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Trends in the Numerical Control of Machine-Tool Systems

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Five classes of Hi-End numerical control systems may be distinguished in terms of their architecture. The first class is computerized numerical control (CNC), based on a PC. In the second class, PCNC-1 (Personal Computer Numerical Control), the computer is only used to operate the terminal.

The third class, PCNC-2, requires two computers: the first provides the core of the real-time numerical control system; the other operates the terminal. This class includes modern numerical control systems with the most powerful computer resources, such as SINUMERIK 840D (Siemens), Typ3-osa (Bosch), PA8000 (Power Automation, and Andronic 2000 (Andron); all these manufacturers are German.

The fourth class, PCNC-3, is based on a real-time computer and takes the form of a single-chip controller built into the terminal—for example, by means of a standard PCI bus. This class includes the PMAC numerical control system (Delta Tau, Britain) and also the PNC and MTX systems (respectively, Bosch and Indramat, Germany).

The use of Intel architecture involves the minimum cost in converting systems from one class to the next—for example, from class PCNC-2 to class PCNC-3 or the appearance of the PNC system based on the Typ3-osa system. However, if the real-time computer is based on RISC architecture—for example, in the SINUMERIK 840D and RA800 systems—transition from PCNC-2 to PCNC-3 is difficult, on account of the need to create appropriate circuit designs.

The fifth class of systems, PCNC-4, uses a single computer for the real-time core of the numerical control system and the terminal. Although they can perform more than 70% of control-system tasks, their development is slowed by the computer power of the processor, which is insufficient for multicoordinate machining of complex systems. The use of a smart controller—capable of handling smaller time intervals and independent autonomic control—is a step forward, to systems of the fourth class. Another approach is to use multicore processors and to assign the real-time tasks and the terminal to different cores, with the prospect of securing a separate core for the electrical automation tasks.

Another recent trend is the use of the SoftCNC system. Its benefits are associated with the openness of its software (contained on a compact disk and compatible with a standard PC) and the use of ready-made hardware.

Analysis of the current market for numerically controlled machine tools shows that Hi-End numerical control systems have PCNC-2 or PCNC-3 architecture. Hi-End systems have the following characteristics.

(1) Openness. They provide the designer and the final user with the possibility of implementing the required technology and incorporating applied software in the numerical control system.

(2) Multichannel structure. Several control programs may be implemented in parallel using a single numerical control system. This property is most often utilized in multispindle machining or in the combined control of the machine tool and the loader.

(3) High-speed machining. For numerical control systems, this implies a short interpolation cycle and high machining speeds in each frame of the control program.

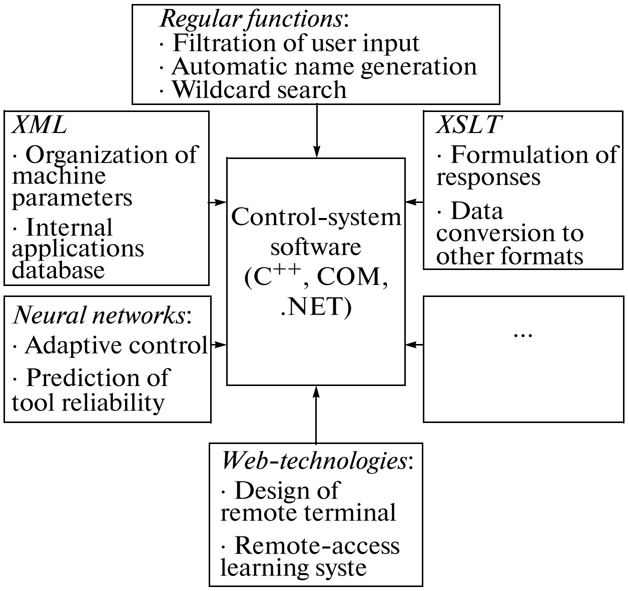
(4) Nanointerpolation. Interpolation is possible with nanometer increments in the calculations.

(5) The look-ahead algorithm. This algorithm permits machining of the contour with maximum possible supply and favorably reduces the speed in critical situations, so as to avoid unforeseen complications.

(6) Spline interpolation. Algorithms for cubic spline, Akima spline, NURBS spline, and polynomial interpolation, in combination with the look-ahead algorithm.

(7) Frame compression. The machining contour may be smoothed in the control programs by converting the linear frames to NURBS contours in processing the control programs.

(8) Remote control. Remote operator terminals may be designed, with remote diagnostics and adjustment of the numerical control system.



Promising development technologies.

(9) Grid functions. The numerical control system may be integrated into production control. The type of product is taken into account, the downtime is monitored, and planned repairs and maintenance of the equipment are tracked.

(10) Simulation of machining: 3D simulation of cutting for preliminary inspection of the control-program results, detection of inaccuracies, and reduction in machining time.

(11) Diagnostic functions. Such equipment includes a logic analyzer, inputs (outputs) of the electrical automation system, an oscillograph for tuning the supply drives, a frequency-diagram analyzer, and the circle test outlined in the ISO 230-4 standard.

(12) A high-level programming language and instruments for control-program development and debugging. This function is used in developing standard cycles and group technologies.

(13) Shop-program applications. Shop-level CAD/CAM systems permit the creation of control programs within the numerical control system, in parallel with the machining of another part. As a rule, these programs are intended for 2.5D machining.

(14) Artificial-intelligence functions for adaptive control, compensation of dynamic errors in the machine tool, and prediction of tool wear.

Control-system manufacturers tend not to offer individual system components but rather complex systems that simply need to be switched on, which are largely based on promising technologies for control-software development, as shown in the figure.

The actual development standard for the core of numerical control systems at present is the language C++; C is only used in rare instances. In developing the terminal, the languages C++, VB, and rarely Delphi are employed; often a mixed solution based on several languages is adopted. In the user interface based on an independent platform, the departure from Java solutions to .NET forms is tracked; the dominant development language is C#.

The component object model (COM) is fairly actively employed. This approach masks the hardware features in creating software and permits parallel development [2].

In organizing the machine parameters of control systems, XML (eXtensible Markup Language) technology is used. This approach permits the use of ready-made software to work with data. For a large number of data, operation is based on high-speed discriminators such as MSXML Parser, LibXMKL (Open Source), or the discriminator built into the NET system.

XSLT technology is used to generate responses regarding the state of the machine parameters or signals relating the diagnostic measurements and drive adjustment. The same technology is used to convert data from one format to another.

Web technologies are used to construct remote control terminals. Using a script and an Internet server built into the core, user-interface screens in standard browsers are generated.

The use of regular functions in control systems permits standardization in the verification and filtration of user input, automatic generation of names, and wildcard search [3].

Adaptive control and the prediction of tool reliability are based on fuzzy logic and neural networks.

HI-END NUMERICAL CONTROL SYSTEMS FROM THE WORLD'S LEADING MANUFACTURERS

FANUC (Japan), a leading manufacture of Hi-End numerical control systems, is expanding the use of artificial intelligence, under the rubric of smart solutions. These solutions are primarily directed toward increasing the machining precision. In such smart high-precision control systems, acceleration and braking is regulated, with preliminary counting of 40 and 180 data blocks for contour and nanocontour control, respectively. This ensures high-speed high-precision machining.

In the RISC system, regulation of acceleration and braking involves the preliminary counting of 600 data blocks. This ensures high-speed high-precision machining, with the maintenance of stable supply speed even for machining programs that consist of supershort linear segments. To obtain parts with high surface purity, in which practically no finishing is required, the contour-machining program may be supplemented by the nanointerpolation function.

The smart compensation system for the temperature deformation corrects for spindle deformation with respect to the Z axis. (The precision of the correction depends on the specific operating conditions.)

Artificial-intelligence principles permit the construction of a system for automatic monitoring of the tool's state (wear)—a system for regulation of the tool's lifecycle. This system tracks the operating time and frequency, with automatic modification in the event that the required operational parameters are exceeded. The built-in system for taking account of tool wear determines the actual load by means of the corresponding load to the spindle's servo drive. This permits optimization of the tool's working life.

The great effectiveness of these smart solutions ensures parallel use of the compensation system for impact perturbations and vibrational perturbations, which automatically corrects the supply in the event of impact perturbations of machining.

In FANUC systems, the latest HRV technology in digital control of the spindle's servo drive is successfully combined with virtual prediction of the machining cycle, with corresponding reduction in the error due to delay of the servo drive and maximum precision of the tool trajectory.

The FANUC 30i/31i/32i MODEL A numerical control systems permit the control of ten channels, 32 axes, and eight spindles. The maximum number of interpolated axes is 24.

The SINUMERIK 840D/Di sl (Solution Line) system—developed by Siemens, a world leader in industrial automation and systems—has an expanded open architecture, permits spline interpolation and frame compression, and includes the ShopMill and ShopTurn support programs, which permit simulation of machine-tool processes. In addition, it includes a startup and debugging utility for the initial stage of operation and a motion-control information system for the coordination of transportation, positioning, use, abbreviation of preliminary and final operations, reduction in downtime, simplification of troubleshooting, and optimal integration of the machine tool in the electronic data-analysis system.

The number of controllable axes in the 840D/Di sl numerical control systems is 64.

Heidenhain (Germany) produces numerical control systems for the support of the technological process, with a powerful set of machine-tool cycles and the CircleDesign tools for their development.

The Expanded Look-Ahead function, with a 1024-frame buffer, permits timely identification of changes in the direction of tool motion, for subsequent correction of the acceleration and braking. Advanced feed control (AFC) regulates the contour speed along the trajectory as a function of the percentage of spindle power employed. The DriveDiag and TNCopt utilities permit diagnostics of the drive components and initialization of the digital control loops.

The Heidenhain numerical control systems considerably expand the scope of machine-tool systems by means of the TeleService tools for remote diagnostics, monitoring, and control of the numerical control system, the TNCremoPlus utilities for data transmission between the numerical control system and the PC; the RemoToolSDK development tools based on a COM system and ActiveX technology for access to the core of the numerical control system; VirtualTNC components for the control of virtual machine tools, which are used to simulate machine-tool operation; and 3D functions monitoring collisions and the appearance of imprecision in implementing the DCM (dynamic collision monitoring) control program on the machine tool.

The Heidenhain iTNC-530 Hi-End numerical control systems, intended for the machining of free surfaces, permit the control of 13 axes during the processing of a frame (0.5 ms). They offer the option of using a numerical control system with two processors and a Windows XP operating system.

The common MTX Advanced numerical control systems (developed by Bosch Rexroth) has 64 controllable axes and 12 control channels (and up eight either interpolated axes per channel); is capable of calculation and interpolation with nanometer resolution; includes the IndraWorks View 3D module for three-dimensional visualization of analysis of the control process and the changes; and includes the IndraWorks machine simulator modules for simulation of the machine-tool peripherals connected to a PROFIBUS bus.

The system has a scaled communications platform ensuring access to the system's open architecture; uses the Pascal-like CPL (Custom Programming Language) higher-level programming language; and is equipped with tools for the development and debugging of control programs in that language. The Cycle Time Analyzer tool records the flux of commands in the numerical control system, the events from the PLC, the signals from the drives, and the signals from the machine tool's peripherals. The results are plotted as a time diagram.

The CNC 8070 numerical control system is a Hi-End system produced by FAGOR. It performs interpolation with nanometer resolution, high-speed analysis of frames and PLC commands, and high-speed analysis in lathes and milling machines. The use of postinterpolation filters yields surfaces of any geometry, cleanness, and precisions. Special algorithms for high-speed machining optimize the process so as to obtain maximum speed, with a smooth contour and the best surface finish.

The system has open architecture and is compatible with a PC and an operator interface based on Windows XP; this permits complete adjustment and adaptation of the user interface for specific problems. The system permits control of up to 28 interpolated axes and, correspondingly, up to four spindles, tool magazines, and functional channels. Several 8070 numerical control systems may be combined into complex systems on the basis of the Ethernet.

The system is equipped with a high-level programming language; a spline interpolator (Spline, ASPLINE); a standard cycle editor; a system for solid graphics simulation; a remote-diagnostics function for preventive maintenance of the equipment; an execution-time estimation function; and setup and startup tools, with an oscilloscope function, body programs, peripherals testing, and a logical analyzer.

The Mitsubishi (Japan) M750 two-computer model is based on a computer with a RISC processor (for real-time problems) and an interface computer with a Windows XP operating system, connected by the Ethernet. The system supports the Complete Nano Control function, with a 1-nm increment of the interpolational computations and permits high-speed machining. Depending on the specific modification, it may accommodate up to four control channels and uses up to 16 controlled axes, of which eight are interpolated simultaneously. The servo drives are controlled by a high-speed optimal network. The system assures the processing of up to 151000 frames per minute in pure technological operations. The iQ Platform, based on a gigabyte Ethernet, combines the individual controllers (regarded as integrating internal buses) into a single control system.

SSS (supersmooth surface) control and the maintenance of constant machining, regardless of the geometry, are based on algorithms for optimization of the acceleration and braking; compensation of the free play and nonuniformity of the drive screw; spline interpolation (cubic spline and NURBS); and automatic angular recognition.

OMR (optimal machine response) control ensures correction of the errors associated with deformation of the coordinate; synchronization of the servo-drive and spindle motion by taking account of the network delay of the commands; and minimization of the influence of vibration.

Prevention of collisions in the course of machining (five-axis machining control) takes account of a model of the machine tool, the relative position of the part, and the tool trajectory. If there is a risk of collision, the drive is stopped, and the danger spot is highlighted in the 3D model.

The system is equipped with a module for machining-time calculation, an NC Configurator module for adjusting the parameters of the numerical control system, the tool parameters, and the global variables; NC-Designer software for creating user interfaces; a remote terminal (NC Monitor module) at a PC, permitting Ethernet control of the numerical control system; and tools for creating milling and lathe control programs (NAVI MILL, NAVI LATHE) at the program PC.

Automatic adjustment of numerically controlled drives by the MS Configurator module assumes the construction of body diagrams, adjustment of the speed and acceleration feedback loops, adjustment of the resonant-frequency filter, and construction of a peripherals test and oscillograms of the servo-drive signals. NC Explorer software permits connection of the components to the numerical control system through the Ethernet and transmission of the technological programs. The Factory Automation Solution module permits integration into shop-level networks and also in the MES (Manufacturing Execution System) and the ERP (Enterprise resource planning) system.

Despite the lack of Russian Hi-End numerical control systems, Russian manufacturers have been making progress toward this goal. Success will depend on the correct choice of the architecture and the technologies employed.

Balt Sistem and Modmash-Soft are vigorously competing in the Russian market for inexpensive universal systems. The FlexNC (OOO Stankotsentr) and IntNC (INELSI engineering center) systems are based on the DeltaTau motion controller, which does not permit monitoring of the core functions [4].

The WinPCNC numerical control system (developed by Stankin Moscow State Technical University) performs the complete set of spline interpolation (cubic, Akima, and NURBS splines) but its applicability is limited by its lack of multichannel structure [5].

Note, in conclusion, that the price range of imported Hi-End numerical control systems begins at 15000 euros for the basic configuration and may reach 40000–70000 depending on the configuration required; the price of the drives is not included in this total. This price is unsurprising if we take into account that the average manufacturer of control systems has a development department with a staff of 70 and invests 300 person-years in numerical control systems every year (including ancillary projects). Most of the systems produced have been in evolution for more than 10–15 years, which provides certain benefits in terms of competitiveness.

The successful development of a Russian Hi-End numerical control system depends on correct development of the architecture; and appropriate selection of the development technology. A task of this magnitude is beyond the scope of any single company and requires the combined efforts of the best minds in academia and industry.

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