Approach to the Diagnosis and Configuration of Servo Drives in Heterogeneous Machine Control Systems

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Abstract. During modernization of machines, development of prototypes, development or the retrofit of special modifications, a part of previously used components stay in the system. It is not rational to replace it. CNC system in this case should support the multiprotocol control and provide the possibility to configure mixed equipment. Modern servo drives have built-in diagnostic tools, they are designed for devices of the same manufacturer and cannot be used in heterogeneous environment. The article describes the approach of development and the use of special-purpose application tools for diagnostics, allowing to collect and analyze data simultaneously from the equipment of different manufacturers with various industrial communication protocols. The research of the application tools in the process of the startup of the milling machine Quaser with SERCOS III and EtherCAT servo drives is also presented. Solution for the milling machine with servo drives SERCOS III and EtherCAT is demonstrated; the results of machining the test part are analyzed.

Keywords: Multiprotocol CNC system · Servo drive diagnostic application tools · SERCOS III · EtherCAT

1 Introduction

In the field of industrial automation is often a need of modification or upgrading of individual machines or entire product lines of machine-tool plants [1, 2]. This need arise in the case of:

- transition to new equipment because of discontinuation of previously used components, such as servo drives;
- transition to other, cheaper components with similar specifications, but with other communication protocols;
- need for rapid prototype production of new machine modification to test technological solutions, when a part of equipment due to technical difficulties is advisable to leave unchanged; servo drivers in such systems can be controlled by different industrial communications protocols;
- application of ready-tested components and assemblies from previous models of machines in design of the new machine.

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There is a need for diagnostic and configuration of the machine, composed of multi-vendor equipment with heterogeneous interaction protocols. The latter circumstance is typical for small-scale production. One of the most difficult tasks is to configure and synchronize the interpolation of servo drives, controlled by different fieldbuses, so as to ensure the technological accuracy of the machine.

Manufacturers of technological equipment supply their own software tools for diagnosing and tuning servo drives and PLC remote I/O modules, such as a digital oscilloscope or logic analyzer, which can only be used with the equipment of the manufacturer [3, 4]. On machines with multi-protocol management [5] and heterogeneous actuating devices, these software packages do not provide the possibility to set up joint work of multiple devices.

Using during commissioning of machines external instrumentation such as oscilloscopes, ballbars, laser interferometers and trackers, allows us to estimate the parameters of the individual parts of the technological system [6]. These devices are used for final adjustment of the machine to achieve the specified accuracy of the positioning and performance. These devices are expensive, and often require special conditions to ensure an environment for its operation. By providing the ability to measure the resulting trajectory of the executive bodies of the machine, at the same time, they do not provide the opportunity to compare these data with internal data of the control system, which is critical in the development and debugging of new algorithms and control approaches.

In view of the above factors, there is a need to support, from the side of the CNC system, of multiprotocol management and parametrization and debugging of heterogeneous hardware component in the machine. The paper considers a unique solution for configuring and synchronizing of the SERCOS III spindle and EtherCAT feed drives on a 4-axis milling machine.

2 Architectural Model of Data Collection Subsystem

NC system kernel getting all necessary information about the logical state and motion parameters of servo drive, which is required for diagnosis purposes and control loop parameters adjustment. The numeric values of these data in NC kernel are updated with a sufficient frequency, equal to fieldbus cycle time for most of parameters.

If additional signals from servo drive side not relative to drive control procedure should be analyzed, they can be temporary added to a cyclic telegram transmitted between drive and CNC system [7, 8]. Some of industrial fieldbuses, such as SERCOS III [9], provides special mechanisms of transmitting the lists of selected parameter values, which can be configured on the flight without passing the device into parametrization mode.

For a user-configured measurement points a special mechanism is presented, which allows real-time recording of values of almost any memory area of SoftPLC controller and NC kernel (Fig. 1). This provides the NC kernel developer with the powerful support tool for debugging and interaction processes adjustment in a modular NC kernel system.

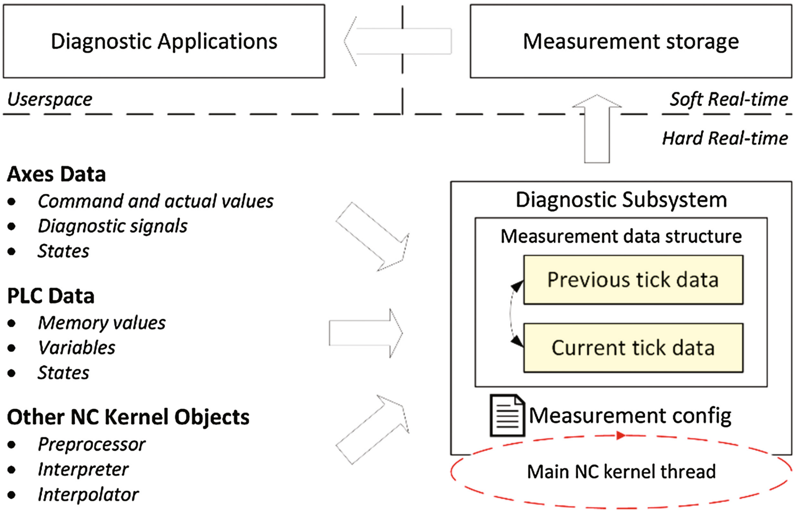

Fig. 1. Architectural model of special-purpose tools for diagnostics and configuration.

Measurement data collection in diagnostic subsystem is made in context of main NC kernel thread. Meeting the requirements of hard real-time functioning applies the corresponding restrictions on the software and architectural solutions can be used on this level.

In particular, the list of signals was defined, composed mostly of parameters relative to axis motion control process (actual and command position, velocity and acceleration for each drive), which is recording regardless to measurement configuration. Signal point for each of these parameters is created in special buffer any time when parameter value changes in CNC system course of work by the help of special inline wrapper functions, which is used in NC kernel code instead of assignment operators. User defined measurement points are recorded once at the end of main NC kernel cycle.

To prevent negative performance effects of cross-thread blocking recorded data are stored in switchable double buffer, each containing the array of measurement points. On each NC kernel cycle one of these arrays is used to store new signal point values, another one at the same time should be read and stored by less priority thread, which serves the measurement storage.

All the actions related to measurement recording are made in hard real-time thread regardless of the fact, whether the measurement is started or not. This allows avoiding the computation load bursts in main NC kernel thread. Measurement control functions, such as starting, stopping, collecting and sending data to user interface diagnostic application, are made in measurement storage software components, which work in soft real-time mode.

Measurement storage software components accumulate signal points in a buffer of configurable length of 10 MB to 100 MB, allowing to continuously record data for a long period of time (up to 10 min for a single axis movement) with a sampling time of 1 ms.

Around 30 signals for each NC axis and additionally up to 128 user configurable measurement points are stored.

Application of described technics in core software components of diagnostic subsystem result in increasing the computation load of main NC thread for just 3–5% depending on hardware platform used, which is quite acceptable.

3 Structure of Heterogeneous Technological System by the Example of Quaser Milling Machine

The prototype model of Quaser high performance milling machine center is the example of heterogeneous technological system. The machine is manufactured under a license, certain parts of it, primarily the control system, is being localized and replaced by domestically produced.

Linear and rotational feed drives where replaced with cheaper but powerful enough localized EtherCAT servo drives (Fig. 2). Some machine equipment, such as motor and servo drive of milling spindle under SERCOS III interface [10, 11], EnDat 2.2 linear measurement encoders and tool changing mechanism, remains unchanged at current stage of localization. Multiprotocol capable NC system AxiOMA Control is used to simultaneously operate the equipment under different industrial fieldbuses [12, 13]. The configuration of the machine parameters in the CNC kernel allowed controlling the spindle using the SERCOS III protocol and the servo drives with the EtharCAT protocol with 1 ms interpolation cycle. This ensures the execution of technological operations that use drive control on both protocols simultaneously. For example, threading with a tap (without a compensating chuck) or with threading tool, when the spindle needs to be switched to the rotary axis and interpolated together with the feed drives.

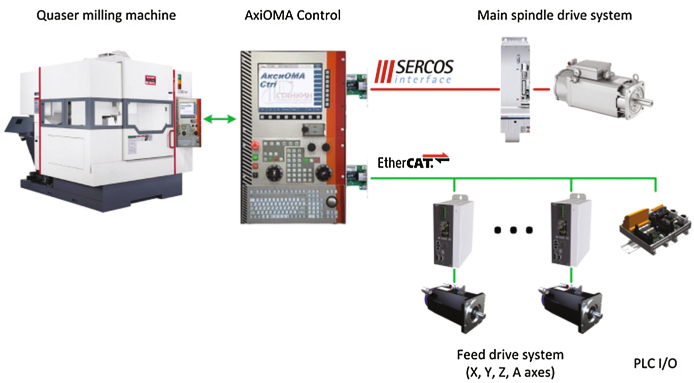

Fig. 2. Quaser machine heterogeneous machine control system.

4 Application of Software Tools for Diagnostics and Configuration for Quaser Machine

On the basis of developed software tools for diagnostics and configuration a set of user interface applications for machine and NC system commissioning was developed.

Digital oscilloscope application is intended for visualization of measured signals in time, allowing to analyze in details the behavior of transient processes in drive subsystem. Due to measurement recording process takes place in NC kernel, actual servo drive position and velocity signals are available to be analyzed along with internal NC kernel variables used in motion control process. The toolset supports the functionalities of scaling, using of cursors to obtain exact parameter values of measured signals, possibility of combining position signals from the set of axes to visualize path of motion in space according to kinematic configuration of machine.

Incremental drawing mode allows rating of different aspects of machine axis motion control process and observing the response of electromechanical drive system on control loop parameter changes. Signal points in this mode are collected at slower rates, than in regular measurement recording mode, number of simultaneously displayed signals is also limited. Only values of displayed on screen signals are being stored in this mode. Collected signal points are being combined into medium sized packets of total length up to 100 ms and then transferred to user interface application, optimizing the utilization of data transfer channel between NC kernel and terminal applications. For a diagnostic application such a delay is not critical and doesn't affect information perception by the operator.

Figure 3 illustrates the usage of incremental drawing oscilloscope application for commissioning of position loop regulator proportional coefficient of SERCOS III milling spindle drive for its usage in position control mode, in example for workpiece measurement cycles. The value of position error between command and actual axis position decreases as a result of parameter value tuning.

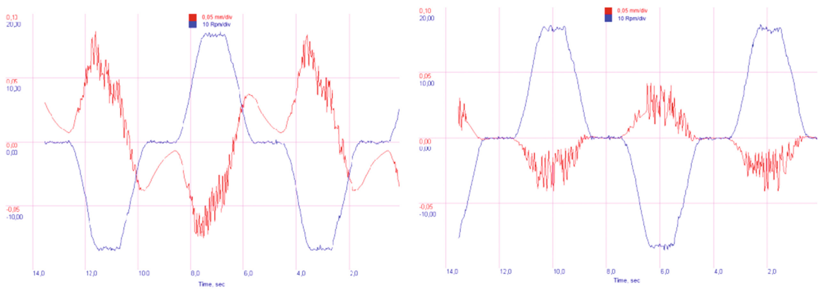

Fig. 3. Oscilloscope in incremental drawing mode: (a) non-optimal settings of position control loop; (b) system response to parameter adjustment first picture.

Circular test is defined by ISO 230-4 standard and being used in drive system commissioning for the purposes of minimization of machine motion contour errors by equalization of axes dynamic response.

Special purpose NC program is being executed in this mode, performing motions of contour entry and exit, circular motion, triggering the beginning and ending of measurement. To analyze contour diagrams diagnostic application provides a set of utility functions, such as changing the contour error scaling, source signal filtering for digital noise smoothing, automatic detection of movement direction (clockwise or counterclockwise), saving and loading measurement results, comparison of two diagrams to rate the effects caused by change of motion control parameters. It should be noted that in distinct from using of external measuring devices, the developed tool allows to analyze not only the actual positioning of the axes, but also visualize the trajectory generated by the interpolator that gives the developer of CNC system important feedback during the implementation of new motion control algorithms [14, 15].

Figure 4 shows the example of circle test tool application for setting up the X and Y linear axes of cross motion machine table, controlled through EtherCAT communication protocol. Two circular motions were made in XY plane, one clockwise one counterclockwise, with radius of 10 mm and 1000 mm/min feed. Y axis of this machine is loaded heavily than X one, so as it carries the weight of mechanical system of X axis in addition to weight of table itself. Initial measurement (drawn in chart with semi-transparent lines) reveals the dynamic error along the circle up to 10 μm, caused by the lack of dynamic responsiveness of Y-axis drive. After increasing of the coefficients of the speed and current control loop in the drive the dynamic characteristics of the axes were aligned and the error along the trajectory decreased to 2 μm. The developed toolkit will allow to preventively determine the necessity of setting up complex technological equipment.

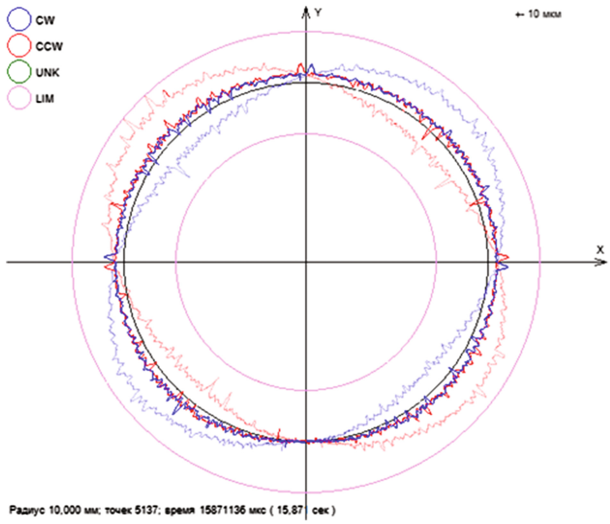

Fig. 4. Circle test application – a tool for compensation drives' dynamic response mismatch.

5 Practical Application of Instrumentation for Diagnosis and Adjustment of Servo Drives for Milling Machining Center Quaser 184P

The check of the described approach and correctness of the adjustment of the servo drives for feed and spindle axes of the Quaser MV184P milling machining center was made by processing a test piece (Fig. 5).

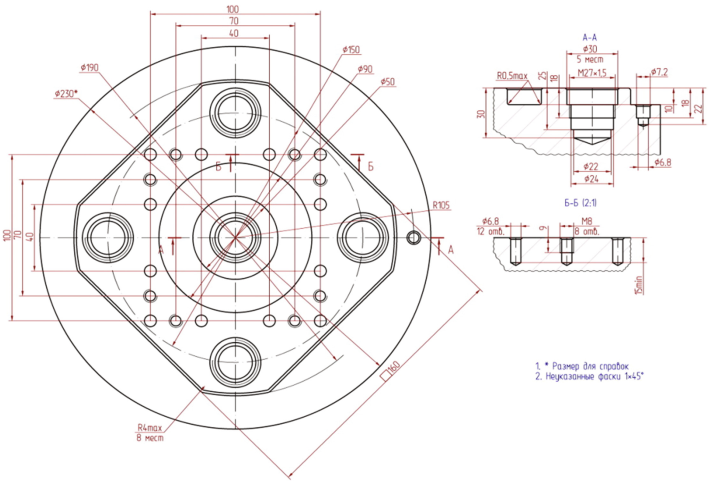

Fig. 5. Initial data for the test part for checking the adjustment of servo drives

To produce a test piece, a large number of technological operations are used, such as: milling operations along the contour (both linear and circumferential), flat surface machining, grooving, drilling and boring operations, tapping.

Thread cutting operations are the most complex and require synchronization of the spindle rotation and the movement of the linear axes, which in this processing center is realized by heterogeneous equipment controlled by various industrial protocols. Thread tapping is realized by synchronizing the rotation of the spindle in the axis control mode, as well as controlling the movement of the vertical axis Z. Thread cutting of a larger diameter hole is realized using a comb cutter. In this case, it is necessary to ensure synchronization of all axes, including the linear axis of movement X and Y.

To verify the reliability of the results obtained, metrological measurements of the treated test piece and comparison of its compliance with the specified standards and deviations were made. According to the results of metrological measurements, deviations from the maximum permissible values were not revealed, which proves the usefulness of the developed toolkit.

The presented results of measurements of the test part indicate the expediency of using the approach proposed in the work, which allows to collect and analyze data from various technological equipment and to adjust their synchronous operation, which allows achieving the necessary accuracy when manufacturing complex products on such machines.

6 Conclusion

The formalization of the basic concepts of tools for diagnostics and configuration of servo drivers, a properly chosen software framework and openness of the CNC architecture allow you to create software solutions that are not tied to specific manufacturers of technological equipment. Using such techniques allows configuring the machine components both individually and in their joint operation.

Application of tools for diagnosing and commissioning of servo drives in heterogeneous systems management does not rule out the use of external tools for machine fine tuning. The results of the research were checked and confirmed for the test part.

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