Unified Approach to Modernizing Numerical Control Machines

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August 10, 2021

UNIFIED APPROACH TO MODERNIZING NUMERICAL CONTROL MACHINES

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***Abstract*— One type of CNC machines modernization is the replacement of obsolete electronic control units with more functional and compact ones, made on modern element base. Different implementers offer modernization options that differ in element base, programming interface, design, and many others. Therefore, there are differences in the preparation and loading of the machines control technology program, which requires the operator to know a variety of interfaces. This diversity makes it difficult to operate machines with different interfaces and also makes it difficult to integrate upgraded machines into a single technological chain. The enterprise becomes hostage to one modernization contract so that all other modernized machines work according to the same algorithm. The purpose of the work is to analyze the possibility of searching for a unified approach to modernize the CNC machines control system from different generations. A generalized structural diagram of the control unit implementing a unified approach to CNC machines modernization is proposed. (*Abstract*)**

Keywords— CNC machine modernization, control systems of CNC machine, CNC machine control circuit, automation of production. *(key words)*

I. INTRODUCTION.

The replacement of the control system is a basic and essential element of the modernization of CNC machines [1]. Many options for such upgrade are now being proposed. But each variant differs by its technical solution, concerning the implementation of the machine control unit itself and the method for the subsequent interface thereof with the mechanical part. Partly, this is due to the fact that the CNC machines of different generations have a control system that differs by the signal type and the method of operating the actuators. As a consequence, there are differences in the preparation and loading of the machine control technology program, which requires the operator to know a variety of interfaces. It is significantly raises the threshold of entry, and lead to the need for retraining and hence additional spending. The modernization market offers advances different own technical solutions, concerning the element base used, design solutions implemented for the operator of the control interface machine. This diversity makes it difficult to operate machines with different interfaces and also makes it difficult to integrate upgraded machines into a single technological chain. The enterprise becomes hostage to one modernization contract so that all other modernized machines work according to the same algorithm. The purpose of this work is to analyze the possibility for a unified approach to modernize the management system of CNC machines from different generations.

II. CNC MACHINE CONTROL SYSTEMS OF DIFFERENT GENERATIONS.

Depending on the component base and level of computer use, CNC systems I, II, III, IV, and V generations are distinguished [2].

CNC devices of I generation are usually analog and are made on discrete elements - relays and transistors with low frequency parameters. A program, recorded on magnetic tape, is used to directly control the machine. It is difficult to record a large number of technology commands to the magnetic tape. Furthermore, the speed and accuracy of their implementation are limited by the characteristics of the tape-handling mechanism, magnetic tape and magnetic heads.

Generation II CNC devices have a small and medium integration element base with higher frequency characteristics, with which a schematic implementation of control algorithms is carried out. Machine control programs are input from external simplest data carrier (usually perpetual). The III generation of control systems were created on the basis of microcomputers, including on large integrated circuits. These CNC systems have advanced technological capabilities, in which a software implementation of control algorithms is implemented. The control program is also entered by means of punches and keyboard. The CNC machines of this generation are equipped with graphical display of the detail on the screen.

Generation IV CNC devices have control from a microprocessor or microcomputer and have much more flexibility in control. The technological functions and dialogue modes programming is performed in high-level languages. The program is downloaded from external data carriers, such as magnetic diskettes. The CNC devices of the V generation are controlled by industrial personal computers and usually do not need upgrading.

The generalized functional diagram of the control system of different generations CNC machines is presented in Figure 1. The executable program, located on the external data carrier, is loaded into the control device and actuates the machine's executive mechanism. The feedback system's (FS) sensor unit forms a closed adjustment system for each position of the working tool and compensates an inaccuracy and irregularities, arising within the machine's operating mechanism.

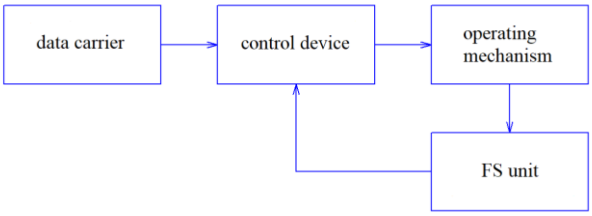

Fig. 1. Generic functional diagram of the intergenerational CNC machine control system.

The I-II generation CNC machines mainly use a phase control system, starting with III generation - impulse systems. Fig. 2 shows the structural diagram of one channel of a typical phase control system on the machine 6M13GN1 example [3]. The diagram is similar for each position of the working tool.

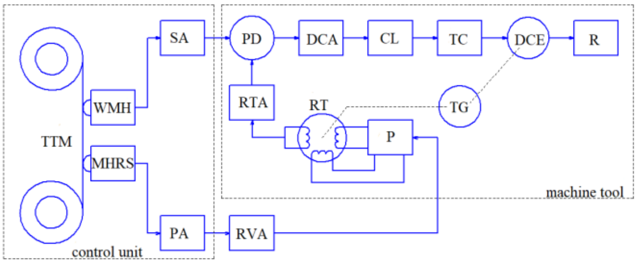

Fig. 2. Structure of the CNC machine phase control.

The control unit comprises a device for reading data from a magnetic tape, which device consists of a tape-drive mechanism (TTM), a working magnetic head (WMH) and a magnetic head of a reference signal (MHRS). The rotating transformer (RT) is a position and speed feedback sensor, since its rotor is kinematically connected to the rotor of the drive engine. The sinusoidal signal, readable by the working magnetic head, is received after amplification in the amplifier (SA) at one of the phase discriminator inputs (PD). The reference voltage $\varepsilon o = Um \sin\omega t$, which is read by the magnetic head of the reference signal (MHRS), passes the preliminary amplifier (PA) and the reference voltage amplifier (RVA), and power the input windings of the rotating transformer stator (RT) with a phase shift of 90° through the phaser (P). Furthermore, the rotary windings induce an EMF, having the same frequency, but being shifted in phase relative to the reference voltage by an angle, determined by the rotation angle of the rotor φ, i.e., $\varepsilon o = Um \sin(\omega t + \varphi)$.

The machine drive is based on a DC engine (DCE), which is controlled by a thyristor converter (TC) and is also connected to a tachograph generator (TG) and a RT rotor. Thus, RT converts the measured movement of the working tool into a signal in the form of a continuously changing phase angle φ sinusoidal oscillations. The output voltage after amplification in the rotary transformer amplifier (RTA) enters the second input of the PD. A slowly changing signal is produced proportional to the phase difference, because of multiplying the signals at the PD output. This signal, after the amplification by the DC amplifier (DCA) and passage through the correction link (CL), enters to the thyristor converter control input (TC). As the phase difference is greater, so the engine control voltage is higher, also the speed of its rotation is higher.

The phase control signals are shown on Fig. 3. at the amplifiers outputs of the reference signal head and the working head, one at each of the three coordinates. The machine tool movement speed will depend on the phase shift between the reference and working signals. If there is no phase shift between the reference signal and the working signal, the voltage on the DCE will be zero and the machine actuator stops.

The feedback system is tightly linked to the power drive device on this diagram. The machine drive replacement may be considered as the machine capital reconstruction, which in terms of cost can be comparable to the new CNC machine cost [4]. The feedback sensor replacement is practically impossible without intervention to the drive, and is advisable only in a few specific cases. Therefore, control methods and feedback sensors changes are difficult, when CNC machines upgrading [2, 5].

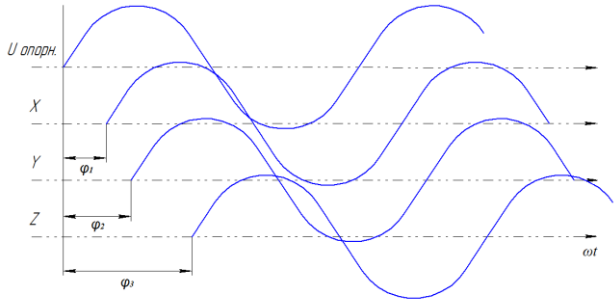

Fig. 3. Phase control system signals for CNC machines.

Phase control systems of CNC machines are especially exposed to noise, interference, distortions. There are distortions of control signals when external influences change: temperature, humidity, appearance of vibrations, due to changes in parameters of circuits, accuracy of reading data from tape (signal from magnetic tape extremely weak). There is a problem of signals accurate transmission over long distances for machine with the analog control, due to imperfect communication line, limited bandwidth of the communication channel, nonlinearity of analog path, and also due to interference [6, 7, 8].

The generalized structural diagram of the CNC machines impulse control system is presented in Figure 4. The control signal is formed by a micro-computer which performs commands from a data carrier and has input-output devices (keyboard and display) for monitoring and controlling technological operations. The executable program is loaded from the carrier into the external memory of the computer. This allows to change the execution program speed and to stop or run the program again. The stepper engine (SE) actuates the machine operating mechanism and the computer-generated control signals are transmitted to the stepper engine control device (SECD) [9]. The power drive of the machine is simpler than the previous generation (figure 3), and the impulse control method itself simplifies the modernization or replacement of the control unit.

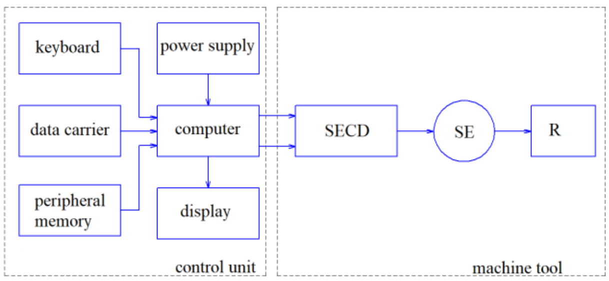

Fig. 4. Structure of the CNC pulse system.

Negative polarity pulses are usually used for SECD (fig. 5) [9]. These signals are less subject to interference than sinusoidal phase control signals. The higher the frequency of the pulses repetition, the higher the move speed of the machine working instrument at the given coordinate. Separate lines are used to move forward and backward. If SECD impulses are not present at the input, the machine will stop working. There is no feedback - discrete rotation of the step engine shaft usually guarantees a high accuracy of the machine working instrument move without any additional measures.

The phase and impulse control considered systems differ in the control signal type, and in the control effects levels also. This will require an electronic interface of the modern digital control unit outputs with the executive mechanism and the FS unit when the CNC machine modernization. The digital control unit for different generations modernized machines must work out different control principles and algorithms, produce different control actions for the same function realization.

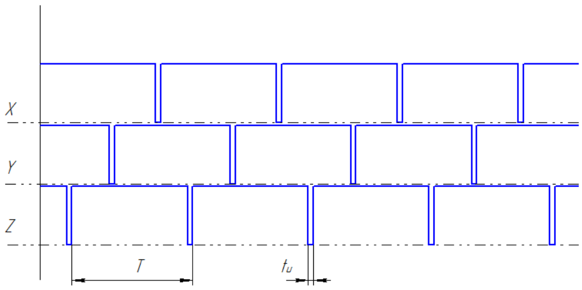

Fig. 5. Impulse control signals for CNC machines [9]

III. MODERNIZATION GOALS.

The CNC machines modernization is aimed to increasing their functionality, their reliability, accuracy, speed, reducing production costs, increasing labour productivity and significantly improving the quality of the produced products. One of the most common types of CNC machines modernization is the replacement of the obsolete control unit to the modern [1]. The equipment is no less than modern equipment in terms of operational and technical characteristics after the modernization, and the mechanical part reliability may even exceed it. The system interface should come closer to modern standards after modernization: it should become more understandable, convenient, adapted for integration with other devices and systems. The modernized control system itself also tends to reduce the size and mass. The obvious advantages of minimal CNC machines modernization by the control unit improvement can be considered: its low cost and the shortest time of realization: usually not more than 2 days per machine. The minimum waiting time is an important condition for the machine-tool fleet modernization under production conditions.

IV. POSSIBLE SOLUTIONS.

There is a question - is there a possibility of a unified approach to modernizing both I-II and III-generation machines? What is - a unified approach to modernizing different CNC machines? It is important for required functions realization and for the technological process rational organization, that one boot file can start performing one operation (manufacture of a product) on modernized machines of different generation. The CNC machines operator should not feel a difference in the downloadable commands and files compilation, a difference in the microcontroller internal algorithms. A block, operating with both phase and impulse signals, should have a single interface (fig. 6). Then the concept of a unified approach is related to the one, same program of technological operation execution and the same boot file for modernized machines from different generations.

There are options for a control system building that adopts a common approach:

1. Different digital control units for different machines (on a microcomputer, for example) with one common interface;

2. A single machine digital control hardware unit with one common interface but with different software implementations of control algorithms and different machine interface devices (modular);

3. A single digital control hardware unit with one large software implementation of all possible control algorithms and with built-in set of interfaces for all generations machines; and a common interface.

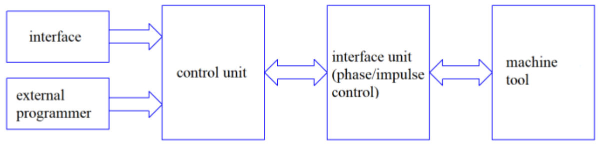

Fig. 6. Functional diagram of the re-engineered control system

Let us consider each option in more detail. The first option is a first step towards technical solutions streamlining of the machines modernize, and perhaps even standardizing the modernization procedure and its results. This option allows various schematic and structural solutions, different element bases, but it assumes a common interface, ensuring the equipment connection with modern CAD/CAM systems, as well as integration into unified process chains.

The second option is to streamline the element selection requirements for CNC machine control systems, which is appropriate under import substitution conditions. It is assumed that if the control system can be based on a modern microcomputer, then with the given algorithms it can develop the required types of control effects, which, by means of electronic interfaces, can be harmonized with machine actuators on levels, signals forms, time parameters, etc. One digital control unit can be created for different generations CNC machines, but with different electronic interfaces to their actuating mechanisms. For each machine, a different control algorithm can be developed or adapted from the existing ones for similar machines. This algorithm is implemented as a microcomputer program.

The third option is the most versatile because of the redundancy introduction in electronic interface blocks hardware implementation and control algorithms software implementation for all CNC machines common series. The versatility result is the technical realization complexity of the control unit and its interfaces with actuating mechanisms, cumbersome construction, complexity of such device tuning and maintenance, requiring the technical specialist preliminary training. The control algorithm complexity lies in the need to analog and impulse control systems both implement. As a result, the high cost of such upgrade can be expected.

The listed options comparison according to criteria such as cost, modernization complexity, time cost for on-site machines modernization, a single interface realization possibility, accuracy, reliability of modernized machine, the probability of failure, including during start-up and installation, the modernization efficiency, the possibility and ease of machines integration into a single technological chain, control units operation stability, including in the devices distributed network, make it possible to point out the greatest utility of the second option.

V. IMPLEMENTATION OF A UNIFIED APPROACH TO A CNC MACHINE CONTROL UNIT MODERNIZING.

The machine control unit proposed for implementation should be based on a modern microcontroller and should have the following capabilities [10]:

1. Use of modern energy-independent memory (for example, Flash memory) as the work programs carrier. The processing program is created not directly on the control device, but on the personal computer;

2. Direct downloading of control programs from CAD/CAM systems by means of a single local technology network and a control interface;

3. Modular principle of installing, changing and connecting electronic interface units. The electronic interface may be either a multi-channel DAC or a buffer amplifier, depending on the control system type (phase or impulse);

4. Ease of operation. The current program selection should be carried out from the list, displayed on the device display, and it must be possible to change and adjust individual parameters of the technical process. The device should be capable of stopping the program and continuing its execution at any time. It is advisable to provide a manual mode to move the tool quickly to the processing site.

5. Small dimensions, mass and high reliability of the device.

The microcontroller-based control system structure is proposed at Figure 7. It provides a common interface and architecture for both phase and impulse control. The control type is selected by means the algorithm and program of the microcontroller, and by interface unit choice.

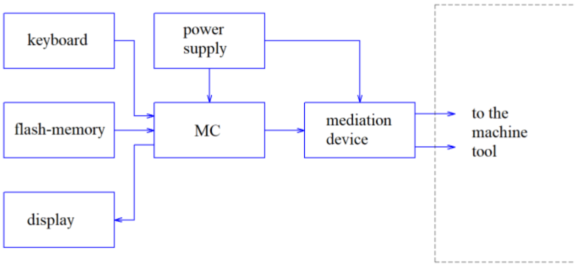

Fig. 7. Structure of the proposed control system.

VI. CONCLUSION

Therefore, we believe that the unified approach concept is related to the one, same technological operation execution program and the same boot file for different generations modernized machines. A unified approach is the same component manufacture on modernized different generations CNC machines according to the same control program with specified accuracy. The common approach is for one function preserve, to provide the specified characteristics and parameters of the technological process, to include machines in a single enterprise control network. A common interface for all machines is mandatory. The technological program should not be different even in the case of control and interface blocks different implementations for different generations machines. This will greatly simplify the machines maintenance, the control programs loading, the action algorithms understanding.

The modern microcontrollers use makes it possible to a machine control unit implement with a single interface and architecture, to control CNC machines of I-III generations. The microcontroller program will be different for each generation of machines.

ACKNOWLEDGMENT

Scientific research was carried out with the financial support of the Ministry of Science and Higher Education of the Russian Federation as part of the fulfilment of obligations under the Agreement number 075-03-2020-051/3 of 09.06.2020 (topic number fzsu-2020-0021).

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