An Approach in Implementing of Logical Task for Numerical Control on Basis of the Concept "Industry 4.0"

Georgi M. Martinov,
Nikolay V. Kozak,
Ramil A. Nezhmetdinov
Moscow State Technological University “STANKIN”
MSTU "STANKIN"
Moscow, Russia
kozak@ncsystems.ru

In article, actual tendencies of construction of modern industrial enterprises are investigated. The analysis of systems of logic control and their conformity to the concept "Industry 4.0" is made. An architectural model of a subsystem for logical control and diagnostics of a CNC system with the ability to transfer data to higher levels of control for integration in digital engineering industries is proposed. Practical aspects of solving the logical control problem are presented using the example of an slant-carriage machine. Signals and their addressing in the shared memory of the CNC kernel are described.

Keywords — logic control, CNC, PLC, Soft-PLC, diagnostic subsystem, technological process, Industry 4.0, smart manufacturing.

I. INTRODUCTION

Nowadays the stage of evolution of society is attributed to the post-industrial. The basis of this stage is information, as a means and object of manufacturing [1]. Under these circumstances, the means of collecting, processing and transmitting information have changed: more and more people use mobile devices to work with information resources, and a global network and cloud technologies are used to access to “big data” [2, 3]. These changes are reflected in industrial technologies that have shifted from the concept aimed at automating individual machines and processes to the concept "Industry 4.0", which provides for the digital representation of all physical assets with subsequent integration into the digital global system, built in conjunction with partners participating in the value chain. The new concept is based on a multilevel, complex, global technological and organizational system that involves the integration of physical operations and their supporting processes into a single information space [4, 5].

The aim of this work is to build a model of a subsystem of logical control and diagnostics of a CNC system with the ability to transfer data to higher levels of control for integration into digital engineering industries. This research was supported by the Ministry of Education and Science of the Russian Federation as a public program in the sphere of scientific activity (N 2.1237.2017/4.6).

TABLE I. ANALYSIS OF THE CONFORMITY OF THE SYSTEMS OF LOGICAL CONTROL OF THE CONCEPT «INDUSTRY 4.0»

The requirement in the concept of «Industry 4.0»	PLC	PAC	Soft PLC	Controller in the concept «Industry 4.0»
Product Lifecycle Management	Communication with PLM systems with the use of an intermediate hardware and software link for the collection and processing of information			Communication with PLM systems directly
Working with large data	–	Depends on the specific software implementation		Resources for working with large amounts of data
«Smart manufacturing»	Supported by individual flagship models	Depends on the specific hardware and software implementation		Implement the concept of smart manufacturing
Cyber-physical systems	Capable to work in a uniform network space of the enterprise if it is realized with support of standards of the concrete manufacturer of the equipment			Work in a single enterprise network space
«Internet of Things»	Supported by individual flagship models	Access to the global network	Depends on hardware platform	Access to the global network
The possibility of linking the equipment of different manufacturers into a single system	Only at the level of hardware signals			Realizes full-fledged synchronization, based on multi-protocol
Interoperability	Support for a specific standard and communication protocol (depending on the manufacturer)			Support for the most common standards

The concept «Industry 4.0» includes 6 aspects, each of which influences the technological system as a whole: product life-cycle management, work with large volumes of data, organization of «smart manufacturing», organization of cyber-physical systems, «Internet of things», interoperability of system elements [6].

Today the most widespread at automation of machine-building manufactures are systems of the logic control based on PLC, at the same time, modern automation tools such as Soft-PLC [7,8] and PAC (programmable automation controller) are gaining in popularity, but none of them fully comply with all aspects of the «Industry 4.0» (Table I).

The logical control system implemented with the support of the «Industry 4.0» concept should:

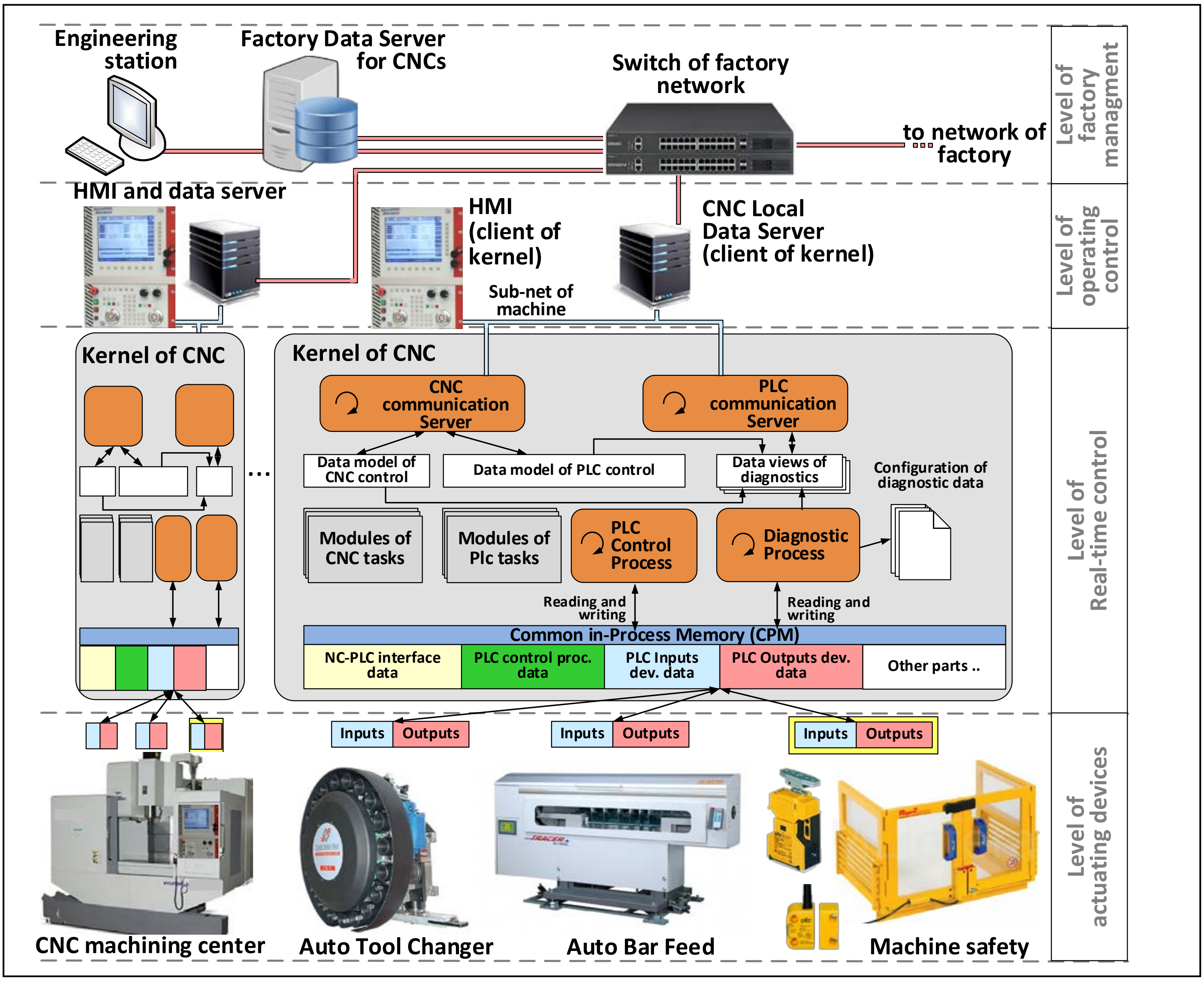
- have a channel of interaction with product lifecycle management systems, which will allow the operative transfer of information on the condition of the material and technical base of individual production units and sites;
- support work with large amounts of data (including through cloud technologies), which are collected directly from the objects of control;
- be able to work in the digital engineering industry, including in the framework of virtual manufacturing corporations;
- support the main industrial and network protocols for interoperability within the enterprise network space;
- have an Internet connection with support for the transmission of control commands and specified information about the operation status of the control object.

To implement the requirements of the concept "Industry 4.0", it is necessary to form the corresponding structure of the logical task as part of control systems [9]. Further, such structure is presented for integrating machine tools with CNC systems into machine-building manufacturing.

II. The Structure of the Logical Control Tasks of Machine for Integration in Machine-Building Manufacturing

When constructing the structure of the logical task at the lower level of management, it is necessary to allocate specialized modules of the control system that provide data collection and transmission.

Fig. 1. Structure of the subsystem of the machine's electrical automation for integration into machine-building manufacturing



These nodes, as shown in Figure 1, are the «CNC Local Data Server» (CNC Local Data Server). These data servers, on the one hand, implement specific functions for working with the CNC system (specificity of interaction puncturing, data configuration). On the other hand, the local data servers of the CNC provide a channel of interaction with level of factory-management systems. [10, 11]

The control system terminal and the local CNC data server are the clients of the CNC system core as part of the interaction on the sub-net of machine (sub-net of machine). In the core structure of the CNC system, two data servers can be distinguished. The CNC communication server provides data related to motion control: the status of the motion drives, the state of the part processing process, the configuration of the control channels, etc. [12]. The PLC communication server provides data on the status of the control of the subsystem of the electroautomatics, as well as the diagnostic data of the control system.

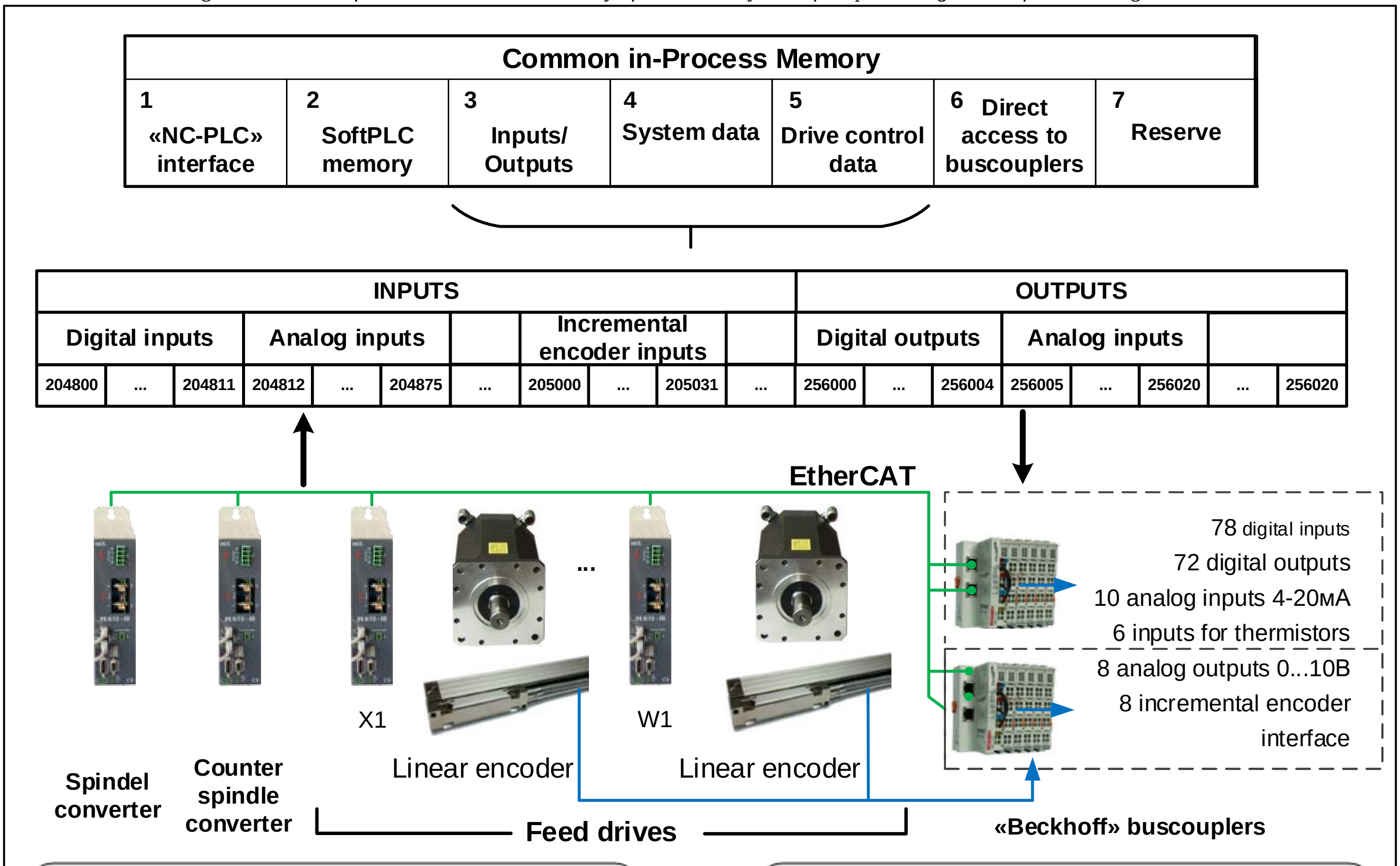
A feature of the presented structure of the control system core is the use of Common in-Process Memory (CPM) in which data is stored as a motion control process, data of the control process of the electroautomatics and diagnostic data. The use of CPM provides the ability to build a diagnostic subsystem with the ability to configure data. When configuring the diagnostics system for the machine's specificity and its technological features, the diagnostic data is configured based on the information from the CPM, for example, signals and information from the "NC-PLC Interface data" section about the M-command being executed and its parameters can be obtained.

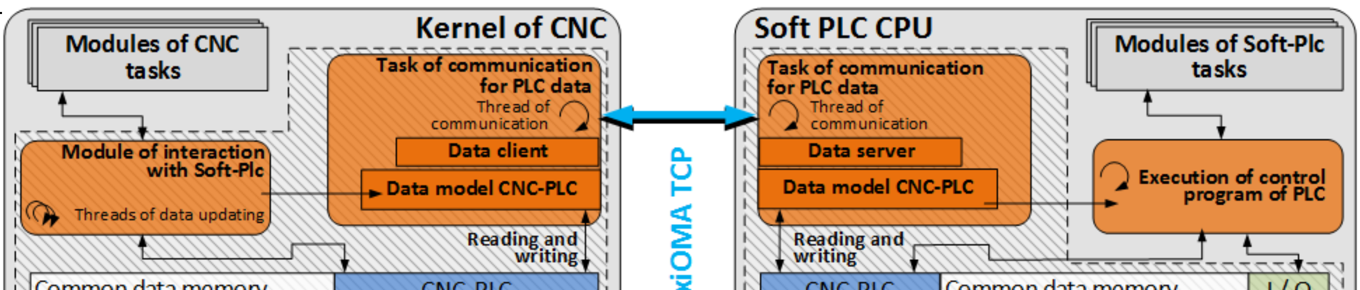
Similarly, from the section "PLC Input device data" it is possible to obtain information on temperature, pressure in the hydraulics subsystem of the machine, and even data that are not directly used in the control algorithm of the electroautomatics, but are important for the collection of technological or statistical information. [13,14]

The machine data for external customers in the facility network is provided by the local CNC data server via a separate Ethernet network interface. This allows to protect the internal network of the machine from unauthorized access. To implement various security requirements from automation systems, firewalls can be configured on the local CNC data servers using an encrypted VPN, which will provide secure remote access to machine equipment data.

The set of technological data received from the machine can be changed depending on the current requirements of the production process in the facility or during the long processing of a complex part. For example, when manufacturing a large batch of simple enough parts on the turning and milling machine, it is necessary to control the feed of the bar, the calculated wear of the tool, possible emergencies when the machined part is automatically removed [15]. And when processing complex parts on the same machine, the control is expanded by transmitting information about the temperature of the machine's nodes, the coolant temperature and information messages about the processing state. Thus, for each use of the machine, it is convenient to have a corresponding data view of diagnostic which will include the currently required set of system variables, memory cell values, information messages, and so on [16].

Fig. 2. *Structure of Common in-Process Memory of the control system of the processing center of* slant-carriage machine





III. Practical aspects of solving a logical control problem (using the example of slant-carriage machine)

As an example of the solution of the logical problem of numerical control, let us consider the control of the electroautomatics of the processing center of the slant-carriage machine CA535 (joint development of JSC SASTA, MSTU STANKIN). Leading world machine-tool companies are actively promoting lathe-milling machining centers for machining complex parts on the market, which allow to carry out complex technological operations on one equipment with many technological transitions in one installation, which ensure higher precision of parts and shorter lead times. Taking into account the arrangement and location of the feed guides, the following types of machining centers are distinguished: slant-carriage machine, vertical arrangement and horizontal arrangement.

The CNC system consists of:

- a real-time machine (operating in Linux OS) with a control system core and a PLC-integrated soft-controller integrated into it;
- the operator terminal (consisting of an operator panel on the .NET platform;
- a standard machine toolbar with an optional hand-wheel, connected to it and a specialized machine toolbar) connected to the core via the TCP / IP protocol; I / O Expansion Modules for connecting the electroautomatics and line measuring devices;
- drive the main movement and feeds; spindle and spindle controllers.

The collection and exchange of data in the network between computing devices is carried out on the basis of the open high-speed EtherCAT protocol. A large number of electrical equipment connected to the control system in the project required the use of two head input / output modules (buscouplers), which allowed distributing the electric load between the individual devices [17, 18].

Buscouplers are expanded with passive electronic input / output modules: 120 digital inputs (fifteen eight channel modules), 48 digital outputs (six eight channel modules), 10 analog inputs (two four channel modules and one two channel module, 4 ... 20 mA) 6 input terminals of RTDs (three two-channel modules), 9 analog outputs (two four-channel and one single-channel, 0 ... 10 V), six incremental encoder interface modules. The number of I / O modules is selected with a margin, which can be used in the future when upgrading the system.

Machining centers contain a large amount of technological equipment: turrets of upper and lower calipers, clamping chucks, tool and machine cooling system, cooling station and hydro-station, chip conveyor, protective fence, air supply system, tool magazine and automatic tool changer, etc. Management of the listed set of process equipment is carried out within the logical task of the CNC and requires the implementation of a number of auxiliary M-functions, in particular (M50, M51), clamping / unclamping of the cartridge

TABLE II. Description of signals of electroautomatics and their addressing in shared memory

Signal designation	Signal Description	Address in shared memory
First buscoupler		
Digital inputs		
I0.0	request to turn off the machine	204800.0
I0.1	the machine is switched off	204800.1
I0.2	phase control	204800.2
I0.3, I0.4	power feeding control	204800.3, 204800.4
I0.5 - I1.1	crashes of axes X1, X2, Z, Z1, Z2	204800.5 - 204801.1
I1.2 - I3.2	switch limit	204801. 2 -204803.2
I3.3 - I4.0	signals from the turret head of the lower caliper	204803.3 - 204804.0
I4.1 - I4.6	signals from the turret head of the upper caliper	204804.1 - 204804.6
I4.7 – I5.1	"Y" axis alarms	204804.7 –204805.2
I5.2	control circuit power supply applied	204805.2
I5.3 - I6.0	signals of the left cartridge	204805.3 - 204806.0
I6.1 - I6.6	signals of the right cartridge	204806.1 - 204806.6
I6.7 - I7.1	signals of the cooling station	204806.7 - 204807.1
I7.2 - I7.5	Hydrostation signals	204807.2 - 204807.5
I7.6 - I9.0	signals of the coolant supply system	204807. 6- 204809.0
I9.1 - I9.3	monitoring the position of protective fences	204809.1 -204809.4
I9.5	Control incl. fans control cabinet	204809.5
I9.6 - I9.7	reserve	204809.6, 204809.7
Digital outputs		
Q0.0	to signal the readiness of the control system	256000.0
Q0.1	turn off the control system	256000.1
Q0.2 – Q0.5	on / off clamping disk of the turret head of the upper and lower calipers	256000.2 – 256000.5
Q0.6, Q0.7	on / off hydraulic brake axle "Y"	256000.6, 256000.7
Q1.0 - Q1.5	left / right cartridges control	256001.0 - 256001.5
Q1.6, Q1.7	cooling station control	256001.6, 256001.7
Q2.0	hydro power plant control	256002.0
Q2.1 - Q2.5	coolant control	256002.1 - 256002.5
Q2.6, Q2.7	shavings conveyor control	256002.6, 256002.7
Q3.0, Q3.1	fence locks control	256003.0, 256003.1
Q3.2	control of the cut-off valve	256003.2
Q3.3	control of pneumatic distributors	256003.3
Q3.4 - Q4.1	disengage the axle brakes X1, X2, Z, Z1, Z2, Y	256003.4 - 256004.1
Q4.2 - Q4.7	reserve	256004.2 - 256004.7
Analog Inputs		
AI1.1 - AI1.9	connection of line temperature sensors 1-10	204812 - 204845
AI1.10	Reserve	204848, 204849
Second buscoupler		
Analog inputs		
AI4.1 - AI6.2	connection of thermistors of lines 1 - 6 in the spindle motor	204852 - 204873
Analog outputs		
AO1.1 - AO2.4	coolant flow on lines 1-8	256005 - 256020
Incremental encoder data		
IN1 - IN8	connection of optical rulers of axes X1, X2, Z, Z1, Z2, Y, C, C1	205000 - 205031

(M21, M22), opening / closing the protective fence (M54, M55), controlling the interception of the part with the spindle (M75), etc.

Data exchange between control system software modules and hardware input outputs is realized on the basis of shared memory (Common in-Process Memory) (Figure 2). The structure of the shared memory contains the following sections: 1- NC-PLC interface area, 2 - internal memory of the software controller, 3 - hardware I / O display area, 4 - system information area, 5 - motor control area, 6 - area of direct access to the "buscouplers", 7 - reserve area.

To exchange with hardware I / O devices, memory space with the following addressing is used: for inputs - from 204800 bytes to 255999, for outputs - from 256000 bytes to 307199 bytes. Each of the sections is further divided into sections that contain data from various types of input / output modules such as discrete inputs / outputs, analog inputs / outputs, incremental encoder inputs. Once in the cycle of the logical control cycle, the inputs are read, the control algorithm is executed, and the outputs from the shared memory are written to the hardware devices. In this case, the logical control program can only access shared memory and do not have direct access to the I / O modules. The description of signals and their addressing in shared memory are given in Table II.

ACKNOWLEDGMENT

The analysis of the conformity of logical control systems to the concepts of "Industry 4.0" is showed that the typical functions of PLC, Soft-PLC and PAC do not fully correspond to all aspects of the concept "Industry 4.0". To extend the functions of the logical task of CNC systems, it is proposed to use the CNC Local Data Server modules, which provide interaction with the CNC kernel and provide data for the level of factory management clients. A feature of the presented structure of the core of the CNC system is the use of Common in-Process Memory (CPM), in which data are stored as a motion control process, data of the electroautomatics control process and diagnostic data of the system.

The advantages of using CPM in the core of the CNC system are described in the example of the control system of the processing center of the oblique configuration. The presence of a structured, publicly accessible memory area within the CNC process and a specialized diagnostic process allows to efficiently solving the task of providing data from the lower levels of control, operating in real time, to level of factory management system. This can be a solution of a number of requirements within the frames of the "Industry 4.0" concept.

REFERENCES

[1] Dotoli, M., Fay, A., Miśkowicz, M., Seatzu, C., A Survey on Advanced Control Approaches in Factory Automation, IFAC-PapersOnLine, Volume 48, Issue 3, 2015, pp.394-399, ISSN 2405-8963.

[2] Schleipen, M., Gilani, S., Bischoff, T., Pfrommer, J., OPC UA & Industrie 4.0 - Enabling Technology with High Diversity and Variability. Procedia CIRP, Volume 57, 2016, pp.315-320, ISSN 2212-8271.

[3] Johansson, A., Commuting operations on signal-flow graphs for visualization of interconnected systems, IFAC Proceedings Volumes, Volume 43, Issue 21, 2010, pp.138-145, ISSN 1474-6670.

[4] Mazzolini, M., Cavadini, F., Montalbano, G., Forni, A., Structured Approach to the Design of Automation Systems through IEC 61499 Standard, Procedia Manufacturing, Volume 11, 2017, pp.905-913, ISSN 2351-9789.

[5] Jiang, Z., Dai, Y., A decentralized, flat-structured building automation system, Energy Procedia, Volume 122, 2017, pp.68-73, ISSN 1876-6102.

[6] Martinova, L., Kozak, N., Nezhmetdinov, R., Pushkov, R. and Obukhov, A. (2015). The Russian multi-functional CNC system AxiOMA control: Practical aspects of application. Automation and Remote Control, 76(1), pp.179-186.

[7] Kovalev, I., Nikishechkin, P., and Grigoriev A. (2017) Approach to Programmable Controller Building by its Main Modules Synthesizing Based on Requirements Specification for Industrial Automation. International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM), pp.1-4.

[8] Martinov, G., Kozak, N. and Nezhmetdinov, R. (2017). Implementation of Control for Peripheral Machine Equipment Based on the External Soft PLC Integrated with CNC. International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM), pp.1-4

[9] Martinov, G., Kozak, N., Nezhmetdinov, R., Grigoriev, A., Obukhov, A. and Martinova, L. (2017). Method of decomposition and synthesis of the custom CNC systems. Automation and Remote Control, 78(3), pp.525-536.

[10] Martinov, G. and Nezhmetdinov, R. (2015). Modular design of specialized numerical control systems for inclined machining centers. Russian Engineering Research, 35(5), pp.389-393.

[11] Martinova, L., Grigoryev, A. and Sokolov, S. (2012). Diagnostics and forecasting of cutting tool wear at CNC machines. Automation and Remote Control, 73(4), pp.742-749.

[12] Bushuev, V., Evstafieva, S. and Molodtsov, V. (2016). Control loops of a supply servo drive. Russian Engineering Research, 36(9), pp.774-780.

[13] Martinova, L., Grigoryev, A. and Sokolov, S. (2012). Diagnostics and forecasting of cutting tool wear at CNC machines. Automation and Remote Control, 73(4), pp.742-749.

[14] Martinova, L., Sokolov, S. and Nikishechkin, P. (2015). Tools for Monitoring and Parameter Visualization in Computer Control Systems of Industrial Robots. Advances in Swarm and Computational Intelligence, 6th International Conference, ICSI 2015 held in conjunction with the Second BRICS Congress, CCI, Proceedings, Part II, pp.200-207.

[15] Konstantinov, I., Ivaschuk, O., Approaches to creating environment safety automotion control system of the industrial complex, Proceedings of the 2013 IEEE 7th International Conference on Intelligent Data Acquisition and Advanced Computing Systems, IDAACS 2013, 2013, pp. 828-831

[16] Grigoriev, S., Teleshevsky, V., Sokolov, V., (2013). Volumetric geometric accuracy improvement for multi-axis systems based on laser software error correction, International Conference on Competitive Manufacturing (COMA '13), pp. 101-106

[17] Grigoriev, S. and Martinov, G. (2016). The Control Platform for Decomposition and Synthesis of Specialized CNC Systems. Procedia CIRP, 41, pp.858-863.

Martinov, G. and Kozak, N. (2015). Numerical control of large precision machining centers by the AxiOMA contol system. Russian Engineering Research, 35(7), pp.534-538.