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Specialized Numerical Control System for Five-Axis Planing and Milling Center

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Abstract—The architecture and design features of the numerical control system for an E7106MF4 machining center are considered. This system permits five-axis machining by three-dimensional planing. Organization of the automatic electrical automation subsystem is discussed. Practical aspects of the control system are presented.

Keywords: numerical control system, planing and milling center, multiaxis machining, electrical automation, NC–PLC interface

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Specialized algorithms for new cutting technologies demand flexible programming and adjustment of numerical control systems [1]. Planing is a productive and precise technology, in which the relative velocity of the cutter and the workpiece may be optimized. The high precision of planing is explained in that the machined surface is formed by cutting edges whose position relative to the blank is determined by the numerical control system.

The efficiency of planing is associated with its high productivity and the simplicity and affordability of the tool employed. At present, designs of numerically controlled machine tools that ensure the required cutting speed, acceleration, and force in the cutting direction are being developed [2].

The E7106MF4 planing and milling center permits center permits five-axis three-dimensional planing and four-axis milling. It is specialized for the machining of complex parts (dies and press molds) from thermally hardened steel and also for the machining of steel, cast-iron, and aluminum-alloy parts. It was created by the Experimental Research Institute of Metal Cutting Machines, STANKIN Moscow State Technological University (Moscow), and ZAO STANKOTECH (Kolomna) and is equipped with a specialized numerical control system based on the AxiOMA Control control platform (developed by STANKIN Moscow State Technological University) [3, 4].

Characteristics of the E7106MF4 machining center include expanded monitoring of tool orientation and wear and the machining quality; a tool-replacement mechanism; a rotary spindle head with hydraulic fixing of the axes; and a high-speed spindle.

ARCHITECTURE AND DESIGN FEATURES OF THE NUMERICAL CONTROL SYSTEM

The design of the E7106MF4 machining center (Fig. 1) is based on the rigidity requirements. Its characteristics are as follows:

Precision class according to State Standard GOST 30027–93	P
Table size (length × width) mm	250 × 400
Travels (*X* axis; *Y* axis; *Z* axis), mm	500; 320; 250
Maximum linear speed, m/min	40
Linear acceleration	2*g*
Rotation relative to *B* axis, deg	± 90
Maximum planing speed along *C* axis, deg/min	500
Spindle speed in milling, rpm	1000–800
Maximum planing force along *X* axis, kg	2000
Machining accuracy, μm	8
Travels increments:	
along *X*, *Y*, *Z* axes, mm	0.001
along *C* axis, s	1.8
Number of tools in store	24

The machining center ensures speeds no lower than 40 m/min and acceleration of around 2*g* along the *X*, *Y*, and *Z* axes and provides force sufficient for margin removal in planing (Fig. 1).

A Duplomatic spindle permits rotation around the *B* and *C* axes, resulting in five-axis machining. These axes are equipped with hydraulic clamps, index clamps, and hoists for operation in interpolation mode. The spindle's hydraulic mechanisms are con-

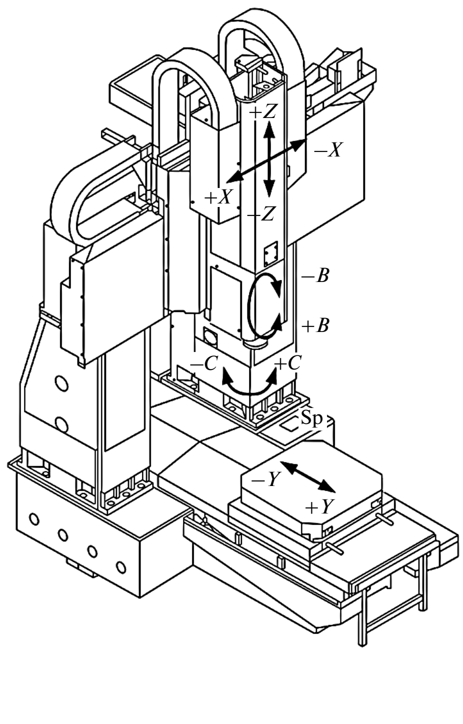

Fig. 1. Kinematics of the E7106MF4 planing and milling center.

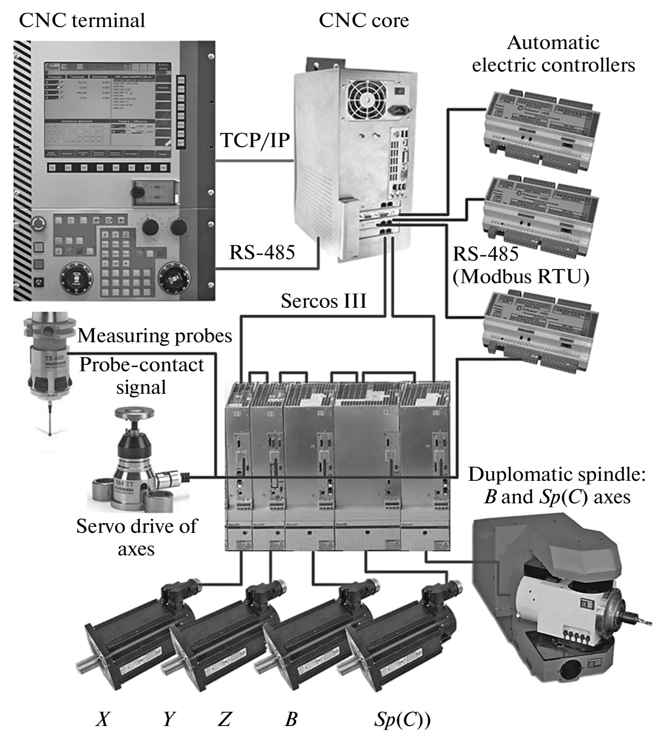

Fig. 2. Structure of the specialized AxiOMA Control numerical control system for the E7106MF4 machining center.

trolled by means of a hydraulic station, gates, valves, and pressure sensors, which, in turn, are regulated by an automatic electric controller.

The automatic electric system of the machine tool is regulated by the controller in the AxiOMA Control numerical control system. Russian Robokon R1456 input and output modules are employed. The Modbus RTU real-time protocol based on the RS-485 serial-port interface is used for interaction with the modules.

The two-computer architecture of the specialized numerical control system (Fig. 2) includes a core operating in the Linux RT system and an operator terminal with the Windows operating system [5, 6]. The terminal includes a panel of functional F and M keys and a machine-tool panel interacting directly with the core of the numerical control system according to an internal protocol based on a serial-port interface [7].

The smart drives are controlled by the standard Sercos III high-speed protocol. The core of the numerical control system is equipped with a Sercans control board, which is the master for the Sercos ring with the drives. The configuration of the Sercos and Modbus real-time subnetworks is based on the set of machine parameters in the numerical control system and the configuration unit for input and output modules [8].

The E7106MF4 machining center is equipped with Heidenhain measuring systems so as to increase the machining precision and monitor the tool wear, as well as special tool-orientation functions prior to planing. The probe-contact signal is sent to the fast inputs of the drive controllers and reproduced at the inputs of the automatic electric controllers. The PLC program processes the signal from the probe, with blocking of some of the operator actions (for example, manual tool replacement).

The proposed measuring-probe system ensures timely reaction to contact, reduces the probability of probe failure, and parallels signal processing. In the G75 measuring cycle, the system receives notification from the drives regarding contact, the coordinates of the contact points, and the coordinates of drive shutdown. Then, depending on the signal at the fast inputs of the drive servos, the numerical control system makes a decision regarding the subsequent motion.

ORGANIZATION OF AUTOMATIC ELECTRIC CONTROL

To control the automatic electrical peripherals such as hydraulic brakes, index clamps, and pulsed lubrication, the numerical control system must be adjusted for the machine-tool design and its set of auxiliary M functions. The AxiOMA Control numerical control system provides instruments for configuring the set of user M-functions within the NC–PLC communications interface.

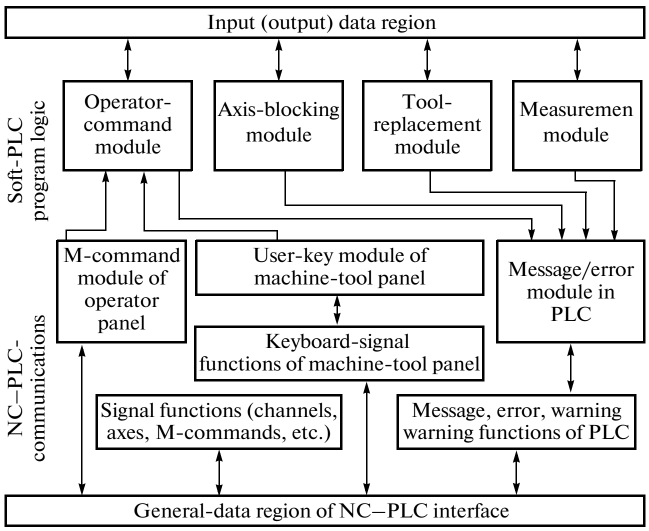

Fig. 3. General structure of the Soft-PLC control program for the electrical automation system of the machining center.

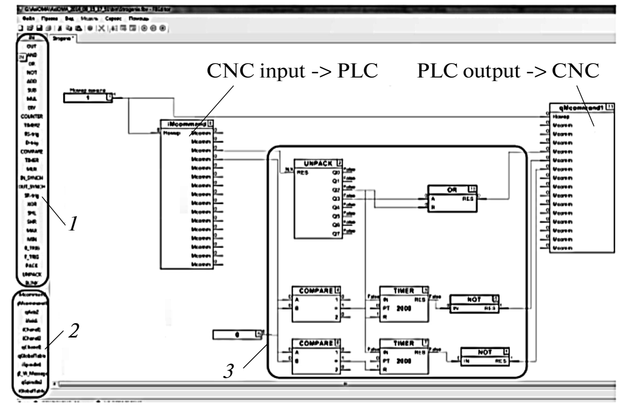

Fig. 4. Module for processing the M-commands of the numerical control system: (*1*) standard logical components; (*2*) user libraries; (*3*) automatic electrical control program.

The Soft-PLC process and the core of the numerical control system interact through the general-data region of the NC–PLC interface, which contains tables of the signals required for interaction of the numerical control system and the programmable logic controller [9, 10]. The abstractions for the formation of signal groups include the following: control channels, axes, the machine tool's spindles, and the configuration of M commands. In the generalized structure of the control program, the programmable logic controllers are functional modules for such signal groups (Fig. 3). For example, before motion begins, the numerical control system must confirm that the *B* axis of the machine tool is not at the hydraulic brake (Fig. 1).

Other signal groups in the general-data region of the NC–PLC interface transmit information when the operator presses keys on the operator panel and the machine-tool panel. The Soft-PLC control program directly processes the manual control signals in the electrical automation system and indicates their state by lighting up keys on the machine-tool panel [11, 12].

Another group consists of functional modules for informing the user about the current state of the PLC program. Three types of notifications may be selected from the PLC control program and displayed in the operator terminal: errors, warnings, and informational messages. The PLC program simply flags the activity of the required message in the signals of the NC–PLC communications interface. The test of the message directly specifies the configuration of the message, by number, at the side of the operator terminal in the required format and language, through an XML file.

The automatic electrical control program is formed as a set of individual functional modules [13, 14]. Each such module processes specific signals from the NC–PLC interface and monitors the state of the hardware inputs and outputs associated with the controlled subsystem of the machine tool.

For example, by means of the modules for control of tool exchange, the M-command signals (M06) are processed, data regarding the number of the tool are taken from the numerical control system, and the appropriate algorithm activates the outputs and monitors the state of the inputs of the built-in tool-store controller. In executing the new control functions, a set of new modules is added: for example, for control of the measurements; for automatic blocking (and unblocking) of the hidraulic brakes of axes; for control and monitoring of the obstacles in the working zone; and for automatic chip removal.

In Fig. 4, we show an example of a functional module for processing the M-commands of the numerical control system. Interface modules are used here, transferring input M-command signals from the numerical control system to the programmable logic controller and output M-command signals from the programmable logic controller to the numerical control system. The output signals confirm completion of the operation. The group of M-command logical elements receives the signal from the input-signal module and executes the necessary algorithm. In the case of successful completion of the operation, the signal is transferred to the output-signal module.

For blocking and unblocking of the *B* and *C* axes (Fig. 1), additional modular M-functions are employed: M904, a prefix command for unblocking the axis; and M905, a postfix command for blocking the axis.

As the first parameter of the M function, we adopt the digital index of the axis (in the range from 1 to

255). Its processing logic is included in the programmable logic controller; the numerical control system simply transmits this parameter. The second parameter is used to indicate special blocking parameters of the same axis. For example, it may indicate that the axis is mounted in an index clamp, which ensures precise positioning with a specified interval (5° for the *B* axis).

PRACTICAL ASPECTS

Measurement of the cutting tool for three-dimensional planing has two functions [15–17]:

(1) measurement and orientation of the cutter before planing so as to establish its longitudinal axis at an angle of 90° (more or less) to the machined surface and the tool's front surface at the specified initial angle to the cutting surface;

(2) measurement of the tool wear.

In designing the subsystem of specialized measurement cycles, the following requirements must be met:

(1) the addition of new permanent (throughout operation) channel variables, where the results of the measuring cycles will be stored;

(2) the addition of data structures corresponding to exchange in the channel between the core and the terminal;

(3) the development of screens in the terminal of the numerical control system for the display of the measurement results in manual operation.

The new control algorithms for three-dimensional planing demand flexibility of the programming mechanisms in the numerical control system [18, 19]. Experience in creating standard machining cycles is used in developing a set of specialized G functions for the basic planing operation and cycles for the machining of standard surfaces by three-dimensional planing. Logical elements corresponding to specialized planing cycles are added on the basis of the preliminary G functions and high-level language [20].

At present, a prototype three-dimensional planing system is in operation at STANKIN Moscow State Technological University, for training purposes and to test the milling and planing functions and the measuring cycles. Young scientists are active in these tasks.

CONCLUSIONS

(1) The E7106MF4 machining center with the AxiOMA Control numerical control system permits three-dimensional planing.

(2) The use of a custom-designed control system guarantees that the relevant know-how will be available as needed. That is especially important from the perspective of import substitution.

(3) The design of the E7106MF4 machining center permits use of hydraulic peripherals in the numerical control system to block and brake the rotary axes of the machine tool and to increase its rigidity in machining.

(4) The control of the automatic electrical devices and the core functions of the numerical control system are coordinated on the basis of a NC–PLC communications interface. For representation of the signals, functional modules for the NC–PLC interface are included in the control program. Those modules provide the basis for individual control modules corresponding to individual automatic electrical functions (tool replacement, processing of commands from the machine-tool panel, chip removal, etc.).

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