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Organizing Interaction of Basic Components in the CNC System AxiOMA Control for Integrating New Technologies and Solutions

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Abstract—The article substantiates the need to have higher openness of modern CNC system for integrating new technologies and solutions. The additional, multi-task communication channel between the terminal part and core of CNC system is offered for implementing the interaction between additional software-hardware modules. The practical aspects of usage of offered mechanisms is shown on example of two software-hardware solutions. Which were integrated into the structure of the CNC system AxiOMA Control.

Keywords: CNC system, openness, interaction of components, multi-task channel, non-specified data format

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1. INTRODUCTION

Today any modern CNC system represents a complex dual-usage system intended for technological equipment control during manufacturing of household products and fulfillment of military orders for a defense-industrial sector. The majority of foreign and domestic suppliers of CNC systems are almost completely restricting the access to the system's core for machine builders and end users, by freezing of its basic functionality. An openness analysis of CNC systems suggested by different suppliers has revealed the following problems:

• no uniform approach to the development of third-party software-hardware solutions and their integration into CNC systems;

• closed architecture or considerably limited integration capabilities (readjustment of the terminal part of CNC systems only);

• the need for modifications in the software architecture of most CNC systems for integration of third-party solutions, which complicates system's scaling or makes this process even impossible;

• expensive licenses for wider functionality of modern CNC systems.

At the same time, the functionality of CNC systems has to be enlarged following the requirements of modern high-tech industries, the tendency towards a wider range of technological tasks and higher attractiveness of a control system itself. The machine makers and CNC end users are interested in their own specialized software products and also in the third-party solutions that supplement the basic software tools provided by the supplier of control systems. Among them it is possible to single out the systems solving such tasks as dynamic spindle balancing, cutting tool wear diagnostics, machine output control, network integration, computer support of CAD/CAM design, program coding and debugging for PLC, and others [1].

If an additional module (solution) has to be used jointly with a CNC system, it is important to integrate this module into the software configuration of the system and also to organize its interaction with the basic components of the system and other integrated solutions of the third-party suppliers.

2. MULTI-TASK INTERACTION CHANNEL FOR BASIC COMPONENTS OF CNC SYSTEM

The architecture of any modern CNC system includes such basic components as the terminal part operating in machine time and the core operating in real time (RT); the latter performs mathematical computations, control of forming and technological equipment. Interaction between the terminal part and the system's core can be implemented using two communication channels (synchronous and asynchronous ones), which differ in the direction of data transfer and the presence of response packets (Fig. 1) [2].

The aggregate of these exchange channels allows clients to request information about current processes from the core as well as to subscribe on some events, thereby receiving notifications of all changes in system operation [2–4].

A specific requirement of data packets transfer in the CNC systems is the guaranteed delivery of commands and messages for minimizing all errors and emergency situations. This is achieved using rigidly specified data packets defined in advance both in the core and in the terminal part. Also the identical data objects with the same description of constants, state identifiers, etc. are defined in advance in the basic components of the control system. This approach allows a guaranteed exchange of basic information between the clients and core for proper operation of the CNC system [3, 5, 6].

For enlarging the functionality of a CNC system and integrating new software-hardware solutions into the system, it is necessary to organize an additional data transfer between the integrated terminal solution and the RT solution. Formation of an individual data transfer specification for each of the integrated subsystems considerably complicates their integration into the CNC system and also their interaction with the core. This causes difficulties in enlarging the CNC system functionality that are connected with data exchange [4].

Consider an approach to organize a multi-task packages transfer channel with XData, a non-specified data format. The concept of a non-specified data format imposes no rigid requirements to specification of the whole data packet structure. Information about the intended purpose of transferred data is stored directly in a data packet in form of a special identifier assigned for each integrated component or solution.

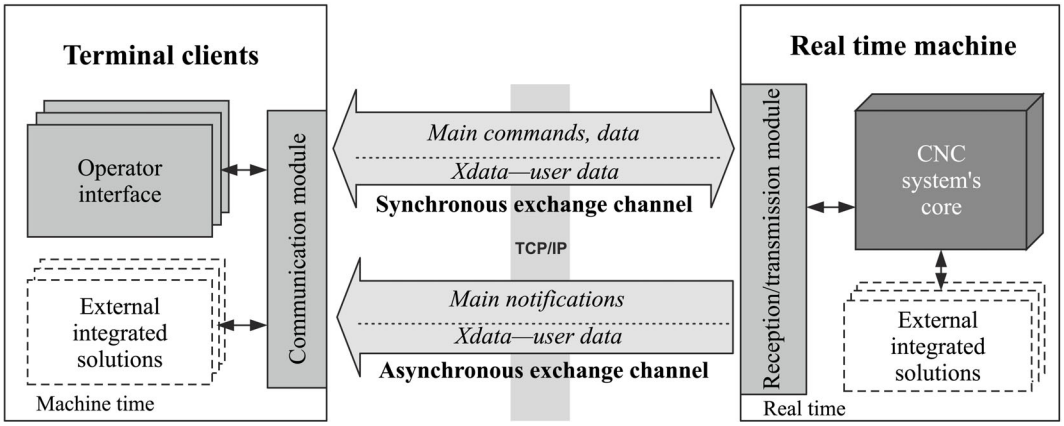

Fig. 1. Interaction scheme of CNC's basic components.

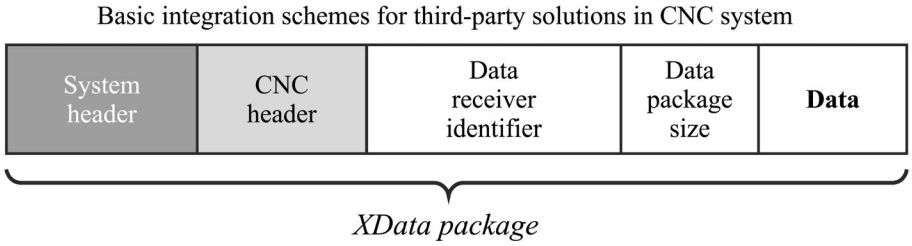

Fig. 2. Structure of package which is transferring through XData multi-task channel.

A transferred data packet consists of the system header, the CNC standard header, the data receiver identifier, the volume of data (in bites), and transferred data. A channel identifier defines for which integrated solution or component this data packet is assigned. Further, the segment data length is written, followed by the data block itself with a specific format for each application (see Fig. 2). This channel implements the transfer of heterogenous information for integrated subsystems and modules, which makes it a multi-task channel for interaction [4].

The suggested organization of a multi-task channel for communication allows to integrate new embedded applications into the CNC's core without additional modifications in a data packet: for each application, its size and content are arbitrary and indicated inside the packet. Thus, it is possible to transfer data for different integrated subsystems and modules, which increases the architecture openness of a CNC system as well as allows to formalize a universal interaction process for embedded solutions and the basic components of the system.

3. CNC OF THIRD-PARTY SOLUTIONS

The integration of a terminal solution into the interface part of a CNC system requires the development of a new terminal screen or mode operating as a part of terminal's standard software (operator's panel, manual control panel) or the development of a third-party application operating as a parallel process. A complete integration of a terminal solution can be used for visualizing the processes that are close to the basic processes controlled by the CNC system, namely, forming, PLC operation control, control of machining parameters, and so on. If an integrated application has to visualize the solution of any third-party or specialized tasks, it is reasonable to choose external terminal solutions not connected with standard visualization means of the CNC system [2, 4].

The CNC core is able to perform a complete integration of a real-time solution directly in the core's software or its parallel operation. Real-time solutions are directly integrated into the core if their operation is connected with the operation of the CNC basic modules, such as the modules of channel, axis, file system, or PLC. In the cases of integrating an additional functionality, it is reasonable to use external real-time solutions, i.e., the applications and libraries operating independently of the core but on the same computer. Also the implementation of an external real-time application allows avoiding the influence of possible errors and failures in an integrated application on the core operation. Note the requirement for executing an external real-time solution on the same computer with the system's core, in contrast to the external terminal solutions that can use the third-party computing means. This requirement has a natural reason as follows. If external real-time solutions are running on the third-party computing machines, it is impossible to guarantee rigid real-time operation for data transfer from the core to an integrated module and also for command transfer from an integrated subsystem to the system's core [4, 6].

Thus we single out four basic integration schemes of third-party solutions into a CNC system (see Fig. 3). An appropriate integration scheme depends on the solution architecture and its tasks.

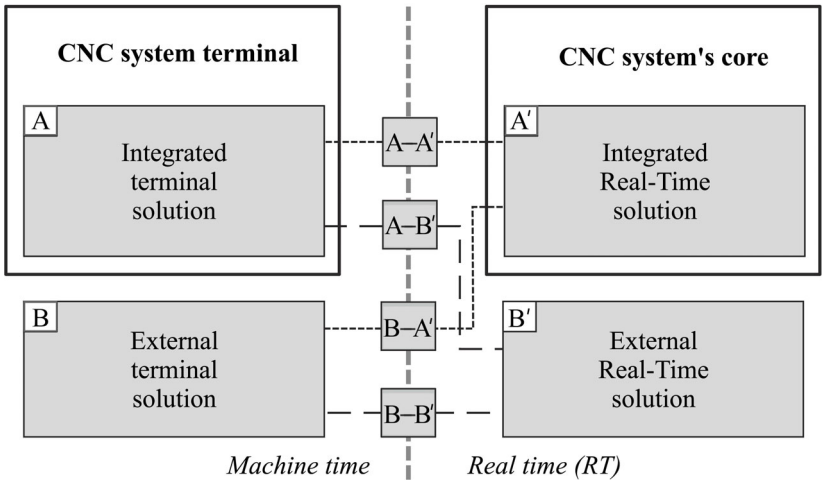

Fig. 3. Basic integration schemes of third-party solutions into CNC system.

A solution completely integrated into a CNC system (A-A') is generally used for improving and enlarging the functionality of the existing operation modes of the system, e.g., for visualization of forming processes. If the operation of an integrated application is connected with the operation of basic modules of the system core, then one can use a partially integrated solution with an external terminal application and an real-time application integrated into the core. For example, such a solution is a software-implemented controller for the cycle logic devices operating in the system's core but with an external terminal editor for control programs coding and debugging [4].

A CNC system may solve additional complicated technological tasks (e.g., permanent cutting tool diagnostics) using the scheme of partial integration: after integration of a new screen into the terminal part of the system, the machine is executing the integrated real-time application parallel to the core. In this case, the current processes are visualized by standard terminal means, and the basic control module in the real-time part is running independently of the system's core, without any interference in its operation.

Sometimes, one can choose the integration scheme of a completely external solution (B-B') for solving additional tasks both in the terminal part and core of a CNC system.

4. INTEGRATION OF CUTTING TOOL CONTROL AND DIAGNOSTICS SUBSYSTEM INTO CNC SYSTEM AXIOMA CONTROL

Diagnostics and control of machining processes and technological equipment are an important aspect of any hi-tech production. Diagnostics aims at maintaining a required level of reliability as well as at satisfying the requirements of safety and efficient utilization of products. Cutting tool diagnostics allows preventing tool failures and reducing the time for tool change, which increases productivity and also the reliability of system operation. Cutting tool diagnostics represents a topical problem for the CNC machines because the basic process of machining is performed without human participation.

Most cutting tool diagnostics systems in the course of machining do not support operation as a part of a CNC system and are represented as separate computing modules. As a result, machining cannot be tuned directly during diagnostics. Integration of a cutting tool diagnostics system into a CNC system allows for a well-timed interference into production in order to make proper adjustments directly in the course of machining by control commands for the CNC system. This solution uses cutting tool control based on detectors for different machining parameters that characterize the current state of cutting tools during production operations [7, 8].

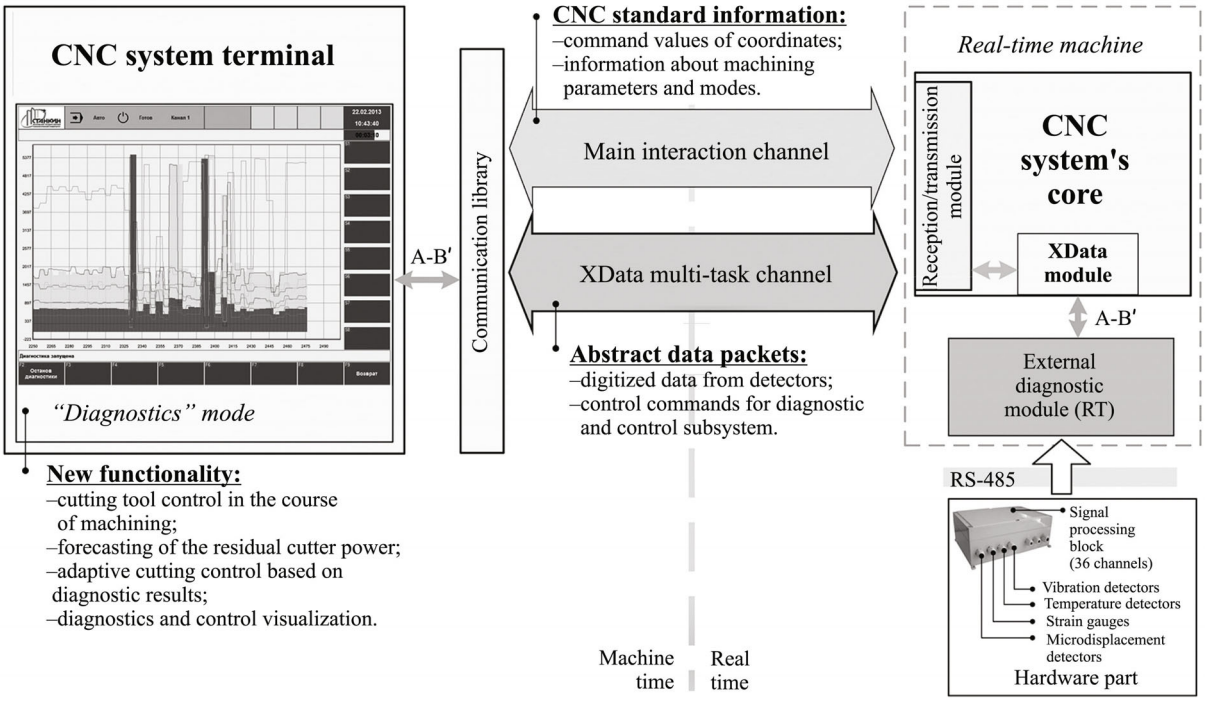

Fig. 4. Structure of cutting tool diagnostic subsystem integrated into CNC system AxiOMA Control.

Integration implies the division of a system into a terminal part operating in machine time and a diagnostic module operating in real time; the latter implements diagnostic algorithms and adaptive control of machining by interaction with the system's core. An appropriate integration scheme was chosen taking into account two factors: (a) control of the diagnostic process from the standard system's terminal and (b) the degree of influence of the real-time module on the core's operation. As the diagnostic real-time module has a completely independent operation with respect to the core, it was implemented in form of an external real-time module. This approach guarantees the independence of the core's operation from the real-time module of the diagnostic subsystem, securing the core against sticking or possible problems with the diagnostic subsystem. A special mode for diagnostics monitoring and control is created in the CNC system's terminal, which eliminates the need for additional work stations and also improves the usability the diagnostic system. Thus, the optimal solution of the stated problem consists in a partial integration of the diagnostic subsystem into the control system according to the integration scheme A-B', see [4, 7].

The structure of the designed diagnostic subsystem (Fig. 4) includes external devices such as different-type detectors and associated signal processing devices as well as a CNC system itself; note that the subsystem is integrated both into the real-time and terminal parts of the CNC system [7, 8].

The diagnostic subsystem includes an external diagnostic module that has parallel operation with the system's core as well as a built-in special mode in the terminal part that visualizes cutting tool diagnostics for an operator.

The diagnostic module is located on the same computer with the system's core but is running as a single process in parallel mode. Such a solution allows to perform diagnostic functions in real time for a proper response to cutting tool processes; this is very important for modern hi-tech production. The diagnostic module is processing data from the detectors using the diagnostic algorithms; so it transfers a set of commands to the system's core for process tuning (supply, speed, tool position), commands for tool change and emergency stop.

Interaction between the terminal part and core is implemented through the main and multi-task channel for interaction. The main interaction channel transfers standardized data on CNC system operation, namely, the current command values of coordinate axes, supply values, spindle rotation speed as well as their corrections [4].

The data on current diagnostic processes is transferred between the terminal subsystem and external diagnostic real-time module through the XData multi-task channel. The specialized diagnostic information includes the current values from different-type detectors for further visualization in the terminal part as well as the commands for the diagnostic subsystem. The packets containing the detector data are transferred in the asynchronous mode with a given frequency. The commands for the diagnostic module are transferred in the synchronous mode.

Integration of the cutting tool diagnostic subsystem into the CNC system AxiOMA Control allowed to enlarge its functionality and implement permanent cutting tool control; to forecast its power and tune the machining process in the real-time mode depending on the diagnostic results; to visualize the diagnostic processes for operators [7, 8].

5. PLC PROGRAMMING AND ADJUSTMENT TOOLS: DEVELOPMENT AND INTEGRATION INTO CNC SYSTEM

As a rule, in CNC systems controllers are implemented by software means (SoftPLC) for solving logical tasks and performing different operations (tool change, machine's protective fence opening/closing, lubricoolant supply, operator's panel buttons, and others) [9].

SoftPLC operation as a part of the CNC system's knoware allows debugging PLC programs directly from the control system. Therefore the development of a software-implemented controller module and its integration into the CNC system as well as the development of a programming environment for SoftPLC are a topical problem. To solve this problem within the CNC system AxiOMA Control, we selected the integration scheme B-A' (partially integrated solution), see Fig. 5 and [10].

It is reasonable to implement the main (computing) module of the controller with a complete integration into the system's core for a direct interaction with other modules of the core during operation. The control program editor on the Function Block Diagram (FBD) language was implemented at the applied level for coding and debugging of the controller's control programs. The developed controller is able to operate as a part of the CNC system and also as an independent product; hence it is reasonable to implement the control program editor as an autonomous application that operates independently of the terminal part of the CNC system. In addition, the standardized interface of the terminal part can not provide users with a convenient tool for control program coding for the controller. The terminal part of the CNC system includes only the debugging mode of programs, i.e., the visualization of current input/output values of the controller [9].

The hardware part of the controller (input/output devices) is controlled through the CNC controller's module that operates in the real-time mode as a part of the system's core. The logic of all functional blocks is also stored in the controller's module. Before execution all data about a PLC program and also the configuration of all connected equipment are sent to the system's core from the external editor. In turn, the controller's module computes the input/output block values and generates signals for the input/output devices using specialized drivers.

The data between the control program editor and the software-implemented controller module that operates as a part of the system's core are transferred through the XData multi-task channel for interaction. For the execution of a PLC program in the system's core, it is necessary to transfer all objects used in this program, such as functional blocks, objects of inputs/outputs, connections, and user blocks. Besides, it is required to transfer specialized commands for program start/pause/stop. Integrating the software-implemented controller into the CNC system, we reduce the cost of logical

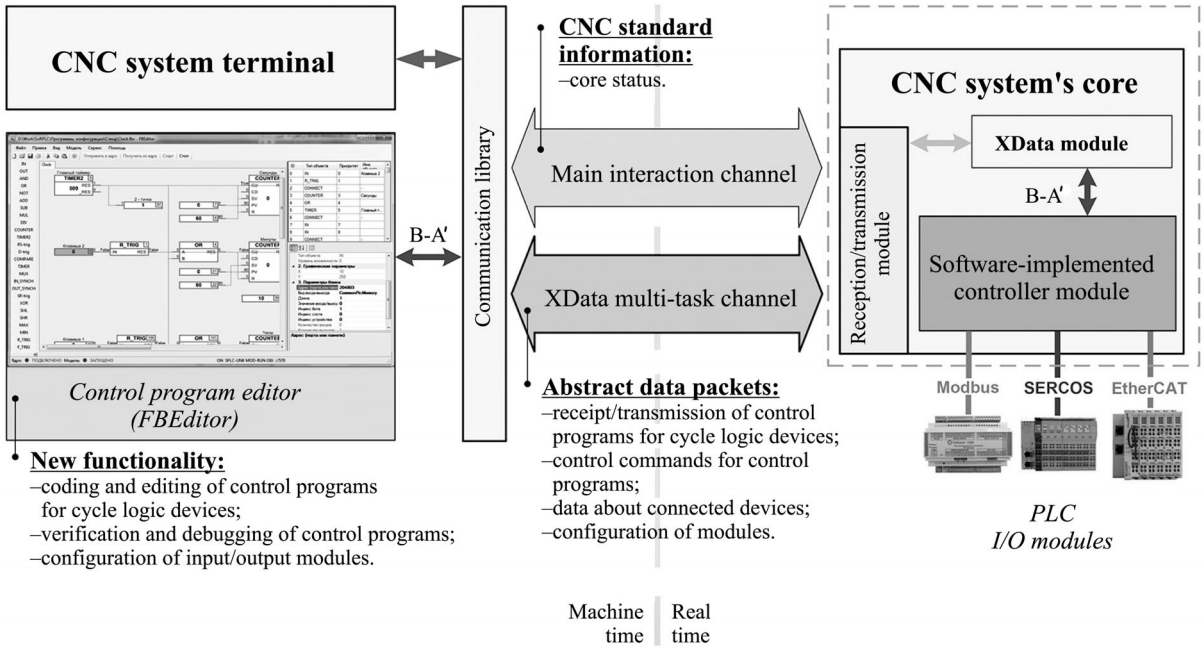

Fig. 5. SoftPLC program coding and debugging toolkit integrated into CNC system AxiOMA Control.

control task solving by eliminating the need for expensive hardware PLCs; in addition, we improve the reliability of equipment operation by a direct interaction between the controller and the CNC system's core [4, 10].

6. CONCLUSIONS

As indicated by the above analysis of the available architecture solutions of CNC systems, nowadays there exists no universal and systematic approach that would allow machine makers and end users to enlarge the functionality of CNC systems for implementing new technologies that are actively embedded into production.

In this paper, we have suggested an universal approach to the integration of the third-party and in-house solutions into a CNC system, including their interaction in the system. The described multi-task channel for interaction enlarges the functionality of a CNC system by integrating the third-party and in-house solutions in accordance with the requirements of reliability, performance and architectural specifics.

The new mechanisms have been applied in practice to design and integrate a cutting tool diagnostic subsystem into the CNC system AxiOMA Control as well as to design a toolkit for control program coding and debugging for a software-implemented controller, which confirms the universalism of these mechanisms.

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