacturers engaged in the production of around 80 different types of microprocessors. The most prominent manufacturers of microprocessors include the firms Intel, Motorola, National Semiconductor, Texas Instruments, Advanced Micro Devices, Rockwell, Signetics, Fairchild, Western Digital, Toshiba, Nippon Electric, Fijitsu and Hitachi. Among the various European manufacturers of microprocessors we should mention Siemens (under the terms of a joint-venture agreement with Intel), AEG-Telefunken, and Philips (under the terms of a joint-venture agreement with Signetics). The most widely used microprocessors include the Intel 8080 and Motorola 6800 models, the production of which has also been taken over by other manufactuers (e.g., the 8080 is being manufactured by Texas Instruments, Signetics, Advanced Micro Devices, National Semiconductor, NEC, and Siemens).

However, the development of microprocessors has not come to a halt. This development work is continuing both at Intel and at other companies. In addition to the CPU, all of these manufacturers are trying to combine other circuits as well into a single housing and thereby reduce the necessary number of integrated circuits in a microcomputer to a minimum. The ultimate design goal is to build an entire microcomputer consisting of a single integrated circuit. Indications of the feasibility of this goal have been provided, once again, by the Intel company which has introduced a single-chip-type microcomputer model 8748/8048, which consists of an 8-bit microcomputer with an electrically (8748) or mask (8048) programmed ROM memory with a capacity of 8k bits, an RAM memory with a capacity of 64 x 9 bits, and built in input-output circuits. This single-chip microcomputer is designed to serve primarily as a control element for various kinds of terminals, e.g., for printing machines, cash registers, automobile instrument panels, and so on. It is certain that we will not have to wait very long before we witness the development of more advanced types of microcomputers with larger memory-storage capacities that can also be used for instrument control purposes.

The new, third generation microprocessors came onto the scene in 1978-1979 with the development of the Intel 8086, Zilog 8000 and Motorola MC 68000 16-bit models. In many respects these microprocessors have surpassed the performance ratings of the MSI minicomputers (e.g., the PDP 11/40 minicomputer). Moreover, the MC 68000 microprocessor has an internal data throughput capacity of 32 bits, a system of 32-bit operations, and a set of 16 registers with a 32-bit capacity. In addition, these third-generation microprocessors are much cheaper than the earlier models.

A comparative breakdown of the first-, second- and third-generation microprocessors manufactured by Intel is shown in Table 3.

Table 3. Three Generations of Microprocessors (A Comparative Survey of Basic Parameters)

	11) 1. generace 1971	12) 2. generace 1974	13) 3. generace 1978
	8008	8080	8086
Technologie 1)	P-MOS	N-MOS	H-MOS
Počet součástí 2)	3000	10 000	30 000
Počet bitů 3)	8	8	16
Rozsah adresy 4)	14 bitů 14)	16 bitů	20 bitů
Délka cyklu 5)	20 μs	2 μs	0,5 μs
Počet instrukcí 6)	48	78	400
Systém přerušení 7)	1 interrupt	maskovaný 16)	vektorový 17)
Hodinová frekvence 8)	0,5 MHz	2 MHz	4–8 MHz
Napájení 9)	+ 5 V, − 9 V	+ 5 V, − 12 V	+ 5 V
Pouzdro 10)	16 vývodů 15)	40 vývodů	40, 48, 64 vývodů

Key:

1) Technology
2) Number of components
3) Number of bits
4) Address range
5) Instruction-cycle time
6) Number of instructions
7) Interrupt system
8) Clock frequency
9) Power
10) Housing
11) First-generation 1971
12) Second-generation 1974
13) Third generation 1978
14) bits
15) lines
16) masked
17) vectored

Conclusion

In part 1 of this article we have reviewed development trends in the field of digital microelectronics which culminated in the production of VLSI circuits, including in particular 16-bit microprocessors and 64k-bit semiconductor memory units. We can only hope that microprocessors and their related circuitry will soon be put to full-scale use in Czechoslovakia as well both for the control of machine tools and in other branches of our machine-building industry. The applications of microprocessor technology in the machine tools industry will be discussed in parts 2 and 3 of this article.

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Machine Tool Industry Microprocessor Applications

Prague STROJIRENSKA VYROBA in Czech No 9, 1979 pp 706-712

[Article by Ivan Krsiak, Research Institute for Machine Tools and Machining Processes: "Progress in Digital Microelectronics and Its Impact on Machine Tools Automation" (part 2)]

[Text] It is a generally well-known fact, sufficiently substantiated by recent world exhibitions of machine tools, that the current state-of-the-art in the development of machine tools control technology is attributable to the use of large-scale integration integrated circuits, including in particular microprocessors and semiconductor memory units.

We gave an account of state-of-the-art developments in the field of digital semiconductor technology in part one of this three-part article. In part two we will be discussing the applications of microprocessor technology in the machine tools industry. We will be citing specific examples in order to show how the use of microprocessors has altered the structure of control systems and how current developments in the field of microelectronics are beginning to have an impact on the machine tools industry as a whole.

Evolutionary Stages in the Development of Control Systems

Before we proceed to discuss microprocessor equipped control systems we will give a brief account of the previous stages in the development of machine tools control technology.

As was similarly the case with most other electronic devices the development of machine tools control systems also went through several distinct generational phases which can be summarized as follows:

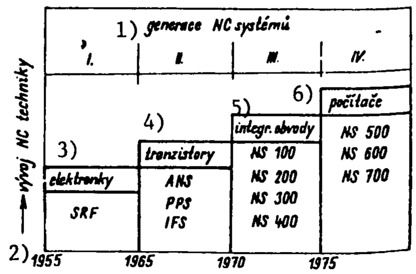
--First generation (vacuum tubes)--used to control workpiece path geometrics and feed-motion speed;

--Second generation (transistors)--standard block program format used to perform linear and circular interpolations, to adjust the length and diameter of tool pieces and to control auxiliary functions;

--Third generation (integrated circuits)--used for absolute and incremental programming, reducing the magnitude of programming and calibration increments from 0.01 mm to 0.001 mm, and increasing the number of feed passes;

--Fourth generation (computers)--used to store a complete program for one or several workpieces in the memory unit, to eliminate the punch-tape reader from the recycling process, to edit the program stored in the memory unit, to record the edited program on punch-tape or magnetic tape, to store and activate various repetitive subprograms, and to perform troubleshooting tasks.

The time scale spanned by the development of machine tools NC systems in the CSSR is shown in Figure 1.



Key:
1) NC system generations
2) development of NC technology
3) vacuum tubes
4) transistors
5) integrated circuits
6) computers

Figure 1. The development of NC systems in the CSSR (dates indicate the start of work on the development of individual NC system generations in the CSSR)

Machine tools control systems can now be classified as belonging to the following basic categories (see Figure 2):

--control of process functions,
--digital control,
--direct computer control.

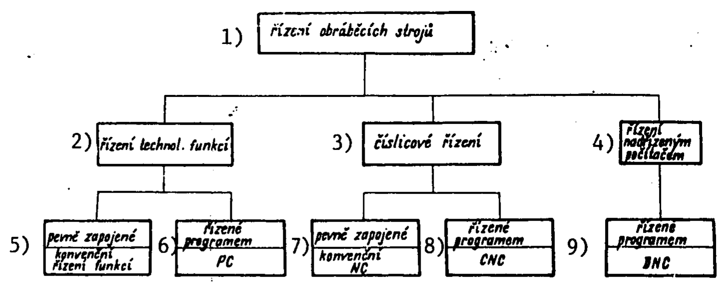


Figure 2. Machine tool control systems

Key:
1) machine tools control systems
2) process control
3) digital control
4) computer control
5) fixed connection/conventional process control
6) program controlled/PC
7) fixed connection/conventional NC
8) program controlled/CNC
9) program controlled/DNC

While in the case of process control systems there has been a clear tendency to move away from fixed-logic relay boxes toward programmable automata (PC--programmable controllers), the development of digital control systems has been marked by a tendency to move away from so-called fixed-logic NC control systems of the third generation toward CNC (Computer Numerical Control) "computerized" systems with built-in minicomputers or microcomputers. Direct computer control systems (or DNC--Direct Numerical Control) are being used for the control of entire production systems (consolidated production departments and flexible production systems).

In this article we will be focusing exclusively on digital control systems for machine tools. The other classes of control equipment exceed the scope of this article.

Microprocessor Equipped Control Systems

The last 5 years have witnessed and are continuing to witness the development of many kinds of microprocessor-equipped control systems in various categories ranging from the simplest kinds of memory-equipped position-indicator control systems to the most complex multiprocessor systems that control intricate centering machines and also the adjustment of workpieces and toolheads. What is the biggest benefit resulting from the application of microprocessors in the machine tools industry? The most important gain resulting from the advent of microprocessors should not be viewed as consisting in the development of complex computer systems stored on a single silicon chip, i.e., in the density of elements per chip in relation to the chip dimensions. Identical or even greater densities were achieved in earlier years in the case of semiconductor memory units and calculators.

The main contribution of microprocessors to the machine tools industry consists in the fact that these components have made it possible for manufacturers of control systems and, more and more often, even the manufacturers of the actual machine tools to take systematic advantage of the opportunities opened up by computer technology.

Attempts to put the computer to work for the control of machine tools were in evidence at the very start of work on the development of NS systems, but at that time the utilization of computers was still too expensive. This situation was changed to some extent with the advent of minicomputers at the start of the 1970s. The relatively low cost of minicomputers made it possible to harness these devices for certain, more complex applications. But it still needs to be said that minicomputers are not now so affordable so as to permit a general shift away from the use of fixed-logic systems (i.e., systems with unalterable logic functions) and toward the use of computerized systems (CNC systems). This transition is just now getting under way thanks to the development of microprocessors and microcomputers. The first CNC systems equipped with minicomputers appeared on the market as far back as 1970. The following systems are among the most noteworthy in this category:

--the Dynapath CNC System 5 manufactured by Bendix,
--the Adapt-a-path system manufactured by General Automation,
--the Series 8300 manufactured by Allen-Bradley,
--the Acramatic CNC system manufactured by Cincinnati Milacron.

But it was not until after 1974, when microprocessor equipped CNC systems began to show up on the market, that computerized control systems began to be used on a much larger scale. This trend is illustrated by Figure 3, which shows the percentage breakdown of fixed-logic NC systems and computerized CNC systems displayed at leading world exhibits of machine tools.

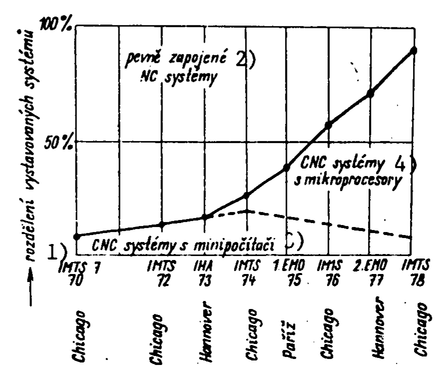


Figure 3. Share of CNC systems in the total number of exhibited systems

Key:
1) breakdown of exhibited systems
2) fixed-logic NC systems
3) CNC systems with minicomputers
4) CNC systems with microprocessors

The increase in the number of exhibited CNC systems after 1974 was attributable to the launching of the production of CNC systems equipped with microprocessors. Thus, for example, at the Second EMO Exhibition of Machine Tools held in Hanover in 1977 out of a total of 345 exhibited NC machines 221 machines, or two-thirds, were CNC systems equipped with microprocessors. This ratio is even more marked in the case of lathes, since out of a total of 156 exhibited NC lathes three-fourths were controlled by CNC systems equipped with microprocessors. The year 1978 witnessed a further intensification of development work on microprocessor-equipped CNC systems, while work on the development of fixed-logic NC and CNC systems equipped with minicomputers leveled off or declined.

CNC systems with microprocessors can, depending on their structure, be classified as belonging to basically three categories which correspond to the classes of machines which they are designed to serve. These categories are described below.

1. Systems With a Fast 16-Bit Microprocessor or Multiple Microprocessors Used for Large-Scale and Complex Machines

These systems are designed to control machines with five or more coordinates and their characteristics enable them to perform the same kinds of functions as the most advanced CNC systems equipped with minicomputers, the only difference being that the number of active components in these systems has been reduced by as much as 60 percent and that they are roughly 30 percent cheaper. In order to make it easier to operate these machines and to edit programs these systems are equipped with an alphanumeric CRT or semiconductor display device, have a well-developed error-detection regime, and with the aid of various subprograms and modular and fixed cycles can simplify the programming of workpieces.

In view of the fact that standard microprocessors manufactured by means of the MOS technology usually have a longer computing cycle time than fast minicomputers and a shorter word length (8 bits in contrast to the most often used 16-bit word length in minicomputers), with the result that a single 8-bit microprocessor would not be able to handle all of the tasks that complex systems are designed to perform, it was necessary to compensate for this deficiency. This was accomplished by using a fast bipolar microprocessor, making provisions for longer word lengths, and building multiprocessor systems.

Some of the most noteworthy systems in this category are as follows:

--the Mark Century 1050 manufactured by General Electric,
--the Sinumerik 7 - System 7 manufactured by Siemens-Fanuc,
--and the Actrion III manufactured by McDonnell Douglas Corp.

The Intel 3000 bipolar cascaded microprocessor with a word length of 16 bits was first used by Siemens in its Sinumerik 7 and Sprint systems. On the other hand, the multiprocessor structure was chosen by firms such as General Electric for its 1050 system, McDonnell Douglas Corp and AEG for the Actrion III system, Gildemeister for its Eltropilot-M system (designed to be used with a dual-spindle facing lathe) and other manufacturers of NC technology.

In the Actrion III system, a block diagram of which is shown in figure 4, three compatible microcomputers, which share a common data memory, operate in a multiprocessor mode. The microcomputers are linked up with this memory on an alternating basis. One microcomputer is designed to process input and output data, the second one is used to compute the continuous feed path, and the third one operates as a central position control unit. All of the processors are hardware compatible, each one is mounted on its own board, and they differ only in terms of the content of the EPRON memory which contains the standard routines. Another advantage of the system is that it has a built-in CRT display device, and a programmable automaton for controlling machine mechanical functions can also be placed in the system console.

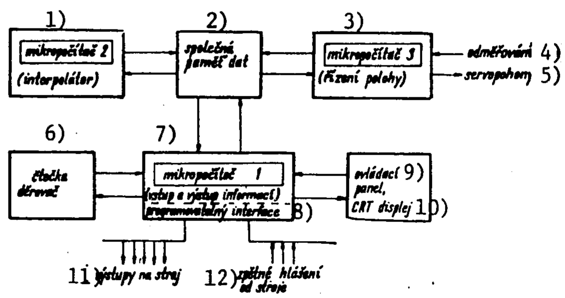


Figure 4. Block schematic of the Actrion III system

Key:

1) microcomputer No 2 (interpolator)
2) common data memory
3) microcomputer No 3 (position control)
4) calibration
5) power unit
6) punch reader
7) microcomputer No 1 (data input and output)
8) programmable interface
9) control panel
10) CRT display
11) output ports to machine
12) feedback ports from machine

The Actrion III system is designed for the continuous-path control of machines with up to 5 coordinates and equipped with DC power units. For example, this system is being used for the control of Beohringer, H.E.S., Heylingenstaedt, Index, Newall and other machines.

In Western Europe the Actrion III system is being sold by AEG under the trademark Numerous System III (see Figure 5).

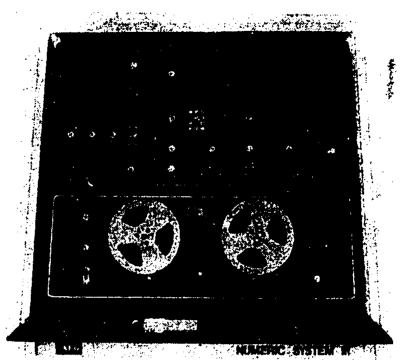


Figure 5. Panel of the Actrion III - Numeric System III system

The General Electric 1050 system (see Figure 6) uses a separate Toshiba 12-bit microprocessor to control all machine coordinates and also to compute interpolations. Overriding the coordinates microprocessors is a so-called look-ahead microprocessor which is used to control transfers of data on the universal bus and to process the system's input and output data.

Figure 6. The General Electric 1050 system

The General Electric 1050 is designed for the continuous-path control of machines with up to 6 coordinates and equipped with DC power units. Calibration is accomplished by means of selsyn or indoctosyn systems. For example, the General Electric 1050 system is used for machines manufactured by the firms Burgmaster, Defum, Excello, Mandelli, Monarch, SHW, Wanderer, Churchill, Lodge-Shipley, Warner-Swasey, Sheldon, Wickman, Brown-Sharpe, Hunger and others.

The Sinumerik 7-System 7 manufactured by Siemens-Fanuc is designed to be used for the continuous-path control of machines with as many as four coordinates and equipped with DC power units. Calibration is performed by means of selsyn or inductosyn systems. This system is used for machines manufactured by the firms Bohner-Kohle, Burkhard-Weber, Cit Alcatel, Droop-Rein, Jungenthal, Mandelli, Oerlikon, and Wyssbrod. It uses only one very fast Intel 3000 16-bit microprocessor.

In multiprocessor systems the various digital control functions are shared by several microprocessor units. This functional breakdown of microprocessor tasks permits a clear and well-arranged control structure from the standpoint of both hardware and software. Due to this parallel data processing arrangement the system can also be programmed to perform other auxiliary functions, e.g., the control of workpiece handling and transport. This design is compatible with current trends in the development of numerically controlled engineering processes, which are characterized by a considerable degree of structural decentralization, and so it therefore appears to have a very bright future.

2. Systems With a Single 8-Bit Microprocessor for Medium-Complex Machines

At the present time this category of systems is most prevalent, since it is designed to accommodate the widest range of machine tools equipped with from two to four coordinates. We have selected the Philips Series 6600 system, a block schematic of which is shown in Figure 7, as a typical example of the architecture of these systems. The Philips 6600 system is organized around an 8-bit microcomputer equipped with an Intel 8080 microprocessor which is modularly linked by means of Interface boards to all input and output devices. Interface boards are used in a similar way to link the microcomputer with the machine, in which case the interpolation function is taken care of by an auxiliary arithmetic unit. This architecture makes maximum use of all the advantages of 8-bit microprocessors and permits the total modular construction of the system in accordance with user requirements. The Philips 6600 system is designed for the point-to-point and continuous-path control of machines with as many as four coordinates. For example, this system is used with machines manufactured by the firms Bohner-Kohle, EMAG, Pittler, and Schmarmann. It is shown in Figure 8 with a Maho milling machine.

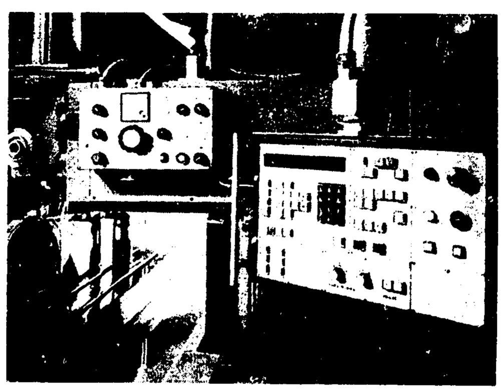


Figure 8. Control panel of the Philips 6600 system together with a Maho milling machine

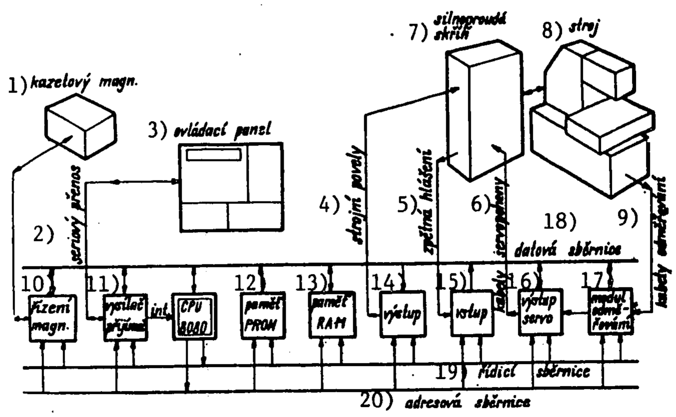


Figure 7. Block schematic of the Philips 6600 system

Key:

1)	cassette magnetic tape	11)	transmitter-receiver
2)	sequence transfer	12)	PROM memory
3)	control panel	13)	RAM memory
4)	machine commands	14)	output
5)	feedback	15)	input
6)	power unit cables	16)	power output
7)	power unit housing	17)	calibration module
8)	machine	18)	data bus
9)	calibration cables	19)	control bus
10)	magnetic tape control	20)	address bus

Some of the most well-known systems in this category, designed along similar lines as the Philips 6600, include the following:

--System 5-Sinumerik 5 manufactured by Fanuc-Siemens,
--NUCON 400 manufactured by ASEA,
--and the RUSC system manufactured by Plessey.

A distinguishing feature of the System 5-Sinumerik 5 system is that, in addition to a Motorola (Fujitsu) 6800 microprocessor and LSI memory unit, it uses additional command LSI circuits for interpolation and position calibration. The System 5-Sinumerik 5, just like the System 7-Sinumerik 7, was developed in cooperation with the firms Fujitsu and Fanuc-Siemens. It is designed for the continuous-path control of machines with as many as four coordinates and equipped with DC power units. The machine is calibrated by means of a rotary pulse reader. This system is used with machines manufactured by such firms as Chiron, Heidenreich-Harbeck, Hitachi-Seiki, Deckel, Scharmann, Schaublin, American Tools, H.E.S., and Dunhan Tool.

The NUCON 400 system manufactured by ASEA is designed for the continuous-path control of machines with as many as five coordinates and equipped with DC power units. These machines are calibrated by means of a rotary pulse reader or inductosyn systems. This system is used with machines manufactured by firms such as Dorries, Georg Fischer, Pedersen, and SKF Machine Tools. The system uses multiple processors whose functions are controlled by an Intel 8080A microprocessor. The NUCON 400 system is also produced under license by the Polish enterprise MERA.

The RUSC system manufactured by Plessey is designed for the point-to-point or continuous-path control of machines with as many as four coordinates and equipped with DC, hydraulic or stepping motor power units. These machines are calibrated by means of rotary pulse readers, selsyn systems, or inductosyn systems. Intel 8080A microprocessors are used in this system.

3. Simplified Systems With Manual Input for the Automation of Conventional Machines

The utilization of microelectronics in the machine tools industry has made it possible to develop a new category of control systems, i.e., manual data input systems which are often referred to as HNC (Hand NC, Handeingabe NC) systems. These systems are compact enough so that they can often be installed directly in the machine control panel (see Figure 9). They are also inexpensive and very dependable. With the aid of a pushbutton keyboard they can be used to insert and alter the program for a machined component while it is still on the machine. These systems are very popular and the number of users of these systems is growing ever larger. Since they are very simple to manufacture owing to the use of microcomputer technology (most of the problems associated with the manufacture of these systems have now shifted into the software area), these systems are now being manufactured more and more often directly by the manufacturers of machine tools who can do the best job of adapting them to machine requirements with respect to control modes, installation on the machine, and hookup with power unit housings (see Figure 10). And it is certainly true that marketing questions and simplified servicing also come into consideration in this regard.

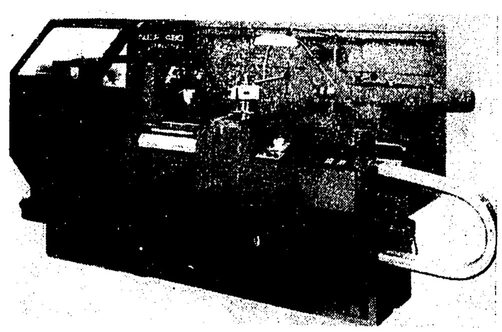


Figure 9. The Gildemeister N.E.F. 480 universal lathe with a Fanuc memory system built into the machine support platform.

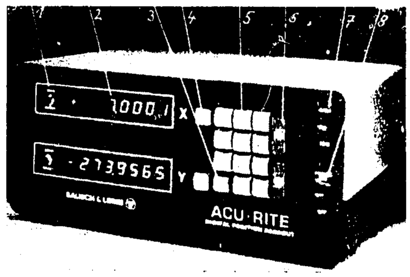


Figure 10. ACU-RITE digital position readout device with memory capacity for 100 coordinate positions manufactured by Bausch and Lomb with built-in calculator: 1)--readout cancel; 2)--coordinate readout; 3)--memory erase; 4)--coordinate callup; 5)--digital keyboard; 6)--coordinate add/subtract; 7)--inch/mm converter switch; 8)--on-off switch.

The following are some of the most well-known systems in this category:

--Fanuc Mate-Sinumerik Mate manufactured by Fanuc-Siemens,
--Mark Century 1050 HL manufactured by General Electric,
--7100 CNC manufactured by Allen-Bradley,
--and the TNC 121 manufactured by Heidenhain.

The Fanuc Mate-Sinumerik Mate system manufactured by Fanuc-Siemens (see Figure 11) is designed for the continuous-path control of DC powered machines with two or three coordinates. The machines are calibrated by means of a rotary pulse reader. This system uses a Motorola 6800 (Fujitsu ME 6800) microprocessor.

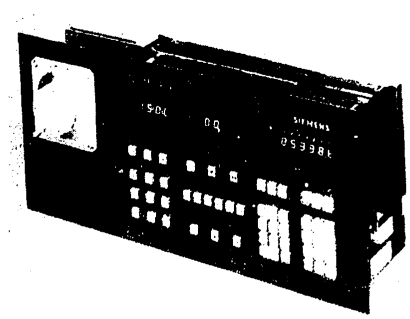


Figure 11. The Sinumerik-Mate system manufactured by Fanuc-Siemens

The latest model of the Mate TG has an interactive graphic display device for monitoring the programmed path of the workpiece and a simplified programming system using coded repeat cycles.

The General Electric 1050 HL system is designed for the continuous-path control of DC powered lathes with two coordinates. It is a scaled down version of the GE 1050 system. It uses Toshiba microprocessors.

The Allen Bradley 7100 CNC system is designed for the continuous-path control of DC powered machines with 2 or 3 coordinates. It consists of three sections, i.e., the control panel, electronic circuits, and power supply unit.

The Heidenhain TNC 121 system is designed for the point-to-point control of machines hooked up to central power supplies with 3 coordinates. This system is used most often with machines manufactured by Maho. Machines are calibrated by means of linear or rotary pulse readers. The system uses an Intel 4040 microprocessor.

In addition to these examples, there are a number of other manual input systems (and other categories as well) which are produced directly by machine tool manufacturers. Among others, we should at least mention the firms Deckel, Klopp, Gildemeister, Pittler, G. Fischer, Schaublin (see Figure 12), Oerlikon, Wotan, Dorries, Scheller, Heckler and Koch, Fehlmann, SIP, Giddings-Lewis, Cincinnati Milacron, Kearney Trecker, Scheiss-Froriep, and Heiligenstaedt.

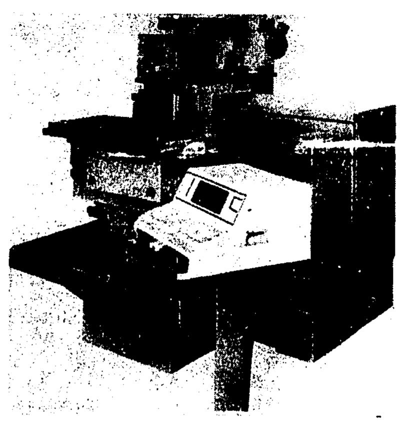


Figure 12.

Conclusion

In part 2 of this article we have described how over the past few years many new microprocessor control systems have been developed in various categories ranging from the simplest memory-equipped position readout devices to the most complex multiprocessor systems used to control complex centering machines and to handle both workpieces and machine toolheads. At the same time it is important to remember that microprocessor-based electronic control technology is beginning to have an impact on the machine tools industry as a whole, since, in addition to NC machine control applications, this technology is also being put to work on an increasingly larger scale for the control of principal machine tool classes, i.e., so-called conventional or hand-controlled machines. These machines are being adapted to incorporate elements and circuitry of NC machines and are in fact being transformed into NC machine tools controlled by microprocessor control systems.

The progress of the structural shift away from the use of conventional machines and toward the use of NC machines varies from one machine class to another. Perhaps the most dramatic progress has been made in the case of universal semiautomatic lathes, which in recent years have been manufactured almost exclusively in accordance with NC design parameters. Noticeable progress has also been made in the application of NC technology to milling machines, horizontal boring and milling machines, drills and upright lathes, but this technology is also beginning to be applied to other classes of machines such as grinders, gear making machines, and automatic lathes.

At the close of part 2 of this article it can be said that the sharp decline in the cost of NC systems together with the improvements that have been made in their functional characteristics make it reasonable to expect that even before the end of the 1980s microprocessor applications will play a crucial role in determining the technical quality of machine tools, their utility, and, hence, their marketability.

In the third and final part of this article we will discuss the progress that has been made to date in the CSSR and the other CEMA countries with regard to finding applications for microprocessor technology in the machine tools industry.

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Control Systems in CSSR, CEMA

Prague STROJIRENSKA VYROBA in Czech No 10, 1979 pp 783-791

[Article by Ivan Krsiak, Research Institute for Machine Tools and Machining Processes: "Progress in Digital Microelectronics and Its Impact on Machine Tools Automation" (part 3)]

[Text] In an effort to keep pace with worldwide trends in the development of NC technology most of the CEMA countries, including the CSSR, have started work on the development of microprocessor CNC systems. In the final part of this article we will show where the development of microprocessor control systems is heading in the individual socialist countries while paying special attention to development work in this field in Czechoslovakia.

State-of-the-Art Microprocessor CNC Systems in the CEMA Countries

Responding to the task set forth by the CEMA Executive Committee calling for the start-up of the production of advanced NC machines and NC systems by the end of 1979, most of the CEMA countries have started work on the development of microprocessor CNC systems. In order to be able to meet the tight deadline set by the Executive Committee work on the development of class 1 CNC systems has been proceeding thus far on the basis of the national economic plans of the member countries, and in this connection the necessary coordination of this work is being taken care of by the NC Systems Task Force which was set up under the terms of the CEMA Countries Agreement on the Joint Planning of Development Work on Selected Machine Tools.

The industrial production of microprocessor systems has already gotten under way in most of the socialist countries. Among the systems that are now in production we should mention the Soviet 1M22 and 2U22 systems equipped with a microcomputer and the Elektronika 60 and 2U32 systems equipped with a NC03T microcomputer, the Hungarian Unimerik 200 and 700 systems equipped with a Texas Instruments 9900 microprocessor, the Dialog system equipped with a Motorola 6800 microprocessor and the Hunor PNC 712 manual data input system equipped with an Intel 8080A microprocessor, the GDR NC 621 and CNC 600 systems equipped with the domestically manufactured microprocessors U 808D (similar to the Intel 8008) and U 880 (similar to the Zilog Z80), and the Polish MERA NUCON 400 system equipped with an Intel 8080A microprocessor manufactured under a license procured from the Swedish firm ASEA. Most of these systems were on display at the CEMA Machine Tools Exhibition held in Brno in November 1978.

Table 1 shows a survey of the basic data in microprocessor CNC systems which are under development or already in production in the socialist countries.

We will now examine at least some of the systems mentioned in Table 1 in greater detail.

The Soviet 2U32 system is manufactured by the LEMZ Association of Leningrad. It is designed for the control of NC milling machines, drilling machines and boring and drilling machines. Using this system it is possible to insert a part program either by means of punch tape or by adjusting the machine directly from the control panel, which can also be used to edit programs. The part program memory has a capacity of 8,000 symbols and it can be expanded to a capacity of 16,000 symbols. The system is organized around a Soviet NC 03T microcomputer which is fabricated

Table 1. Microprocessor CNC Systems in the Socialist Countries

Pol.	Typ 1)	Země 2)	Pro stroje 9)	Počet souř 16)	Program. jednotka 17)	Rychloposuv 18)	Rozměry 19)	Ukončení zkoušek strojem 20)	Poznámka (MP = mikroprocesor) 21)
1	2	3	4	5	6	7	8	9	10
1.	Programma 201	BLR 3)	soustruhy 10)	2	0,01 mm	10 m/min		1980	systém s ručním vstupem, MP Motorola 6800 22)
2.	Hunor PNC 712	MLR 4)	soustruhy	2	0,001/ /0,0025	10/20 m/min	vestavné provedení 600×280×200	1979	systém s ručním vstupem, MP Intel 8080A 23)
3.	Unimeric 200	MLR	soustruhy frézky 11)	2/3	0,01 mm	6 m/min	500×640×1320	1979	MP Texas Instruments TMS 9900
4.	Unimeric 700	MLR	soustruhy frézky obr. centra 12)		0,001 mm	10 m/min	680×640×1820	1979	více MP Texas Instruments TMS 9900 24)
5.	Dialog	MLR	soustruhy frézky obr. centra	2–4	0,002 mm	10 m/min	600×600×1600	1979	MP Motorola 6800
6.	NC 621	NDR 5)	soustruhy pravoúhlý 13)	3	0,005 0,001 mm	10 m/min 20 m/min	600×400×1600	1978	vstup informace 25) kulič. krokovým bubínkem, MP U808D
7.	CNC 600	NDR	soustruhy frézky obr. centra	6	0,001 mm	20 m/min	600×600×1800	1979	více MP U880 (Zilog 80) 26)
8.	MERA CNC NUCON 400	PLR 6)	soustruhy frézky obr. centra	5	0,001 mm	15 m/min	750×750×1930	1979–1980	MP Intel 8080A
9.	NUME-ROM 440	RSR 7)	soustruhy frézky obr. centra	3	0,001 mm	30/8 m/min		1980	
10.	2U22	SSSR 8)	soustruhy	2	0,001 mm	15 m/min	700×700×1850	1979	po vypnutí sítě 27) 100 h bez ztráty informace, mikropočítač Elektronika 60
11.	2U32	SSSR	vrtačky frézky 14)	3	0,001 mm	15 m/min	700×700×1850	1979	po vypnutí sítě 28) 100 h bez ztráty informace, mikropočítač NC 03T
12.	1M22	SSSR	spec. stroje (elektrojiskrové) 15)	2	0,0005 mm	240 mm/min	600×650×1650	1979	pro krokové motory, mikropočítač Elektronika 60 29)

Key:
1) type of system
2) country
3) Bulgaria
4) Hungary
5) GDR
6) Poland
7) Romania
8) USSR
9) types of machines
10) lathes
11) milling machines
12) machinery centers
13) point-to-point
14) drills
15) specialty machines electrospark)
16) number of coordinates
17) programming unit
18) feed speed
19) dimensions
20) date machine testing completed
21) comments (MP = microprocessor)
22) HNC system, MP Motorola 6800
23) HNC system, MP Intel 8080A
24) multiple MP, Texas Instruments TMS 9900
25) data input by cylindrical sprocket drum, MP U808D
26) multiple MP U880 (Zilog 80)
27) no loss of information after 100-hour power loss, Elektronika 60 microcomputer
28) no loss of information after 100-hour power loss, NC 03T microcomputer
29) used with stepping motors, Elektronika 60 microcomputer

out of LSI integrated CMOS-technology circuits (series K 587). The error-detection programs make it easy to rectify problems. The system is designed to control DC electrical feed drives and to calibrate positions it uses either a linear inductosyn or a resolver system. A block diagram of the 2U32 system is shown in Figure 1.

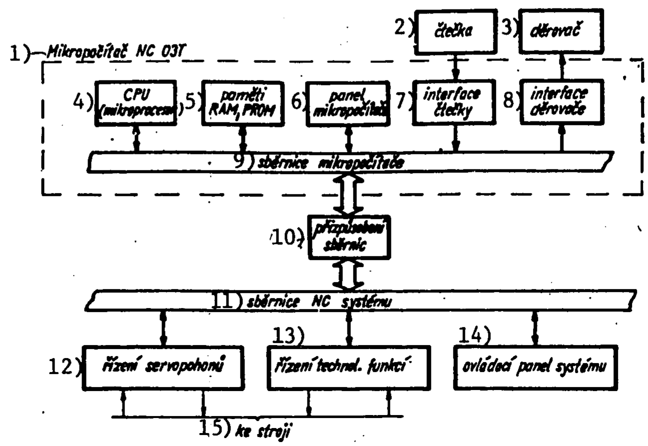


Figure 1. Block diagram of the Soviet 2U32 system

Key:

1) NC 03T microcomputer
2) reader
3) punch
4) CPU (microprocessor)
5) RAM, PROM memories
6) microcomputer panel
7) reader interface
8) punch interface
9) microcomputer buses
10) bus matching
11) NC system buses
12) power unit control
13) process control
14) system control panel
15) to machine

The Hungarian manual data input Hunor PNC 712 system, which is manufactured by the EMG measurement instrumentation plant, was displayed at the machine tools exhibition in Brno in November 1978 in conjunction with an EEN 630 universal lathe (see Figure 2) and it attracted a great deal of attention among the visitors to the exhibition. The system is built into a portable console located as close as possible to the machine operator.

The system's control panel (see Figure 3), which consists of a compact module comprising the system's electronic circuitry, is very well designed, and the programming of parts on the machine can be learned in just a few hours. The system does not have a console with its own cooling cycle, so the machine manufacturer has to take care of building the system

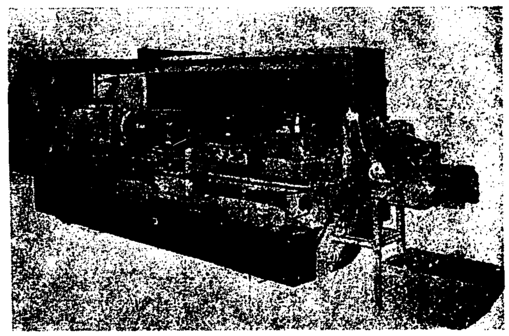


Figure 2. The Hungarian EEN 630 lathe together with the Hunor PNC 712 system built into the machine's retractable cabinet cover

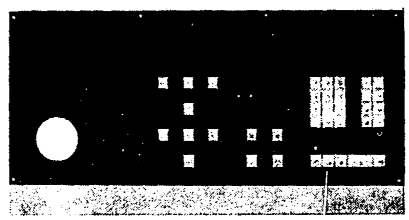


Figure 3. Control panel of the Hunor PNC 712 system

into the machine and providing it with a cooling cycle. The heart of the system is the Intel 8080A microprocessor, the 16k-byte capacity of the PROM memory, and the up to 8k-byte (cca 8,000 symbols) capacity of the part program RAM memory. Circular interpolation is taken care of by the system's hardware. The component program can also be entered into the system's memory by means of a cassette magnetic tape. The magnetic tape can be prepared externally on a separate Hunor 716 programming machine to which a printer and drafting table can be hooked up to monitor the writing of the program.

The Polish MERA CNC NUCON 400 system is manufactured in the Warsaw division of the MERA enterprise under a license from the Swedish firm ASEA. At first the system was merely assembled from imported parts, but this year the plant started producing the entire system on its own. The system is designed to control machines with up to 5 coordinates. In addition to its other functions, the system makes it possible to perform spatial

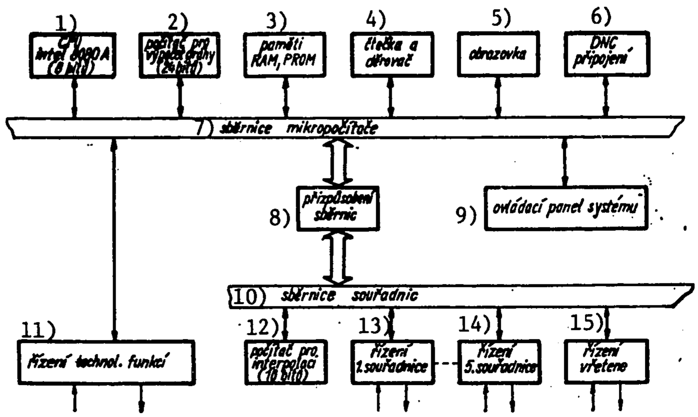


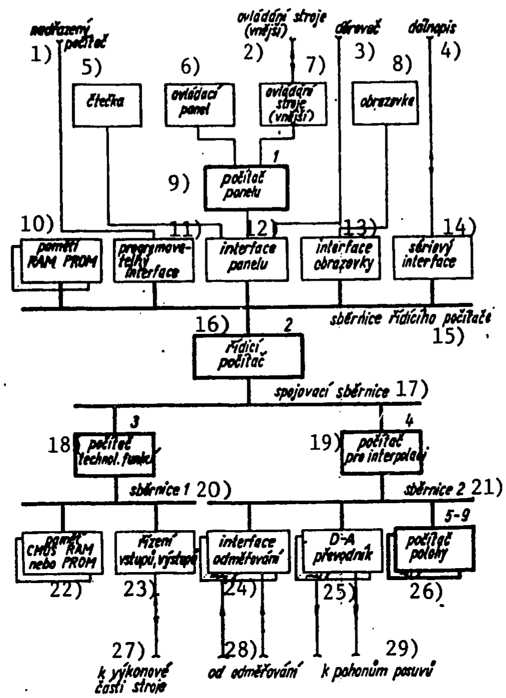
Figure 4. Block diagram of the Polish MERA CNC NUCON 400 system

Key:

1) CPU (Intel 8080A--8 bits)
2) computer for calculating center path (24 bits)
3) RAM, PROM memories
4) reader and punch
5) CRT
6) DNC connection
7) microcomputer buses
8) bus matching
9) system control panel
10) coordinate buses
11) process control
12) interpolation computer (16 bits)
13) control for one coordinate
14) control for five coordinates
15) spindle control

interpolations and to program the final shape of the workpiece (the center path of the toolhead, including angular approximations, is computed by the system itself). A block diagram of the system is shown in Figure 4. The system is controlled by an Intel 8080A microprocessor. In addition to the microprocessor, the system is made up of two other fixed-logic computing units, one for the computation of the toolhead center path (with a word length of 24 bits) and one for the computation of interpolation (with a word length of 16 bits).

The interesting CNC 600 system from the GDR, which is manufactured by the Karl-Marx-Stadt division of the VEB Numerik "Karl Marx," was exhibited at this year's Leipzig spring fair. The CNC 600 system (see Figure 5) employs a multiprocessor structure based on the use of U880 microprocessors manufactured in the GDR (analogous to the Zilog 80 microprocessor). The block diagram (see Figure 6) shows that each system comprises four basic microcomputers (a control computer, a control panel computer, an interpolations computer, and a process control computer). For every coordinate these computers are backed up by an additional computer designed to control



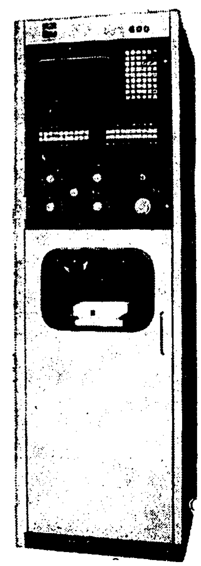


Figure 5. The multiprocessor CNC 600 system manufactured by the Numerik "Karl Marx" enterprise

Figure 6. Block diagram of the CNC 600 system

Key:
1) main computer
2) machine control (external)
3) punch
4) teleprinter
5) reader
6) control panel
7) machine control (external)
8) CRT
9) panel computer
10) RAM, PROM memories
11) programmable interface
12) panel interface
13) CRT interface
14) sequence interface
15) control computer bus
16) control computer
17) connecting bus
18) machine process computer
19) interpolation computer
20) bus No 1
21) bus No 2
22) CMOS RAM or PROM memory
23) I/O control
24) calibration interface
25) digital-to-analog converter
26) position computer
27) to machine output sections
28) calibration feedback
29) to feed drives

workpiece positions. So when the system is built to accommodate the maximum load of five coordinates it will consist of nine microcomputers with U880 microprocessors. The system comes with an alphanumeric CRT display device which makes the programming of components much easier.

The capacity of the part programming memory ranges as high as 32k bytes (in modules of 8k bytes each). It is also important to note that the system contains machine and process control adapter circuits.

In closing it can be said that the CEMA countries are now beginning to offer a wide selection of microprocessor CNC systems that run the gamut from the Hungarian PNC 712 Hunor system with manual data input for conventional machines, through the Soviet 2U22 and 2U32 systems for medium-complex NC machines, to the Polish MERA CNC NUCON 400 system and the GDR CNC 600 system which are used in conjunction with the most advanced five-coordinate machining centers.

State-of-the Art Microprocessor CNC Systems in the CSSR

In the CSSR work is under way on the development of microprocessor CNC systems at the TESLA and ZAVT [expansion unknown] VHJs.

The TESLA-Kolin n.p. has been working on the development of a microcomputer system ever since 1975. In view of the unavailability of certain microprocessor circuits this development work has been carried out using components obtainable within the CSSR. But this work has been proceeding in such a way so that the central unit is completely interchangeable with the Intel 3000 assembly or, for simpler applications, with the Intel 8080A assembly. At the present time the TESLA-Kolin n.p. is wrapping up its development work and has started the production of the NS 660 system which is designed for the continuous-path control of lathe machines. The TESLA-Kolin n.p. is also working on the development of the NS 670 system which is designed for more exacting applications (centering machines, continuous milling). In the case of both systems it is possible to install a programmable NS 900 series automaton for machine process control in a console with dimensions of 600 x 1,800 x 600 mm. The TELSA-Kolin n.p. is working with the Research Institute for Machine Tools and Machining Processes in Prague and the TESLA VUST [expansion unknown] on the development of software for both systems.

On 1 January 1977 the ZPA-Kosir [Instrumentation and Automation Plants in Kosir] n.p., working together with the VUOSO [Research Institute for Machines Tools and Machining Processes] in Prague, started work on the development of the point-to-point systems NS 632 for drills, NS 633 for milling machines, and the continuous NS 642 system for lathes.

This development work is being carried out on the basis of the imported Intel 8080A microprocessor assembly and CMOS-type memory units with battery-backup power systems. Tests of the first system in this series, the NS 633, were successfully completed in conjunction with an FCR 50 NC milling machine manufactured by the TOS [Machine Tools Factories] n.p. in Kurim. The production of these systems is slated to get under way at the ZPA Kosir in 1980.

The HNC NS 560-570 systems which were developed by the TESLA-Kolin n.p. are scaled down versions of the NS 660-670 systems. Working together with VUOSO, the ZPA-Kosir n.p. also developed the HNC systems NS 510 (for lathes) and NS 520 (for milling and drilling machines).

A survey of the basic specifications of the microprocessor CNC systems developed by the TESLA-Kolin and ZPA-Kosir national enterprises is shown in Table 2.

Table 2. Microprocessor CNC Systems Developed in the CSSR

Pol.	Typ 1)	Výrobce 2)	Pro stroje 3)	Počet souř. 8)	Program. jednotka 9)	Rychlo-posuv 11)	Rozměry 12)	Ukončen zkoušek (MP se strojem 17)	Poznámka (MP = mikroprocesor) 18)
1	2	3	4	5	6	7	8	9	10
1.	NS 510	ZPA Košiře	soustruhy 4)	2	0,01 mm (délka i průměr) 10)	15 m/min	vestavené provedení 13) 400×200×250	1979–1980	systém s ručním vstupem informací MP Intel 8080A 19)
2.	NS 520	ZPA Košiře	frézky 5) vrtačky 6)	3	0,01 mm	15 m/min	vestavené provedení 400×200×250	1980	systém s ručním vstupem informací MP Intel 8080A
3.	NS 560	TESLA Kolín	soustruhy	2	0,002/ /0,001 mm	24 m/min	elektronika 14) 400×490×230, 15) panel 490×320		odvozen od NS660, modulové provedení 20)
4.	NS 570	TESLA Kolín	frézky vrtačky	4	0,002/ /0,001 mm	24 m/min	elektronika 620×490×230, panel 490×320		odvozen od NS670, modulové provedení 21)
5.	NS 632	ZPA Košiře	vrtačky	3	0,001 mm	15 m/min	600×600×1800	1980	MP Intel 8080A pravoúhlý 22)
6.	NS 633	ZPA Košiře	frézky	3	0,01 mm	6 m/min	16) kazety, zdroj a panel samostatně	1979	MP Intel 8080A, modulové provedení 23)
7.	NS 642	ZPA Košiře	soustruhy	2	0,001 mm	15 m/min	600×600×1800	1980	MP Intel 8080A
8.	NS 660	TESLA Kolín	soustruhy	až 4	0,002/ /0,001	24 m/min	600×600×1800	1979	
9.	NS 670	TESLA Kolín	7) obráběcí centra	5	0,002/ /0,001	24 m/min	600×600×1800	1980	

Key:

1) type of system
2) manufacturer
3) type of machine
4) lathes
5) milling machines
6) drills
7) centering machines
8) number of coordinates
9) programming unit
10) length and diameter
11) feed velocity
12) dimensions
13) built-in single-module design
14) electronic circuitry module
15) panel module
16) cassettes, power and panel modules designed as discrete units
17) date machine testing completed
18) comments (MP = microprocessor)
19) HNC system, MP -- Intel 8080A
20) based on design of NS 660 system, modular design
21) based on design of NS 670 system, modular design
22) MP -- Intel 8080A, rectangular
23) MP -- Intel 8080A, modular design

Let us now proceed to discuss the individual series of systems developed in the CSSR in somewhat greater detail.

The NS 510 and NS 520 systems are designed for the control of simpler, so-called conventional machine tools, i.e., the NS 510 is designed for use with lathes with 2 coordinates and the NS 520 is designed to be used with milling machines with 3 coordinates. These systems are classified as HNC systems and are similar to such systems as the Fanuc Mate and Hunor PNC 712. These systems allow for the easy operation and manual control of machines and make it possible to insert component programs for batches of up to 100 units. They are designed to control machines equipped with "Mezomatic" automatic feed drive mechanisms manufactured by MEZ [Moravian-Silesian Electrical Engineering Plants] Brno with pulsed data input (one input pulse corresponds to a movement of 0.001 mm). It is also possible to use stepping motors or hydraulic cylinders with closed-position couplings, e.g., by means of a linear inductosyn system whenever these drive mechanisms have pulsed data input.

Both systems are designed to be self-contained units with a panel (see Figure 7) that comprises control and imaging elements. The dimensions of the system including the panel are approximately 420 x 250 x 200 mm. The system is designed to be installed in a built-in mode, e.g., into the control panel of a machine. The system must be mounted in a dust-free receptacle with an internal cooling mechanism (provided by the machine manufacturer).

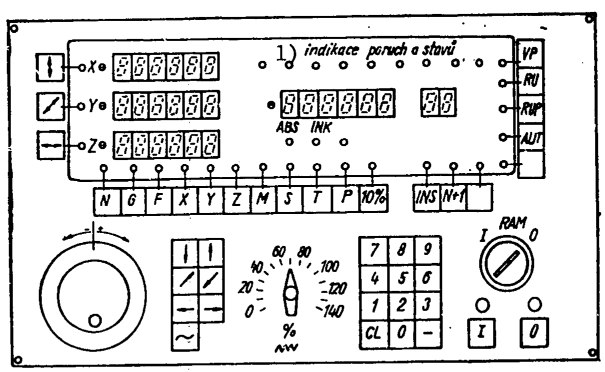


Figure 7. The control panel of an HNC NS 510-NS 520 system

Key:
1) trouble and status readouts

The NS 510 and NS 520 systems are assembled from the following functional units which are mounted on four separate large-scale printed-circuit boards:

--the microcomputer (comprising the CPU and RAM and EPROM memories),

--path generation system (contains the velocity control unit and a linear and loop DDA [digital differential analyzer] interpolator),

--input-output control system (contains the necessary machine-system connecting circuits; galvanic separation is performed by DIL language converters which are controlled by Intel 8212 circuits),

--panel unit (contains command and readout elements including a dial for manual feed control),

--power unit.

The individual units are linked by buses. The buses are connected and controlled in accordance with the recommendations of the firm Intel-Multibus. The systems control microcomputer uses an Intel 8080A microprocessor. Thirty-two Intersil IM 6508 circuits (static CMOS memory unit with a 1,024 x 1 bit organization) were used for the RAM memory unit with a capacity of 4k bytes. The data stored in this memory (the part program and the machine constants) are protected against loss of power for a period of at least 72 hours by a VARTA nickel-cadmium battery with sintered electrodes that permits a steady flow of power into the system. The EPROM memory with a capacity of 8k bytes, which is also mounted on the microcomputer board, consists of 8 Intel 2708 circuits (an EPROM memory with an organization of 1,024 x 8 bits).

Ever since May 1978 VUOSO in Prague has been collaborating with ZPA-Kosir on the development of the NS 510 and NS 520 systems. At the present time two working models have been built that have been tested together with models of the Mezomatic autonomous drive mechanism at VUOSO in Prague. At the end of 1979 work will begin on the testing of the SKI 16 machine at the TOS n.p. at Hulin.

The NS 632, NS 633 and NS 642 systems are designed to be used for the control of moderately advanced machines. Namely, the NS 632 system is to be used for the control of drilling machines with 2 or 3 coordinates, the NS 633 system--for the control of 3-coordinate milling machines equipped with central feed drives or with electromagnetic couplings, and the NS 642 system--for the control of lathe machines with 2 coordinates. The functional parameters of these systems are approximately the same as those of such systems as the Philips 6600 or the Plessey RUSC.

The NS 632, NS 633 and NS 642 systems are installed either in a large console with an FS 330 photoelectric reader or in a small console without a photoelectric reader (in which case an FS 751 tabletop photoelectric reader can be used) or they are designed as built-in units with separate control panels.

The NS 632 and NS 633 are point-to-point control systems, and the NS 642 is a continuous-path control system in which the interpolation function is taken care of by an auxiliary arithmetic unit. The development of these systems is geared primarily toward engendering innovations within the existing third-generation NS 316, NS 320 and NS 421 systems manufactured by ZPA-Kosir. The new systems offer a number of advantages both for the user and for the manufacturer. Let us list at least some of these advantages:

--the ability to write and edit a program directly on the machine,

--the ability to record a used program on a punch tape by means of a portable punch or to record the program on a cassette magnetic tape,

--the elimination of the punch-tape reader from the recycling process (i.e., the workpiece is machined according to the instructions in the program stored in the system memory),

--easier programming and the abbreviation of part programs by means of parametric subprograms,

--the modular construction of individual system types (i.e., systems for drilling machines, milling machines and lathes will be assembled for the most part from identical modules),

--the utilization of LSI circuits (a reduction in the number of components which thereby enhances dependability),

--the simplification of servicing (the utilization of troubleshooting techniques tested by digital computers).

The general block diagram architecture that is common to all ZPA systems in the NS 600 series is shown in Figure 9 [i.e., Figure 8; typographic error]. Not all of the modules can be used in any single system type at the present time. Thus, for example, a given system will be equipped with either binary inputs and outputs for the control of machine processes or with an interface for a programmable automaton. Similarly, these systems will operate either with punch tape or with cassette magnetic tape depending on the preferences of the user. This is the standard practice among most foreign manufacturers of CNC systems.

All of the electronic modules shown in the block diagram are mounted on modular circuit boards used in third-generation ADP devices (URS), i.e.,

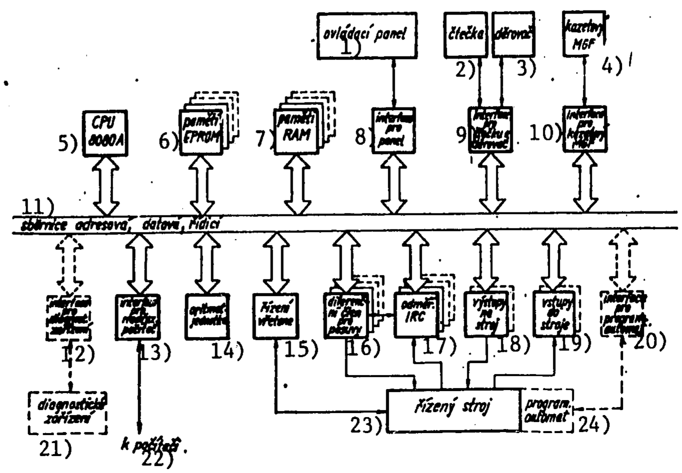


Figure 8. Block diagram of the NS 632, NS 633 and NS 642 systems

Key:
1) control panel
2) reader
3) punch
4) cassette magnetic tape
5) CPU 8080A
6) EPROM memory
7) RAM memory
8) panel interface
9) reader and punch interface
10) cassette magnetic tape interface
11) address, data and control buses
12) interface for error detection devices
13) interface for control computer
14) arithmetic logic unit
15) spindle control
16) differential link for feed
17) IRC calibration
18) outputs to machine
19) inputs to machine
20) interface for programmable robot
21) error-detection devices
22) to computer
23) controlled machine
24) programmable automaton

according to the traditional modular design of NC systems. When it came time to select the components base a decision was made to use circuits manufactured by Intel together with the Intel 8080A microprocessor supplemented by an Intersil IM 6508 CMOS-type RAM memory. It is anticipated that all of these circuits will soon be produced by the CEMA countries, so they will be gradually replaced by equivalent circuits manufactured by these countries.

The basic type of calibration mechanism used in the NS 632, NS 633 and NS 642 systems is incremental calibration with IRC 110 rotary photoelectric readers. Whenever phased calibration is used (resolver or inductosyn systems) the feed phase is converted into impulses that match the impulses of the incremental reader. The further processing of calibration impulses is identical to that which takes place in the case of incremental calibration. The increment of calibration and programming in the NS 633 system amounts to 0.01 mm and to 0.001 mm in the NS 632 and NS 642 systems.

The NS 632, NS 633 and NS 642 systems are being developed at the ZPA-Kosir n.p. in cooperation with VUOSO Prague. Thanks to the generosity of the workers at the SKLOSTROJ n.p. in Turnov who let the engineering team have one of their machines on loan, the first working model of the NS 633 system was successfully tested with a FCR 50NC milling machine (see Figure 9). The NS 632 system is being prepared for test runs with a VR 5NA drilling machine. The NS 642 system will be tested in 1980. The mass production of these new systems will get under way in 1981.

Figure 9. Testing of the NS 633 system with a FCR 50 NC milling machine

The NS 660 and NS 670 systems are designed to be used for the control of more advanced machines. Namely, the NS 660 system (see Figure 10) is designed to be used for the control of lathes with as many as 4 coordinates, while the NS 670 system is designed to be used for the control of milling machines or centering machines with as many as 5 coordinates. These systems permit linear and circular interpolation, thread cutting, the control of constant cutting speed, and limited-path adaptive control. They are equipped with a program memory with a maximum content of up to 64k bytes. They make it possible to completely override a part program and call up subprograms or specific cycles including repeat cycles.

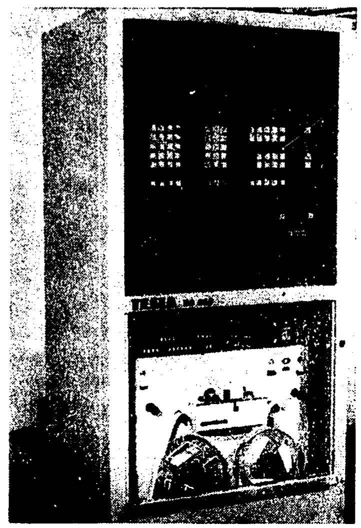


Figure 10. The NS 660 System

The heart of the NS 660 and NS 670 systems as they are presently designed is the 8-bit processor unit which consists of three 220 x 170 mm units with integrated circuits, most of which are in the MSI category. The processor unit developed by TELSA-Kolin is based on the instruction set of the Intel 8080A microprocessor, the only difference being that the gap of the instruction code of the 8080A was used to fill in several additional instructions that are useful for purposes of numerical control.

But the design of the processor unit itself is only one of the problems that had to be resolved. No less important are the memory units, but due to their size they posed a much greater problem. In the opening phase of the development work tests were conducted using so-called filament memories in which cata are recorded on thin sheets of magnetic material. These tests showed that these memories possess certain advantages such as the ability to retain information in spite of power losses.

But it is by now quite clear that current trends are headed toward the universal acceptance of semiconductor memories, the properties of which are constantly being refined and the cost of which is rapidly declining. Hence, systems are being designed so as to permit the use of various types of memories without altering the internal structure of central processing units.

At the present time work on the testing of a prototype version of the NS 660 system with an SPT 16NC lathe is nearing completion and the production of pilot series is already under way. TESLA-Kolin plans to gradually extend the modular compatibility of the NS 660 and NS 670 systems to other types of machines, e.g., shaping machines, gearing machines, electrospark machine tools, and automata.

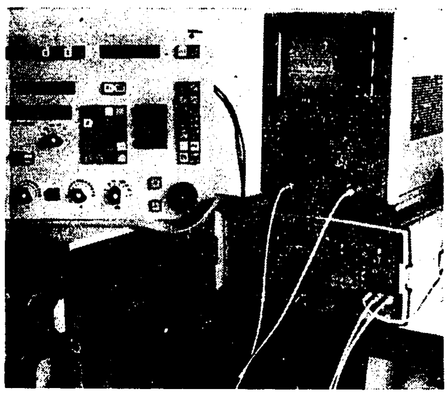


Figure 11. A Tektronix logic analyzer which makes it possible to monitor as many as 16 operations on buses

Figure 12. An Intel development system useful for software development

The NS 560 and NS 570 systems are conceptually derived from the NS 660 and NS 670 system series. But in view of the fact that they are designed for the control of less complex machines they are characterized by a different architecture, certain functional simplifications, and a reduction in the number of controlled coordinates. The systems are designed to be built into the machine's matching circuits in 19-point holding frames. The approximately 490 x 320 mm panel can be mounted, for example, in the machine control panel. Those elements which play an important role in the manual operation of the machine are located in a highly visible position on the control panel. The NS 560 and NS 570 systems will go into production after the testing of the NS 660 and NS 670 systems has been completed.

The main problem associated with the production of microprocessor CNC systems in the CSSR is the shortage of suitable microelectronic circuits, including microprocessors in particular, but also semiconductor memories and other LSI circuits, most of which still have to be imported from the capitalist countries. This situation will improve during the period 1980-1982 after the production of certain types of necessary circuits gets under way in the CSSR. In addition, it will be necessary to speed up efforts geared toward the importation of needed circuits from the CEMA countries, especially from the USSR and the GDR which have made the greatest progress in this area.

Another major problem associated with the production of microprocessor CNC systems involves the procurement of the necessary kinds of instrumentation hardware which is specifically required for the construction of microprocessor systems (logic analyzers, error-detection instruments and, most importantly, development systems for the creation of software). Furthermore, an effort must be made to develop the manpower resources that are required for the manufacture of CNC systems, especially when it comes to workers who have been trained in the development of software for microprocessor technology.

In this three-part article we have outlined state-of-the-art trends in the development of digital semiconductor technology, shown how these development trends have had an impact on the machine tools industry, and reported on the progress that has been made to date in the development of microprocessor technology in the CSSR and in the other CEMA countries.

It is apparent that in the years that lie immediately ahead the application of advanced electronic components will result in a major acceleration of the development of numerically controlled machine tools. The share of NC machines in the total output of machine tools will continue to increase and by the end of the 1980s, at the very latest, it is to be expected that the volume of NC machines manufactured in the advanced industrial countries will surpass the production volume of all other categories of machine tools. If we are going to keep pace with all of the developments implicit in this assumption, we must immediately take whatever steps are necessary so as to insure that we will be prepared for this change in the output structure of the machine tools industry.

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