Decentralized CNC Automation System for Large Machine Tools

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Abstract
The specifics of part processing on large machine tools are determined, solutions for building of large machines are investigated and requirements for the control system are systematized. A cross-platform approach for building a CNC kernel is proposed with the implementation of abstraction levels, which allows using a wide range of OEM equipment from various manufacturers based on modern industrial protocols.
The practical aspects of the implementation of a distributed CNC system for the VMG50 machine tool and organization hierarchical network for management of servo drives and PLCs in real time are illustrated.

Keywords
decentralized CNC , control panel, multidrive control, large machine tool, SERCOS III

1 INTRODUCTION

Manufacturers of CNC systems annually invest hundreds of person-years in the development of control systems, and about 80% of them in the software. CNC developers are interested in creating a basic platform to configure on it the solutions for different price categories, different types of machining and different kinematics of machine tools. Machine tool builders use a modular solution of CNC which allows arranging the system for a specific machine tool. Such CNC system along with all the requirements for conventional machine tools should provide multiple control channels working in different modes, a decentralized system of inputs/outputs and simultaneous operation of several industrial interfaces for the exchange of cyclic data.

Those requirements for modern CNC systems are valid also for the control systems of large machine tools.

The increasing demand for big parts is promoting interest in the large machine tools. Aerospace and power generation markets require large structural elements. Large parts that were previously assembled from separate parts are now machined from monolithic blocks, which increases the need for large and precise machine tools. Transportation costs and low volumes usually make the production of large parts abroad unprofitable. Previously the problem was to find large machine tools for processing products, now the question is time and the cost of treatment.

A big machine is a relative term, but in general, a “big” machine tool can be defined as a machine center with a work area larger then 1m3 or a lathe that can handle work pieces with the diameter of more than 1m [1]. Although these machine tools execute the same operations as the conventional ones, but due to the large size of parts and their massiveness the processing is organized differently. In particular, for the treatment of such details, it is important to reduce the number of part setups, as well as to provide the possibility of measuring directly on the machine and immediate input correction to prevent scrap. In addition, large parts are most often made of new materials and monitoring and remote controlling of the process are important [2]. The manipulation of large work pieces is more difficult, it takes longer to setup them. Analysis of the world leading machine tool builders Mazak Corp., Amera Seiki Corp., Cincinnati Machine LLC, DS Technology (USA) Inc., Haas Automation Inc., Hurco Cos. Inc., Makino Inc., Mori Seiki U.S.A. Inc., Mazak Corp., SCHIESS GmbH (Germany), Pietro Carnaghi spa (Italy), Sedin (Russia) shows that the aim is to construct multitasking machines, to avoid unnecessary setups, caused by the need to perform operations on different machine tools. Previously large machines were not associated with high precision, today these machines’ positioning accuracy and repeatability are comparable to conventional machine tools.

The control system should take into account the specifics of the large machine tools. The work area often could be tens of meters or more, so the operator must have a remote control panel, a few stationary control panels and the possibility of using remote terminals. The cost of work piece starts from several hundred thousand dollars and in case of not regular emergency switch-off the cutting tool should be urgently removed with the help of additional capacitor energy [3]. The axis is constructively implemented by two or more distributed servo drives, such schema is required in order to achieve the desired torque and to prevent structural deformation, the control system should provide a multidrive control functionality [4]. The multidrive control uses the concept of gantry axes - or master and slave axis. Constructively the elements of control systems are decentralized, and the solutions and components from different manufacturers are used, which may have different control interfaces and protocols, but must be connected to the CNC system.

2 DEFINITION OF THE REQUIREMENTS FOR DECENTRALIZED CONTROL SYSTEMS

The decision goes beyond the classical control systems [5]. Modern control system is constructed on the basis of the synthesis of heterogeneous computing components, such as conventional control systems (CNC systems, PLCs and motion controllers), industrial computers and specialized control systems, which are incorporated in the information- computing environment via industrial networks [6].

Key requirements are illustrated on Figure 1.

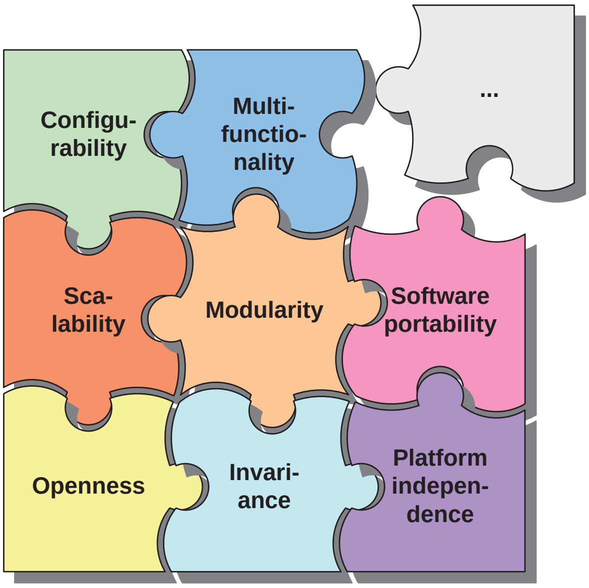

Figure 1 - Key requirements decentralized control system

Platform independence implies the possibility of using the CNC kernel software on different hardware and software platforms. *Invariance* means ensuring consistency of control process in a variety of implementation ways; it may be an in-house decision or one based on OEM equipment.

The *scalability* of the system allows to "clone" existing functionality several times, and is provided by multi-channel support of CNC system. The axes are attached to the channel, each channel can execute its own part program, and as a result, several part programs could run on CNC system concurrently. Most often, this feature is used for multispindle processing or for joint control of the machine tool and the loader.

Configurability means the ability to configure the CNC system for different technological tasks, and different price categories.

The *openness* of architecture allows machine builders and end users to integrate their know-how in the area of high-speed cutting technology, including special canned cycles, interpolation algorithms, kinematic transformations, adaptive management and etc. in the CNC system.

3 VARIANTS OF ARRANGING THE CONTROL SYSTEM

Modern technological processes require a distributed work of managed components what is carried through industrial networks [7,8]. Property of configurability implemented in CNC system allows to arrange the controlling peripheral devices through industrial networks SERCOS II and SERCOS III, Step/Dir, CanBus, EtherCAT and others, including the use of external PLCs for special purposes (see Figure 2).

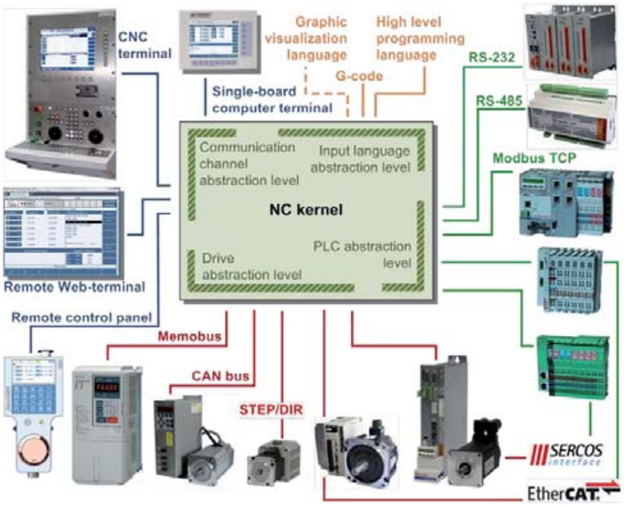

Figure 2 - Variants of arranging the control system

A solution based on the built-in kernel soft PLC means that inputs and outputs are implemented on the basis of a bus coupler with interface SERCOS III or EtherCAT. Commands of outputs control and signals of the inputs status are integrated in the cycle of drive control and transferred through the same interface.

The remote terminal connected via TCP/IP allows the operator to monitor the machine tool using a simplified HMI. The service department remotely diagnoses and configures digital drives according to the machine tolerance with the help of the web-terminal.

4 CONFIGURING THE BASIC CROSS-PLATFORM KERNEL

A control system, as a virtual machine, has a multi-layered structure (Figure 3), which is configured for a certain solution. The lowest level is standard industrial PC-hardware and specialized NC-hardware for the process equipment connected through fieldbus. Together with real time operating system Linux RT, part of the next level, they form the platform of control system.

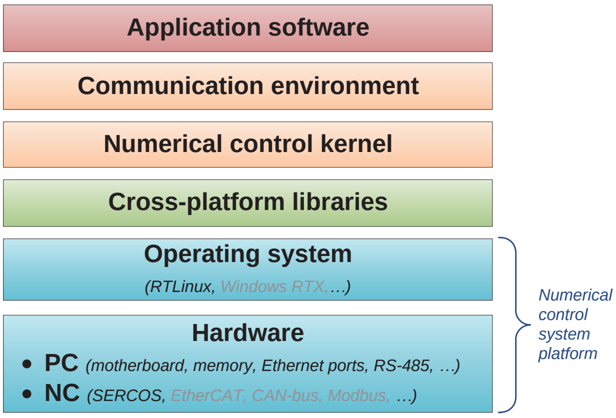

Figure 3 - Cross-platform implementation of the control system

The platform-independent layer, located above, hides the specific of the platform from the upper levels of the software implementation. Timers, mutexes, shared memory, wrappers of the Run Time Library functions and other elements that are specific for each operating system are implemented in that layer.

The part program interpreter, interpolation algorithms, the look-ahead algorithm, algorithms for the kinematic transformation, algorithms for geometric error compensation, SoftPLC and cycle logic control algorithms, together with task scheduling are implemented on the layer of kernel.

The level of communication environment provides information exchange between the control system kernel and application software executed on different terminals.

The interface of the operator of the machine tool, the editor of flow programs, the machine parameters editor, terminal part of the special diagnostic applications, for example, a digital oscilloscope, logic analyzer or a subsystem for monitoring and tool life prediction are located at the application level. Most of these applications are implemented on the platform .NET, but solutions based on web-browser can be applied, such as remote terminal of CNC system, or a solution based on Qt to implement remote control panel for Linux.

5 PIPELINE DATA PROCESSING OF DECENTRALIZED CONTROL SYSTEM

Pipeline processing of flow program, written in G-code (ISO 6983) or in high-level program language, determines the sequence of calling modules in the process of work.

The architecture of pipeline data processing includes two or more user terminals based on OS Windows with platform .NET, a remote control panel with restricted functionality based on Linux and Qt library and the kernel operating in real time under Linux RT (Figure 4).

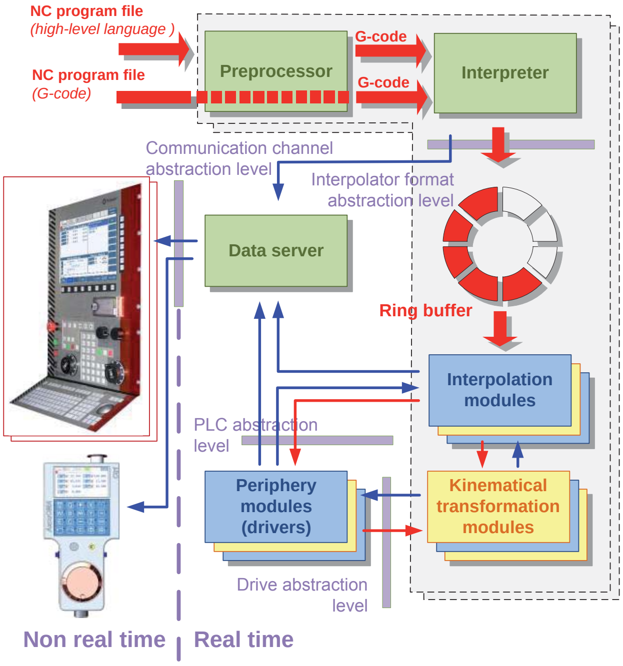

Figure 4 - The structure of the data processing pipeline

The flow program file in G-code or in the high-level program language is interpreted and the result is written into the ring buffer of prepared interpolator commands, which allows to use look-ahead algorithm and to optimize the movement of executive mechanisms of the machine. The preprocessor is used in case of high-level language constructions, based on the notation ANSI C. It works with local, global and system variables, loops, conditional and unconditional jumps, and so on. The preprocessor ignores flow programs in G-code and passes them through itself without any changing. Interpolator implements the basic types of interpolation (linear, circular, helical) and splines (Akima, cubic splines and NURBS).

As a result of interpolation control commands for servo drives and PLC are generated. Information on the execution of flow program, the current state of servo drives and PLC is transmitted to the data server for displaying on the user interface. A special mechanism of synchronous and asynchronous requests along with event requests implemented in the data server optimizes the traffic of information exchange.

The kinematic transformation module converts the coordinates taking in consideration the kinematic scheme of the machine tool and the need to ensure constant contour processing speed. The need to use a particular kinematic transformation module is determined at the stage of setting NC machine parameters in accordance with the machine tool kinematics.

The openness of control system architecture is concentrated in the levels of abstraction, which ensures the kernel independence from the shared level specific implementation. Abstraction on the level of the interpreter allows using any description language for the workpiece processing to transfer data in the interpolator.

Abstraction at the communication channel level is implemented with the help of streaming data and provides connectivity to the kernel data server for multiple terminal clients, including those connected via Internet remote terminals.

Abstraction at the level of drives and PLC ensures the independence of the control system kernel from the field bus interfaces of drive controllers and PLC. Additionally, it allows using the same interface SERCOS-III for the PLC and the servo drive controllers.

6 SPECIFICS OF THE MACHINE TOOL VMG50

The turning and milling machining centre (Figure 5) has a gantry with a travel area of 12 meters along the slideways to operate the turning and milling tables. The operator can control the machine from one of the two stationary control panels or with the help of a remote control panel. The electrical cabinet is divided into two parts, the first one is placed on the foundation of the machine, the second one - on the gantry in close proximity to the executive devices, thus reducing the length of the cable and getting rid of the problems associated with induction.

On the left side is boring rack, which is controlled by the second channel of the CNC. Machine design provides a replacement of the boring rack with a measuring tower for monitoring machined parts. The control system provides the configuration described by the machine tool layout.

Four servo drives carry out the movement of the gantry to the axis Y - two on each slideway on the opposite sides (Figure 6). The control task of CNC system is to synchronize the servo drives with the help of the master-slave scheme and track error value in order to compensate for the gantry skew. The gantry solution with multiple servo drives is imposed by the necessity to ensure structural rigidity and reduce possible errors from mechanical gears and deformation.

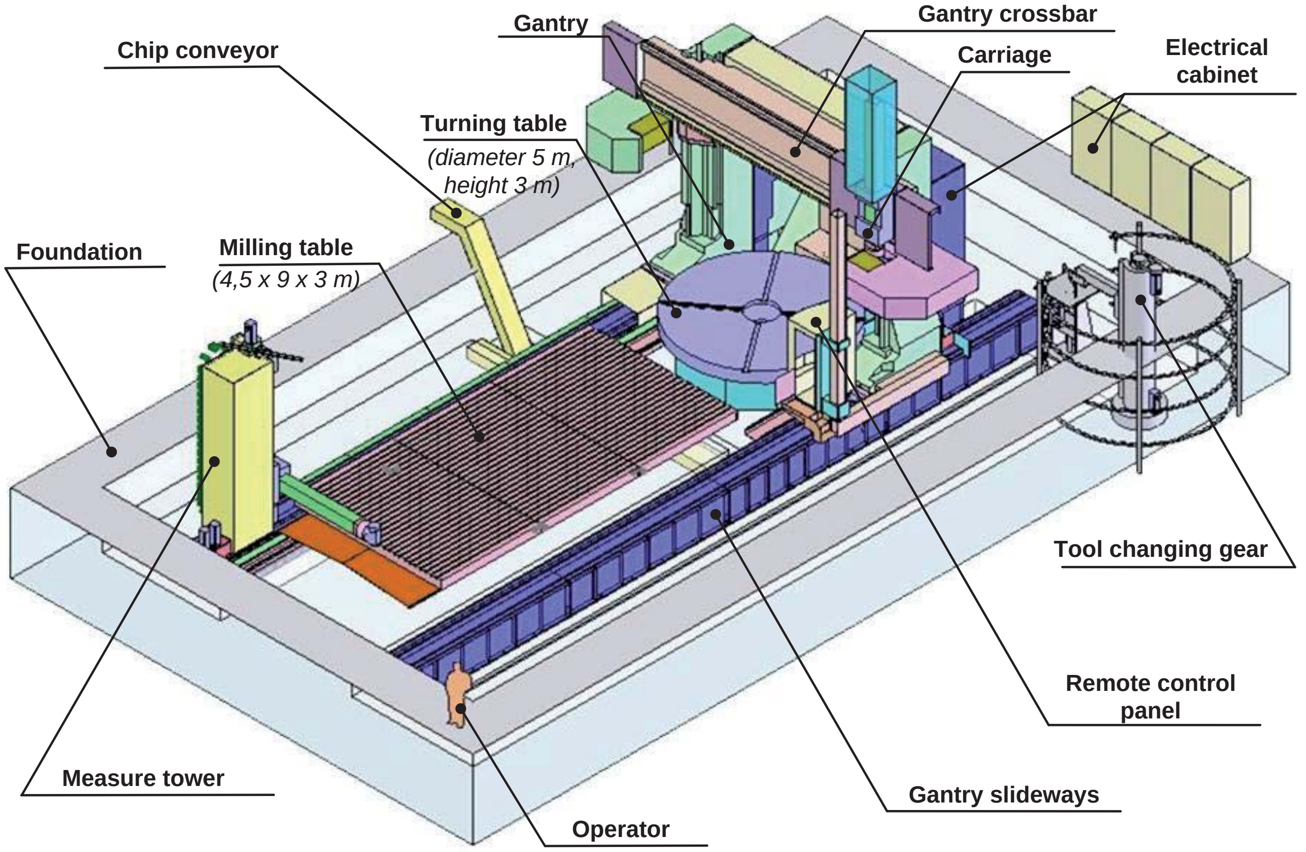

Figure 5 - Sketch of the machine tool

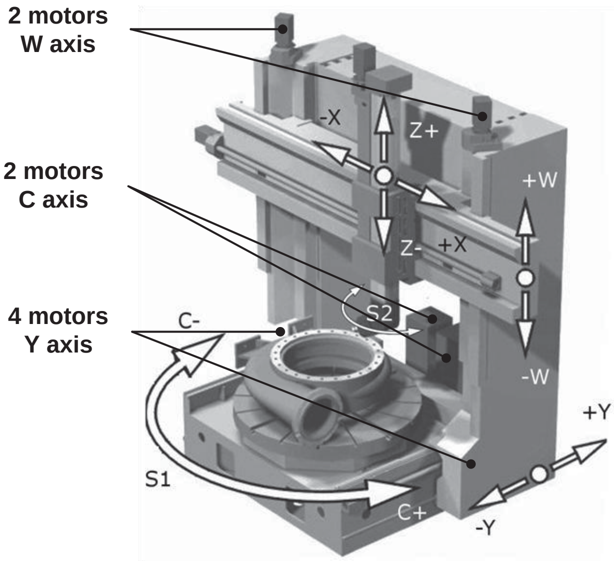

Figure 6 - Physical-axis of machine tool

7 PRACTICAL ASPECTS OF THE IMPLEMENTATION

Decentralized architecture of the control system (Figure 7) includes the kernel running on the operating system Linux RT, with the PCI board SERCANS, which is the master for the main SERCOS III network. Axes C, W and X have their own SERCOS III subnets built on the principle of master-slave.

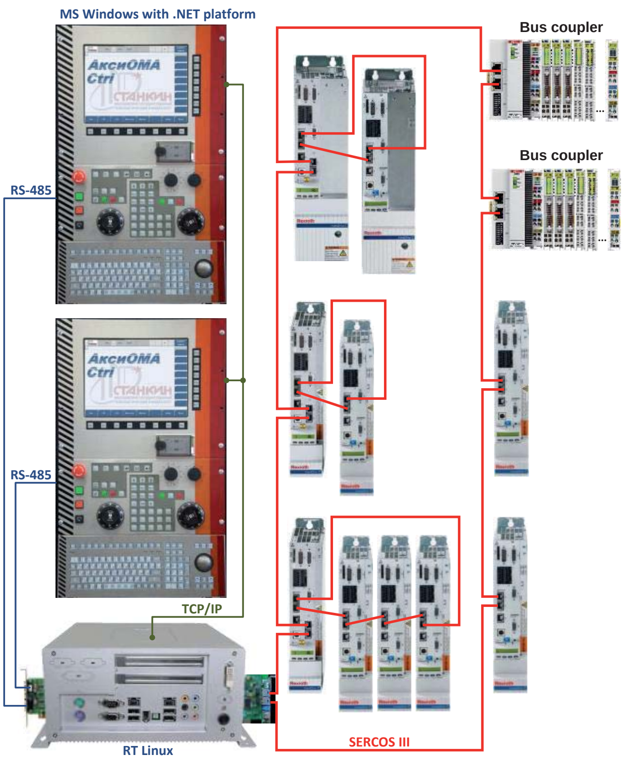

Figure 7 - Decentralized CNC system for VMG50 machine tool

The configuration of subnets is implemented with the help of the control system machine parameters. Configuration information is passed to the master servo drives at the stage of initialization via SERCOS parameters. Bus couplers with a corresponding set of I/O are built in each part of electrical cabinet and connected to the main SERCOS III network.

Two stationary control panels and the remote control panel are connected through an industrial Ethernet hub to the CNC kernel. User interface screens are synchronized automatically. The CNC kernel accepts the commands only from the active control panel. A special mechanism is implemented to transfer the control between the panels.

8 CONCLUSION

Technology of processing large workpieces though externally similar to the processing of traditional parts, still has its own peculiarities. Large machines are built on a modular principle, in order to reduce the number of parts setups, implement multitasking processing, allow measuring parts directly on the machine [9,10], ensuring accuracy in the range of 10 microns.

The application of abstraction levels in the architecture of the CNC system allows implementing multiple protocols for controlling servo drives and PLCs and expanding the list of supported OEM equipment, which is important for large machines.

Abstraction on the level of communication channel allows the CNC kernel to work with multiple terminals and remote control panels as separate clients.

The control system provides the synchronization of visualization data across all the panels and implements a special mechanism for the transfer of control actions between the panels. The CNC system accepts commands only from one active client at a time.

Machine tool builders use in large machines for one coordinate axis two, four or more servo drives, which are simultaneously controlled by the CNC system. Servo drives are organized in hierarchical networks on the basis of master-slave mechanism. Configuring the real time subnets in the CNC system is carried out with the help of machine parameters.

The electrical cabinet is divided into sections that are placed in different zones of the machine tool in order to save on cables and logical separation of managed units. CNC system should synchronously interpolate servo drive controllers that are in different sections of the electrical cabinet, and probably in different industrial networks.

9 ACKNOWLEDGMENTS

This research was supported in part by Federal target programs “Scientific and Scientific-

Pedagogical Innovation. Staffs of Russia" in 2009–2013 and "National Technological Base".

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11 BIOGRAPHY

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