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The control platform for decomposition and synthesis of specialized CNC systems

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Abstract

Modern CNC systems applicability to prospective production technologies is investigated. A systematic approach to building the control platform and creating on its base specialized CNC systems is proposed. The application of the decomposition method in CNC systems allows allocating a limited, but extensible set of software and hardware components that implement the treatment technology, and construct a matrix of solutions for the subsequent synthesis of specialized CNC systems. Synthesis is performed by arranging the hardware and software modules that create a control system according a particular processing facility.
The creation of specialized CNC system for multi-tasking planning and milling machine is illustrated.

Keywords: control platform; specialized CNC systems; multi-tasking machining; five-axis planning and milling machine;

1. Introduction

Very often the small innovative enterprises organized by the University, start to build a prototype or pilot version of new technological equipment just for testing the idea. Such projects use OEM components with different fieldbuses and manage various industrial protocols. As a result, very nontrivial requirements are imposed on the control system. This list of requirements forces the CNC manufacturer to raise the questions: how many of such control systems will be purchased for a year, and how profitable it is to be engaged in making this original product.

Often answers those questions causes discrepancies between the potential customer and CNC manufacturer [1,2].

- The tasks of controlling non-traditional processes go beyond the capability of classical open CNC systems which does not allow them to be used to solve the new range of tasks:
- The absence of an effective overall approach to building control systems to support new technologies like additive manufacturing technology; hybrid processing technology associated with the simultaneous exposure of the material to two or more dissimilar energy factors; processing technologies based on new physical principles; processing on innovative machines;
- The openness of the classical NC systems on the market is limited, although they provide the ability to integrate custom algorithms in the real-time subsystem;
- While using classical NC systems there is no way to change the principle of controlling devices.
- Developers of new equipment and machine tool builders are forced to use the CNC systems that implement the control of used devices.

The paper describes an approach to building specialized CNC systems based on control platform and adjusting those systems to handle specific technological solutions.

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2. The specifics of the CNC system

CNC systems have some distinct peculiarities. First of all, they implement the control of complicated technological equipment in the hard real-time mode [3]. Secondly, their work comprises the computing and the technological aspects, which makes them more complicated. This defines the specific requirement for the CNC system as a hardware and software complex, being the information source for the control systems of upper level, like the ERP or MES systems.

Thirdly, the CNC system is a complex hardware and software product which is constantly evolving. The development of new versions is undertaken continuously. As a rule, the concept of the CNC system kernel doesn't change from version to version, and the evolution is carried out by the improvement of the program code, which is accomplished by means of revealing and excluding bugs and code optimization, as well as via the extension of kernel functional capabilities [4]. It is the software part of the CNC system that varies the most during the stage of development, yet it is as well more vulnerable to bugs, and therefore in some cases end users need to receive the software updates of the CNC system (like the updates of office software products). But to the contrary of office software products, CNC system works in more complicated conditions, since it implements the control in hard real-time mode, and in emergency situations, the controlled machines can not only present danger to the staff, but also be seriously damaged themselves, with their price sometimes exceeding a million euros. These circumstances make impossible the online updates of CNC system software, given the possible dangers. Meanwhile, the idle time related to software updates, engenders financial losses (German specialists estimate one hour of idle time of a CNC machine tool in €150 on average). Besides, the software updates can require changes in part programs for ensuring the correct work of machine tools.

Fourth, the CNC system is a product developed for machine tool builders who use these systems on their technological equipment, with the end user of the CNC system effectively using this equipment at the shop floor. The CNC manufacturer creates his product focusing on the demands of the machine tool builders, while the latter form their demands (in particular, related to the functionality of the CNC system) according to the needs of the end user. In future all the questions related to using the CNC system should be addressed by the end user to the CNC system manufacturer, yet this relation is usually not at all developed, thus creating problems at the shop floor, including the damage of the machines.

3. The formation of control platform

The control platform is an extensible set of hardware and software solutions, of which are composed specialized CNC systems of technological equipment. This can be not only CNC system but a PLC, PAC (Programmable Automation Controller), Motion Control and in the future - Robot Control systems. The composed control system is focused just on specific technological equipment and it has no redundancy, which is typical for CNC systems offered in the market.
On the lower level the hardware layer is placed (Fig. 1). The Kernel of the control system, depending on the requirements, can be implemented on standard PC components (motherboard, memory, ports ...) and NC-specific hardware that realizes the field bus protocols (SERCOS, EtherCAT, ...). Alternatively, it can be implemented on single-board computers hardware, for example, ARM architecture. The HMI (Human machine interface) in the terminal part can be built on the PC or ARM processor.

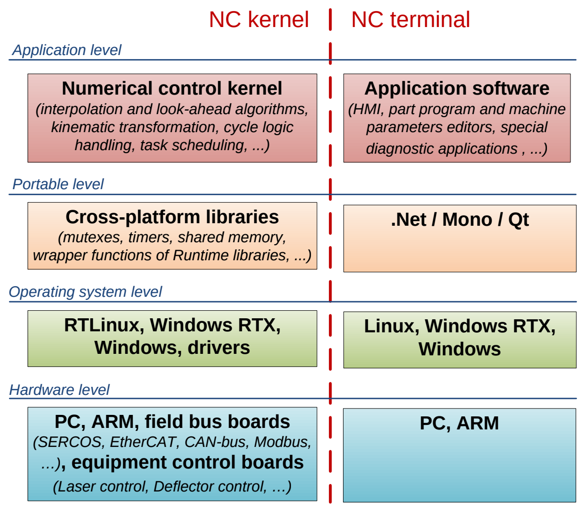

Fig. 1. Hierarchical structure of control platform.

Above there is the layer of the operating system. The kernel uses real time operating system (RTOS) RTLinux and Windows RTX (Real Time eXtension), but in future it will be possible to extend the supported RTOS with Windows CE or VxWorks. Solutions based on Windows involve kernel working in non-real time, which is often used to control the test benches.

Hardware layer together with the operating system layer form a system platform, which on the one hand, is the basis for the development of control systems, and on the other hand, is open for new solutions in accordance with the future trends in the computer industry.

The idea of cross-platform approach assumes masking system platform features of the CNC application software through a portable layer of cross-platform libraries [5]. At the control system kernel a platform-independent library is created, which provides timers, mutexes, semaphores, shared memory, threads, wrappers of Runtime library functions, and other elements that are specific to real time operating systems. The standard solutions available on the market are used in the terminal part.

The layer of CNC application software is written using only cross-platform library functions, with no direct access to the functions of the operating system. The control system kernel implements the algorithm of part program interpretation, interpolation algorithms, including spline interpolation (cubic, Akima, NURBS), the look-ahead algorithm, kinematic transformation algorithms, SoftPLC algorithms and scheduling algorithms. In the terminal part implements the HMI, various editors, specific diagnostic applications, etc. [6].

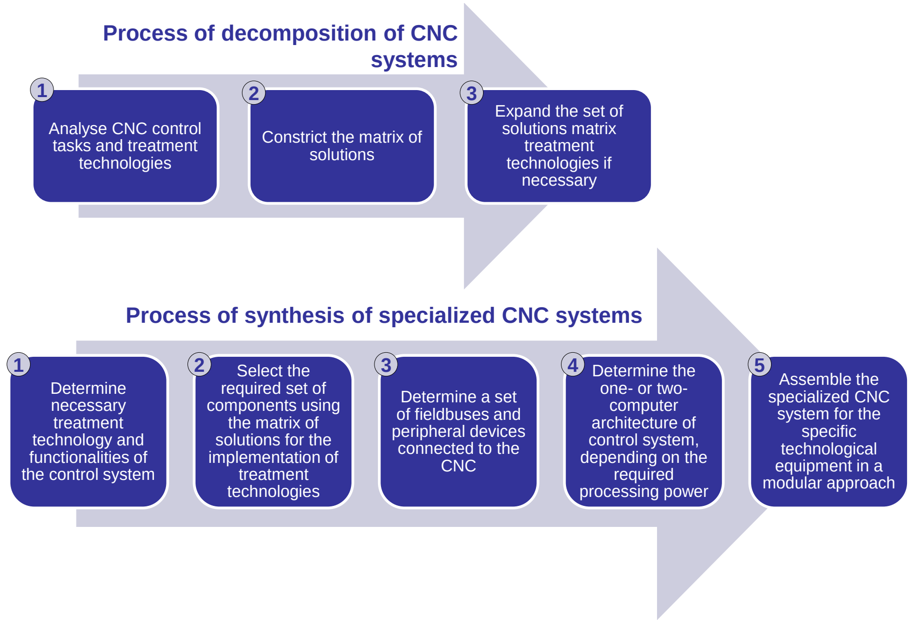

Fig. 2. Decomposition and synthesis of specialized CNC systems.

Treatment technologies	CNC control tasks					
	Geometric	**Logical**	**Terminal**	**Communication**	**Technological**	**Diagnostic**
Continuous laser machining		Processing of laser signals	Preparation of part programs	Communication functions for laser	Adaptive control of laser emission	Diagnostics and monitoring of laser parameters
Pulsed laser machining	Synchronization of movement and laser pulses			Communication functions for laser beam deflection	The adaptive control of laser pulse frequency	
Multi-axis machining	Kinematic transformation		Interface of multi-channel control	Multiprotocol communication interface with servo drives	Adaptive compensation	Logic Analyzer
	Electronic gear box			Control of drives via the "master-slave“ scheme	Prediction of tool wear	Digital Oscilloscope
Hybrid and multi-tasking machining	External interpolator	Synchronization of control of different treatment energies	Specialized function of visualizing hybrid and multi-tasking machining		Specialized canned and measuring cycles	
Water jet machining	Correction contour according to the jet shape	Control system of high pressure station	Displaying and setting the parameters of water jet	Communication with the high pressure station	Adaptive control of parameters	Diagnostics and monitoring of high pressure station
3D planing machining	Tool orientation before planing		Displaying and setting the parameters of planing		Specialized canned and measuring cycles	

Fig. 3. Expanding the solution matrix with 3D planing technology.

4. Decomposition and synthesis of specialized CNC systems

Formally, the decomposition and synthesis of control systems is divided into two processes. The decomposition process at the first step assumes the analysis of CNC control tasks and treatment technologies (Fig. 2). At the second step the solution matrix is constructed in which the treatment technology are arranged vertically, and CNC control tasks – horizontally [7]. At the intersection of matrix cells are located hardware and software components that implement the treatment technologic functionality according to specific control tasks.

The third step assumes an extension of the set of solution matrix treatment technologies if necessary. This step is performed iteratively to expand the range of available treatment technologies. An example (Fig. 2) illustrates adding the technology of 3D planing.

The synthesis process consists of several steps. The first step determines the necessary processing technology and the functionality of the control system.

The solution matrix includes the following treatment technologies: continuous and pulsed laser machining [8], multi-axis machining [9], hybrid and multi-task machining [10], water jet machining and 3D planing machining. The second step selects the required set of hardware and software components using the matrix of solutions for the implementation of treatment technologies.

The third step determines a set of fieldbuses and peripheral devices connected to the CNC. At present, supported by high-speed SERCOS III and EtherCAT buses, as well as popular CANbus, Memobus, SERCOS II and others buses [11,12].

The fourth step determines the one- or two-computer architecture of CNC system, depending on the required processing power and a number of additional factors, such as the minimum interpolation cycle, integration in automatic line or standalone work, etc. [13]. Variants of using a one- or two-computer architecture of CNC system are summarized in Table 1 and Table 2.

Table 1. Variants of CNC kernel.

CNC kernel	Hardware	OS	Interpolation cycle range
Linux PC based	x86	RT Linux	0.1÷4 ms
RTX PC based	x86	MS Windows +RTX	0.1÷4 ms
PC based	x86	MS Windows	1÷4 ms
ARM based	ARM	Linux	0.1÷4 ms

Table 2. Variants of CNC terminal.

CNC terminal	Hardware	OS	Frame work / API
Regular	x86	MS Windows	.NET
Remote	x86	MS Windows, Android, iOS, Windows Mobile	Web browser
Simplified	ARM	Linux	Qt, Java

Any version of the terminal can be connected to any kernel version of the CNC system. Take in consideration that a full-featured CNC version of one computer architecture is a combination of RTX PC based kernel and regular terminal. The variant of single-board ARM computers (ARM-based kernel with simplified terminal) is applied to control simple technological equipment.

The fifth step assembles the specialized CNC system for the specific technological equipment in a modular approach according to the previous steps.

As an example of the proposed approach, the next chapter illustrates a synthesis of specialized CNC systems for five-axis planing and milling machine tool.

5. Building the control system for five-axis planing and milling machine tool

The design of the machine tool is chosen based on the requirements of rigidity. The linear axes X, Y, Z provide movement at a rate not lower than 40 m/min (Fig. 4) and an acceleration of 2g, also providing sufficient force for planning (Table 3). Rotary axes B and C ensure the 3D planing and are implemented in the spindle head. The spindle head is equipped with a hydraulic clamp for fixing and removing the backlash in rotary axes during machining. PLC controls the tool change mechanism, the hydraulic clamp of spindle head, the cooling and air-purging spindle system, the impulse lubrication of slideway, the miscellaneous functions for measurement and other.

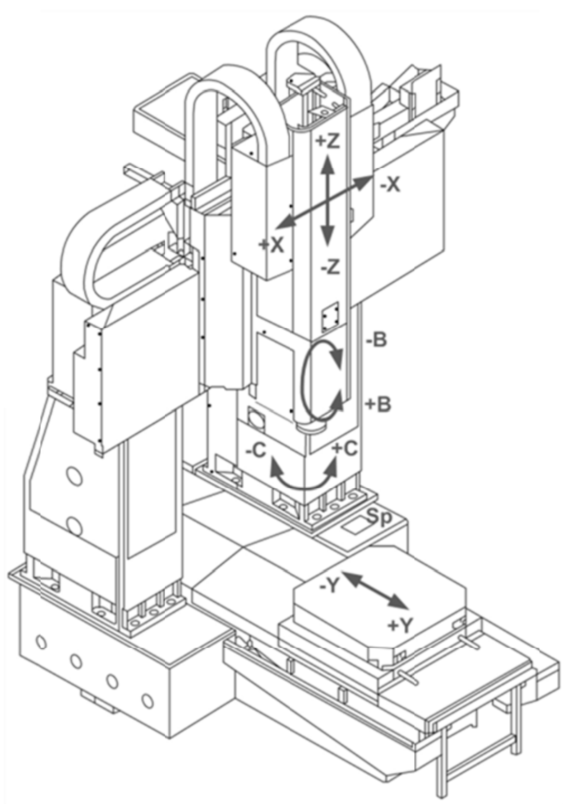

Fig. 4. Kinematic of five-axis planing and milling machine tool.

Table 3. . Machine tool parameters.

Parameter	Value
Working area X/Y/Z	500/320/250 mm
Axis B rotation	± 90 deg
Max planing force on axis X	2000 kg
Max planing speed for C-axis	500 deg/min
Max speed of a linear axis	40 m/min
Linear axes acceleration	2g
Machining accuracy	8 µm

Following the declared sequence of synthesis, first is determining the required treatment technology from the solutions matrix. The CNC should implement multi-axis machining with kinematic transformation, hybrid and multi-tasking machining with specialized canned and measuring cycles and 3D planing machining (Fig. 5).

The structure of the control system is shown in Fig. 6. Integrated in CNC SoftPLC system performs the cycle logic functions. I/O modules are connected via SERCOS III interface bus coupler.

The CNC system has a two-computer architecture, Linux PC based kernel and regular terminal. The structure of the terminal part includes the operator panel function F-keys and machine M-keys, machine tool panel and industrial PC keyboard. Machine tool panel communicates directly with the CNC kernel through internal protocol based on the serial port interface.

Servo drive control is performed via the standard high-speed protocol SERCOS III. The CNC kernel is equipped with a SERCANS PCI board, which is the master for SERCOS ring and the servo drives and bus couplers are the slaves in the ring. A set of machine parameters configures the SERCOS real-time network in the control system, including the addresses of passive I/O modules.

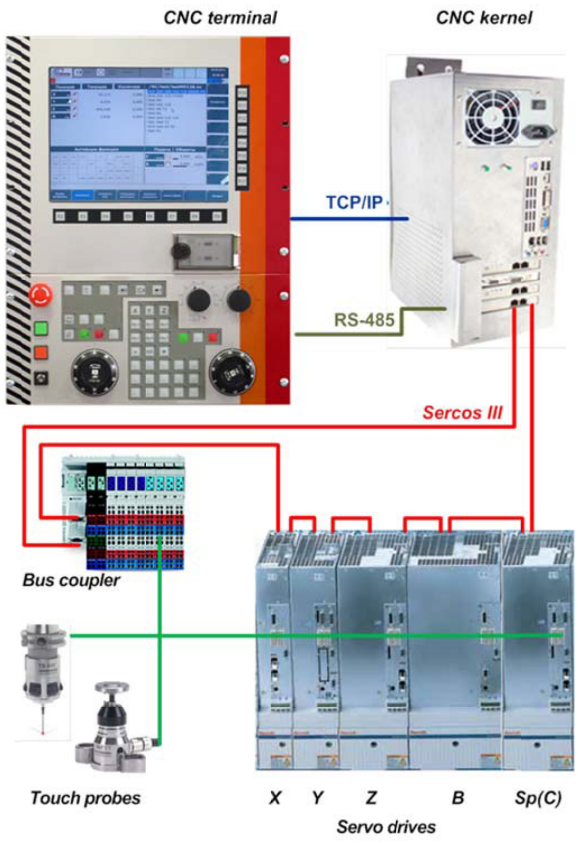

Fig. 6. Kinematic of five-axis planing and milling machine tool.

The machine tool is equipped with a measuring system for increasing the accuracy of processing and forecasting of cutting tool wear system [14,15], as well as for special functions for tool orientation before planing (Fig. 7). Touch

Treatment technologies	CNC control tasks					
	Geometric	Logical	Terminal	Communication	Technological	Diagnostic
Multi-axis machining	Kinematic transformation		Interface of multi-channel control	Multiprotocol communication interface with servo drives	Adaptive compensation	Logic Analyzer
					Prediction of tool wear	Digital Oscilloscope
Hybrid and multi-tasking machining		Synchronization of control of different treatment energies	Specialized function of visualizing multi-tasking machining		Specialized canned and measuring cycles	
3D planing machining	Tool orientation before planing		Displaying and setting the parameters of planing		Specialized canned and measuring cycles	

Fig. 5. Set of solutions for control systems of five-axis planing and milling machine tool.

probe signal is supplied to the fast drives controller inputs and it is duplicated on the PLC inputs. PLC processes the signal from the touch probe and blocks the execution of a number of operator actions, such as a manual tool change. The proposed scheme of connecting the touch probe provides a timely response movement stop to the event of touch, reduces the risk to damage the touch probe and parallelize the processing of the signal. The CNC during executing measuring cycle receives notification of touch event, saved coordinates of the contact point and the current coordinates of stopping.

Fig. 7. Carry out research on five-axis planing and milling machine tool with specialized CNC system.

6. Conclusion

The synthesis of specialized CNC systems for concrete technological machines is performed by combining the required hardware and software modules. Using a matrix of solutions significantly reduces the development time and permits the control systems for a wide range of technological equipment enter the market.

The proposed approach has been successfully tested in building control systems for five-axis planning and milling machine.

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