ISSN 1068-798X, Russian Engineering Research, 2015, Vol. 35, No. 7, pp. 534–538. © Allerton Press, Inc., 2015.
Original Russian Text © G.M. Martinov, N.V. Kozak, 2015, published in STIN, 2015, No. 1, pp. 6–11.

Numerical Control of Large Precision Machining Centers by the AxiOMA Contol System

G. M. Martinov and N. V. Kozak

Stankin Moscow State Technological University, Moscow
e-mail: kozak@ncsystems.ru

Abstract—The design of the VMG 50 precision machining center for superlarge parts is considered in control terms. The requirements imposed on the control system by specific features of the machining center are analyzed. The design of a specialized numerical control system is illustrated for the example of the VMG 50 precision machining center, on the basis of the AxiOMA Contol system.

Keywords: numerical control system, large machining centers, multicoordinate machining, multiterminal control, CNC–PLC interface, programmable logic controller (PLC)

DOI: 10.3103/S1068798X15070114

Krasnodar machine-tool factory "Sedin" specializes in the production of precision lathes, milling machines, and systems for the broaching and abrasive machining of large ferrous, nonferrous, and nonmetallic components, in one-off and batch production. These machine tools must meet market requirements. In particular, they must ensure high-quality machining with specified precision and high productivity. A key aspect of machining centers for large components is maximum concentration of the machining operations with minimum repositioning of the blank [1, 2].

The VMG 50 turning and milling center (developed within the framework of a Russian federal program) is equipped with a specialized Russian numerical control system based on the AxiOMA Contol system (developed by Stankin Moscow State Technological University [3]).

Imported analogues of the VMG 50 machining center are the UniMill centers (Pietro Carnaghi, Italy) and PowerTec systems (Waldrich Coburg, Germany). As a rule, SINUMERIK 840 D Solution Line control systems (Siemens, Germany) are installed in such machining centers.

The distinguishing features of VMG machining centers are expanded quality-control functions; video observation of the cutting zone; the use of tool stores and high-capacity tool heads; the use of replaceable tool heads with controllable motion along different axes; a six-position cutter turret; tool heads for the incision and grinding of gears; and the use of high-speed spindles.

Another option is an automated pallet system for the faceplate. Note the need for hot switching of the additional interpolated axis on installing the tool heads [4]. All of these functions determine the requirements on the numerical control system.

ARCHITECTURE AND DESIGN OF THE MACHINING CENTER

The range of VMG machining centers employs standardized modules to create machine tools capable of meeting specific customer requirements. Modules includes a horizontal-broaching support, a measuring gantry, a second support in specialized versions (for lathe, broaching, grinding, hybrid, and other applications), chain and drum tool stores, faceplates, and milling tables [5]. The need for a high concentration of machining functions in a single center, together with monitoring and diagnostic functions, imposes high requirements on the control system [6, 7].

The basic configuration of the VMG 50 machining center includes a gantry with a working zone corresponding to 14-m motion along the guide system for maintenance of the turning and milling turns. The diameter of the blank at the faceplate is 5 m. The electrical cabinet of the control system is divided into two autonomous parts: one rests on the center's base; the other is on the gantry in the immediate vicinity of the working components.

This design reduces the length of the power cables and permits information transfer between the two electrical cabinets through a SERCOS network. The operator controls the center from one or two terminals or a portable manual panel. The operator cabin with the control terminal and the portable panel is equipped with a hoist and attached to the gantry. Accordingly, turning or milling operations may be monitored in the immediate vicinity of the faceplate or milling table.

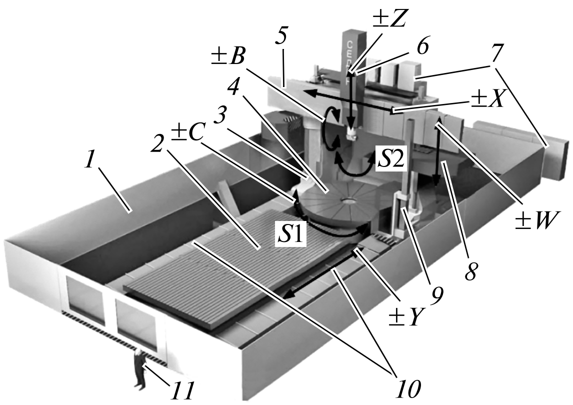

Fig. 1. VMG 50 machining center (with operator *11* to provide a sense of scale): (*1*) barrier; (*2*) milling table of blank (4.5 × 3 m); (*3*) gantry; (*4*) turning table (diameter 5 m, height 3 m); (*5*) gantry crossbar; (*6*) carriage; (*7*) control-system cabinets; *8*) tool-replacement mechanism; (*9*) operator cabin with terminal and portable control panel; (*10*) guides for gantry.

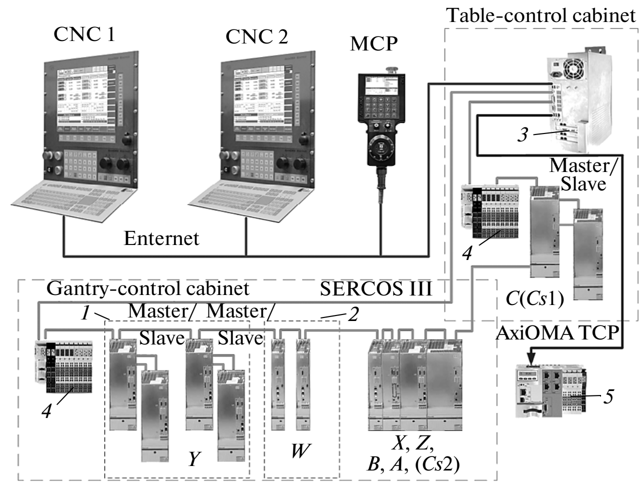

Fig. 2. Modular structure of the AxiOMA Contol CNC system for the VMG 50 machining center: MCP, manual control panel; (*1*, *2*) gantries; (*3*) CNC kernel; (*4*) bus coupler; (*5*) controller of autonomous equipment.

A fundamental requirement in the design of numerical control systems for the VMG centers is an open control system. Imported control systems are not sufficiently open to permit the integration of specific control algorithms and the integration of specialized (external to the numerical control system) hardware or software subsystems [8, 9].

In the VMG 50 machining center, four drives move the gantry along the *Y* axis: opposing pairs on each side (Fig. 1). That ensures structural rigidity and reduces the possible imprecision due to mechanical error, deformation, etc. The goal of the numerical control system is strict synchronization in master–slave mode and tracking of the discrepancy so as to prevent skewing of the gantry. Synchronized control of two drives is also ensured for vertical motion of the crossbar (the *W* axis) and faceplate rotation with respect to the *C* (*S*1) axis.

MULTITERMINAL CONTROL OF LARGE MACHINING CENTERS

The architecture of the numerical control system (Fig. 2) includes a kernel operating in the Linux RT system with a SERCANS control circuit (the master for the basic SERCOS network). The *C* and *Y* axes have their own SERCOS subnetworks controlling drives in master–slave mode. By transferring the control of the slave drives to smart controllers of the master drives, the computing resources of the CNC system may be freed up.

The CNC system permits real-time configuring of the subnetworks on the basis of the machine parameters. Kernel (*3*) of the CNC system synchronizes the drives of the *Y* and *W* axes for gantries (*1* and *2*). Passive inputs and outputs of the automated electrical system are connected through bus coupler (*4*) in a SERCOSIII protocol for operation with the Soft-PLC controller built into the CNC system [10]. Bus-coupler modules with arrays of inputs and outputs are included in each cabinet of the automated electrical system and connected to the primary SERCOS network.

SERCOSIII is an open real-time industrial protocol and represents the international standard for motion control systems and input–output modules. A design with redundant ring network topology is adopted [11]. That ensures continued operation after failure of one of the devices in the ring. The SERCOS cycle time for the control of drives and inputs (outputs) of the primary network is 1 ms. Where necessary, it may be reduced to 250 μs by adjusting the parameters of the CNC system.

Bosch Rexroth Advanced servo drives have a built-in control function for the paired motors. The use of this function for the servo drives corresponding to the *Y* axes (two drives on each side of the gantry) and the *C* axis (to close the control loop for the subordinate drive) improves the reliability of the distributed control system and frees up the computing resources of the CNC system. Conversely, in controlling gantry axes *W* and *Y*, the control loop of the two motors is closed within the kernel of the CNC system, since independent control is required in order to prevent skewing of the gantry.

The two operator panels and the portable manual control panel are connected through an industrial hub to the kernel of the CNC system in an Ethernet network. The kernel of the CNC system receives control commands only from the active control panel. To that end, there is a special mechanism for transfer of con-

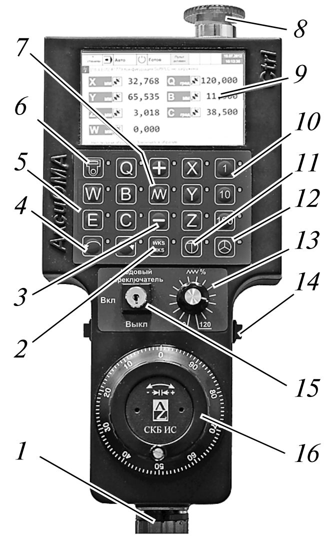

Fig. 3. Specialized manual control panel for the VMG 50 machining center: (*1*) jack; (*2*) blank/machine-tool selector; (*3*) selection of the direction of axial motion (plus or minus); (*4*) clockwise or counterclockwise spindle startup; (*5*) key for selection of the active axis; (*6*) activation of the control panel; (*7*) accelerated motion (fast control); (*8*) emergency-stop button; (*9*) operator screen; (*10*) key for increment selection (1, 10, 100); (*11*) key for abrupt spindle motion; (*12*) key for selecting flywheel conditions; (*13*) corrector of axial supply; (*14*) button of safety for confirming panel operation; (*15*) switch for operation with panel; (*16*) electronic flywheel.

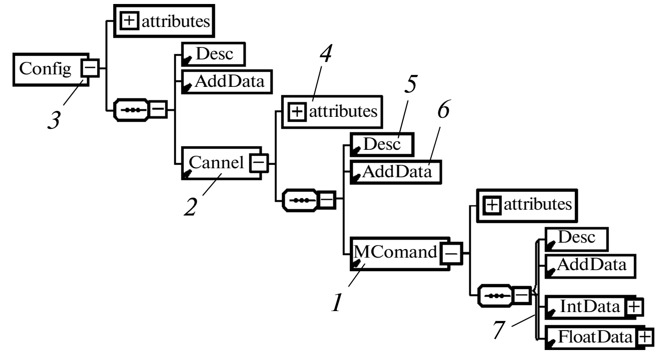

Fig. 4. Structure of the file data for the configuration of M commands at the CNC–PLC interface: (*1–3*) configurations of the M-command, the control channel for the command, and the CNC–PLC M commands, respectively; (*4*) attributes with data fields; (*5*) text description; (*6*) additional data set; (*7*) command parameters.

trol between the operator panels and the portable control panel.

Current CNC systems employ multiterminal connection of visualization and input/output devices for the user interface. For example, Siemens uses special multipoint interfaces (MPI) to connect data servers (the kernel of the control system) with clients.

These hardware modules must be included in each device for network communications. The MPI interface permits the linking of up to 32 network nodes, which may be programmers, controllers, operator terminals, portable panels, or other components of the human–machine interface.

The AxiOMA Contol platform permits the organization of network and remote access to CNC functions [12]. In the internal network of a machine tool, shop, or enterprise, direct connection to a local network of up to eight clients is possible. The clients are the control terminals, the manual control panel, and mobile clients. In this case, access to the CNC functions is clearly defined [13].

In the local network of the VMG 50 machining center, the clients of the CNC system's kernel are two terminals and a specialized manual control panel (Fig. 3). In terms of hardware, the operator terminal, the manual control panel, and the CNC kernel are connected by means of an industrial network concentrator, through an Ethernet network. The activity of a particular client is monitored by a specially developed mechanism in the kernel [14].

The multiterminal control component of the CNC system's kernel has information regarding the connected clients and their configuration. Several clients (the operator panel and the machine-tool panel) may be combined into the control terminal. Commands for client activation or disconnection are handled in the system kernel on the basis of current data, while queries regarding the possibility of client activation are generated in the control program of the programmable logic controller (PLC).

The portable manual control panel requires a special design workup. The panel in the VMG 50 machining center is used by the operator in tool attachment, when mobility is required. Some of the built-in functions are control of the machine-tool axes (up to seven) from buttons and an electronic flywheel; modification of spindle operation; correction of the supply; and selection of the displacement increments (Fig. 3). The manual control panel (safety level IP65) uses only Russian components and the Linux operating system (the version for ARM processor architecture).

SPECIALIZED AUXILIARY FUNCTIONS

Modification of the machining center requires change in the M functions performed by the CNC system for control of the automated electrical peripherals (such as hydraulic braking of the axles, index clamping, and hydrostatic control of the axles in the machine tool). The AxiOMA Contol platform provides instruments for configuration of the set of user M functions in the CNC–PLC switching interface.

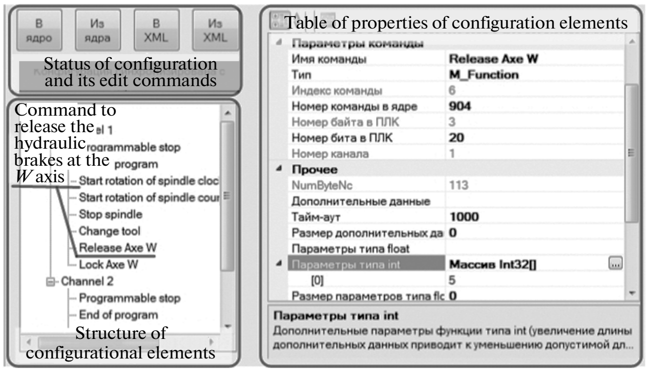

Fig. 5. Dialog screen for editing the command to release the hydraulic brakes at the *W* axis for the CNC–PLC interface.

In Fig. 4, we show the structure of the data in the xsd format (XML Schema definition, the language for description of the structure of an XML document) for description of the configuration of user M commands in the machining center.

The basic structural elements are the configuration (Config), channel (Channel), and M command (MCommand). The configurations describe the set control-system channels. Each channel contains data regarding the M commands that it contains. The M command is described by attributes and childs elements of the command parameters (Desc, IntData, FloatData, etc.). This data structure permits the specification of fulfillment parameters and processing methods in the PLC.

The editing screen for the set of M commands at the CNC–PLC interface is used to adjust the auxiliary commands of the CNC system for specific functions of the machine tool. Options include modification of its configuration, loading the configuration, storing the configuration in a file, and creating and correcting the configuration in the kernel of the CNC system (Fig. 5).

As an example, consider command M904, which releases the hydraulic brakes at the *W* axis. The right column in the table of command parameters indicates the number of the command for the CNC system, the number of the bit in the table of M-command data on the PLC side, the execution time, and the set of whole-number data corresponding to the axis index.

Thus, in terms of its size and kinematics, the VMG-50 machining center is of nonstandard design. Such machine tools impose stringent requirements on the CNC system. The modular structure and scope for expanding the functions of the machining center (for example, the use of a broaching column) call for a control system that is open and scalable.

The use of the Russian AxiOMA Contol platform to construct the control system for the machining center is critical to ensuring the technological independence of the manufacturing industry.

The control system of the machining center employs specialized program modules for multicoordinate machining, constructing a communications channel with an external PLC, and permitting expansion of the set of specialized functions at the user's disposal.

The design options made possible by user M commands permit rapid adjustment of a specific set of auxiliary functions for the control of specialized electrical equipment in the machining center (the hydraulic station, chip removal, the hydraulic brakes for the machining axes, lubrication of the gantry guides, etc.).

ACKNOWLEDGMENTS

This work was conducted as part of a program for state support of scientific institutions (program NSh-3890.2014.9). Financial support was also provided by the Russian Ministry of Education and Science and under a presidential grant for state support of young Russian scientists (contract 14.124.13.6495–MK).

REFERENCES

1. Martinov, G.M., Martinova, L.I., Kozak, N.V., et al., Design principles for a distributed CNC system in machines on the basis of open modular architecture, *Spravochn., Inzh. Zh.*, 2011, no. 12, pp. 45–41.
2. Martinov, G.M., Obuhov, A.L., Martinova, L.I., and Grigoriev, A.S., An approach to building specialized CNC systems for non-traditional processes, *Sixth CIRP International Conference on High-Performance Cutting (HPC2014): Procedia CIRP*, 2014, vol. 14, pp. 511–516.
3. Martinov, G.M., Kozak, N.V., Nezhmetdinov, R.A., et al., Analysis and synthesis of modern CNC systems, *Avtomat. Prom.,* 2013, no. 5, pp. 8–14.
4. Martinov, G.M., Kozak, N.V., Abdullaev, R.A., and Kovalev, I.A., Construction of a specialized distributed control system for the VMG 50 precision machining center, *Avtomat. Prom.*, 2014, no. 6, pp. 16–20.
5. Multifunctional vertical machining centers: VMG (L, F) series, http://stankozavodsedin.ru/VMG.html.
6. Grigoriev, S.N. and Martinov, G.M., Research and development of a cross-platform CNC kernel for multi-axis machine tools, *Sixth CIRP International Conference on High-Performance Cutting (HPC2014): Procedia CIRP*, 2014, vol. 14, pp. 517–522.
7. Martinov, G.M., Ljubimov, A.B., Grigoriev, A.S., and Martinova, L.I., Multifunctional numerical control solution for hybrid mechanic and laser machine tool, *Procedia CIRP*, 2012, pp. 277–281.
8. Martinov, G.M. and Grigor'ev, A.S., Diagnostics of cutting tools and prediction of their life in numerically

controlled systems, *Russ. Eng. Res.,* 2013, vol. 33, no. 7, pp. 433–437.

9. Nezhmetdinov, R.A., Sokolov, S.V., Obukhov, A.I., and Grigor'ev, A.S., Extending the functional capabilities of NC systems for control over mechano-laser processing, *Automat. Rem. Control*, 2014, vol. 75, no. 5, pp. 945–952.
10. Grigoriev, A.S. and Martinov, G.M., Decentralized CNC automation system for large machine tools, *Proceedings of COMA 13: International Conference on Competitive Manufacturing*, Stellenbosch, South Africa, 2013, pp. 295–300.
11. Sosonkin, V.L. and Martinov, G.M., Architecture of digital servo supply drives in technological machines, *Mekhatron., Avtomat., Upravl.*, 2005, no. 10, pp. 24–30.
12. Martinov, G.M. and Martinova, L.I., Trends in the numerical control of machine-tool systems, *Russ. Eng. Res.*, 2010, vol. 30, no. 10, pp. 1041–1045.
13. Martinova, L.I., Pushkov, R.L., Kozak, N.V., and Trofimov, E.S., Solution to the problems of axial synchronization and exact positioning in a numerical control solution, *Automat. Rem. Control*, 2014, vol. 75, no. 1, pp. 129–138.
14. Martinova, L.I., Grigoryev, A.S., and Sokolov, S.V., Diagnostics and forecasting of cutting tool wear at CNC machines, *Automat. Rem. Control*, 2012, vol. 73, no. 4, pp. 742–749.

Translated by Bernard Gilbert