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# Diagnostics of Cutting Tools and Prediction of Their Life in Numerically Controlled Systems

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Diagnostics of cutting tools and prediction of their remaining life must be regarded as a priority in numerically controlled systems, where the operator does not intervene in the process, which must be completed without fracture and replacement of the tool [1, 2]. The problem is that, even within a single batch, tool life may vary widely (by 15–35%). If the life is determined on the basis of the worst tool in the batch, the most durable tools will utilize only 65% of their available life; that clearly results in unnecessary expenditures on tool replacement [3].

The production of parts compliant with current quality standards requires continuous monitoring of the machining processes. Commercial systems mainly focus on the diagnostics and monitoring of tools, without predicting their remaining life, and can only be used with the numerically controlled systems for which they were developed. The extensive research on the prediction of tool wear is not aimed at real-time operation [4].

## ANALYSIS OF EXISTING DIAGNOSTIC SYSTEMS

The range of systems for assessing the reliability of automated machining may be attributed to the different criteria adopted in evaluating tool wear and the lack of a unified approach. Table 1 summarizes commercially available autonomous diagnostic systems.

It is evident that the available non-Russian systems largely focus on the diagnostics of tool wear and the identification of the time of tool failure, so as prevent serious fracture of machine-tool components. Real-time prediction of the tool's remaining life is not a goal. There are no Russian commercial systems for real-time tool diagnostics [5–8]. Our analysis permits the formulation of various requirements for a system capable of real-time diagnostics and prediction of the tool's wear in turning.

## CONSTRUCTING A MODEL OF A SYSTEM FOR TOOL PREDICTION AND DIAGNOSTICS

The diagnostics and prediction of tool wear may be divided into four phases.

The first involves data collection from the cutting zone, by means of tensometric sensors. (Other sensors may also be used, with corresponding changes to the diagnostic algorithm.)

The second phase is digitization and preliminary analysis of the signals, by means of autonomous devices or circuits built into the computer. As a rule, standard devices are employed, but they are designed for relatively fast processes. For example, for continuous measurement (within an interval of 10 min) of the cutting-force components by means of the National Instruments DAQ 6024E system, 600 MB memory is employed. The measured data are normalized (to eliminate random values of the signal), averaged, and sent to the diagnostic algorithm.

In the third phase, the diagnostic and prediction algorithm assesses whether the tool life is sufficient for completion of the next technological process; whether the supply must be reduced for successful completion of the next technological process; and whether the tool must be replaced to prevent fracture.

In the fourth phase, commands generated by the diagnostic algorithm are sent for execution in the numerical control system responsible for machine-tool operation.

In Fig. 1, we show a model of the system for real-time diagnostics and prediction of the tool wear.

This model corresponds to the architecture and the sequence of actions required for correct collection and analysis of the data from the sensors, with its subsequent utilization in various diagnostic algorithms.

The first step is the collection and analysis of signals from the instruments (such as the vibrational sensor, acoustic-emission sensor, and tensometric sensor) in the cutting zone. Those signals indirectly characterize the tool wear. On the basis of the RS-232 data transmission standard, the signals are corrected in the program core (the module for signal collection and analysis). The signals are converted to information that may be used by the system, which is stored in the form of a file (a correctable XML file) [9].

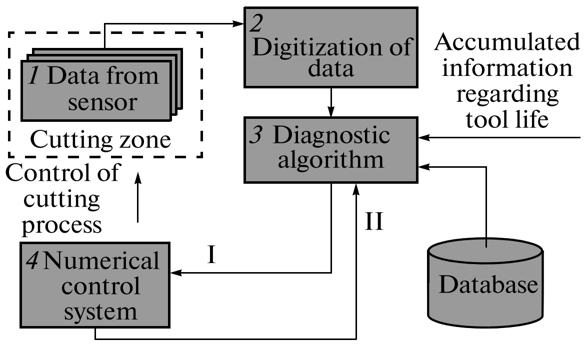


**Fig. 1.** Model of the system for real-time diagnostics and prediction of the tool wear: the database contains values of the diagnostic parameters for the tool–blank pair; control of the cutting process includes adjustment of the machine tool, discontinuation of tool operation and replacement of the tool, and correction of the machining conditions; (I) control (protocol for interaction with the numerical control system); (II) information regarding the control process (time of technological process).

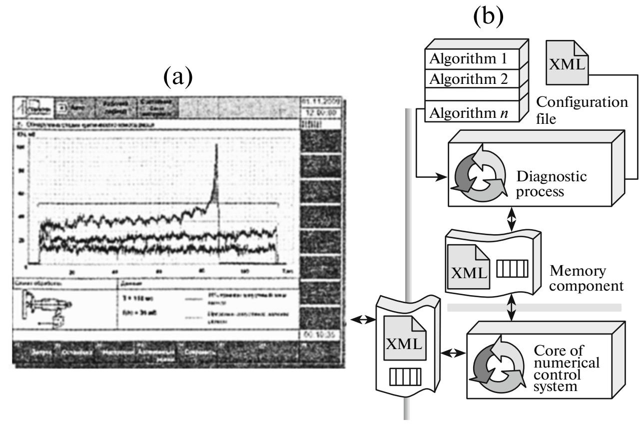


**Fig. 2.** Generalized architectural model: (a) display; (b) real-time operation.

For prediction of the state of the tool, the information is sent to the diagnostic-algorithm module, where corresponding control signals are formulated and sent to the numerical control system. The diagnostic coefficients employed in the algorithms are derived from test data. The test data are stored in a database, from which they are sent directly to the diagnostic-algorithm module. The control signals in the numerical control system may initiate machine-tool adjustments, discontinuation of tool operation, tool replacement, or correction of the machining conditions.

## GENERALIZED ARCHITECTURAL MODEL

The following requirements are imposed on the system for real-time diagnostics and prediction:

(a) real-time operation;

(b) compatibility with different sensors;

(c) compatibility different numerical control systems;

(d) the ability to change and adjust the diagnostic algorithms without changing the system’s architecture;

(e) functionality both as an integrated component of a numerical control system and as an autonomous external module connected to a numerical control system.

In Fig. 2, we show a generalized architectural model of the diagnostic subsystem within a numerical control system. The diagnostic module is triggered in real time as a separate process (the diagnostic process) in parallel with the core. The module may run on a separate computer (as an external module) or on the real-time machine (as an integrated component). This approach protects the core against any errors or malfunctions of the diagnostic module [10].

The diagnostic process operates within the framework of the triggering and execution of autonomous diagnostic algorithms. Possible algorithms are written in the XML file, and their starting parameters are determined. Each algorithm obtains the necessary information from the sensors and sends control commands to the core of the numerical control system according to the specified interaction protocol.

The graphical component of the diagnostic module is integrated with the operator interface. The diagnostic subsystem transmits data through the core of the numerical control system to the graphical component, in XML format. The graphical diagnostic component interprets the data from the diagnostic subsystem and displays it on the screen in graphical or text form.

## INVARIANCE OF THE SYSTEM ARCHITECTURE

The information obtained for predicting the state of the tool is sent to the diagnostic-algorithm module, where corresponding control signals are generated for the numerical control system. The diagnostic algorithms take the form of compiled libraries and may be loaded as necessary. The control signals in the numerical control system may, for example, initiate machine-tool adjustments, discontinuation of tool operation, tool replacement, or correction of the machining conditions.

The proposed architecture permits operation of the diagnostic system either as an integrated component of the numerical control system or as an external module.

*Operation as an integrated component* (Fig. 3) involves the analysis of information by diagnostic and prediction algorithms within the numerical control system. In that case, the program components

**Table 1**

| Parameter / System | PROMETEC PRomos (Germany) | NORDMANN (Switzerland) | ARTIS Orantec (United States) | MONTRONIX Diagnostic Tools (Germany) | Brankamp iM Board (Germany) | Brankamp CMS (Germany) | Stankin Machine Tool Diagnostics (Russia) |
|---|---|---|---|---|---|---|---|
| Display of results | Graphical? | Graphical? | Graphical? | Graphical? | Graphical? | Text only | Graphical display of force–time relation |
| Integration with numerical control systems | SINUMERIK 810D/840D | SINUMERIK 840D, REXROTH, FUNUC | SINUMERIK 840D | SINUMERIK 810D/840D | SINUMERIK 810D/840D | Autonomous module | SINUMERIK 840DAxiOMA CTRL |
| Diagnostic data | Forces $P_x$, $P_y$, $P_z$, energy, power. Vibrosensors | Forces $P_x$, $P_y$, $P_z$, energy, power. Remote monitoring. Vibrosensors | Forces $P_x$, $P_y$, $P_z$, energy, power. Vibrosensors | Forces $P_x$, $P_y$, $P_z$, energy, power. Vibrosensors | Operation with different sensor | Energy and longitudinal deformation | Forces $P_x$, $P_y$, $P_z$ |
| Real-time prediction | No | No | No | No | No | No | Yes |
| Real-time diagnostics of cutting tool | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Independence from numerical control system | Only the integrated version | Only the integrated version | Only the integrated version | Only the integrated version | Only the integrated version | Autonomous module | Possible operation as an autonomous module |
| Compatibility with different diagnostic algorithms | Not supported | Not supported | Not supported | Not supported | Not supported | Not supported | Yes |

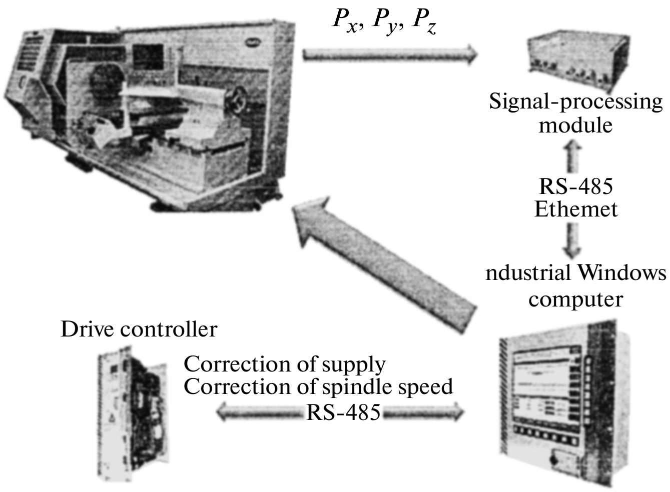


**Fig. 3.** Diagnostic system as an integrated component of a numerical control system.

required for diagnostics are built into the numerical control system [11]. The numerical control system interacts directly with the signal-processing module through an RS-485 or Ethernet interface.

*Operation as an external module* (Fig. 4) ensures that the diagnostic and prediction system is independent of the numerical control system. In that case, a single diagnostic system may be used with an infinite number of numerically controlled machine tools, from different manufacturers.

An automatic electrical controller permits real-time control.

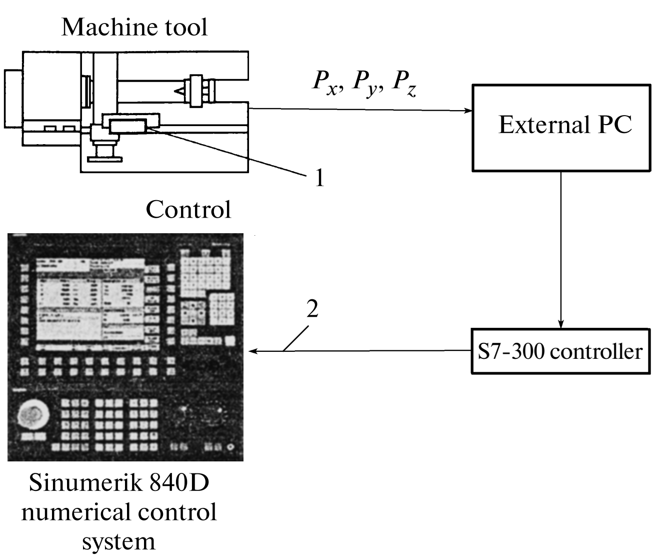


**Fig. 4.** Diagnostic system as an external module: (*1*) tensometric sensors; (*2*) correction of supply and spindle speed.

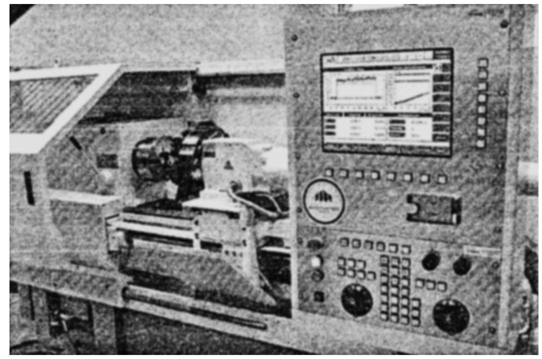

**Fig. 5.** Modernized 16A20 lathe with a diagnostic module integrated into the numerical control system.

## PRACTICAL ASPECTS

Correct determination of the cutting-force components requires calibration of the sensors and the compilation of tables for conversion from the sensor readings to values of the forces (Table 2). The calibration table (amplification factor 75) is formulated to determine the forces with respect to the three axes. The forces are measured with different amplification factors.

In tests, blanks are turned on a lathe by means of pass-through cutters. After each pass, the cutter wear is compared with the cutting force. This information improves tool monitoring.

In machining, it is very important to ensure that the tool can complete the next technological operation without replacement. At Stankin Moscow State Technical University, this is accomplished by monitoring and prediction of the remaining tool life in the course of machining [12].

Tests have been conducted on the modernized 16A20 lathe shown in Fig. 5 (produced by OAO Krasnyi Proletarii), with a specially designed numerical control system (consisting of servo drivers and an automatic electrical controller) and a system for collection of the diagnostic data (produced by Stankin Moscow State Technical University) [13, 14].

## CONCLUSIONS

Our analysis reveals a lack of systems for real-time diagnostics and prediction of the remaining tool life.

The proposed diagnostic system improves the dimensional precision of the machined blank and the final surface quality, with significant reduction in the rejection rate at quality control.

The chosen architecture is open and permits expansion of the system and the incorporation of new algorithms for predicting tool wear.

**Table 2**

| Load, N | Dynamometer reading | Inclination | Dynamometer reading | Inclination | Dynamometer reading | Inclination |
|---|---|---|---|---|---|---|
| | Measured force $P_x$ | | Measured force $P_y$ | | Measured force $P_z$ | |
| 10 | 0.1435 | 0.0065 | −0.24 | −0.02245 | 0.0205 | −0.00205 |
| 20 | 0.202 | 0.006175 | −0.476 | −0.023025 | 0.0755 | 0.001725 |
| 30 | 0.2495 | 0.0057 | −0.7195 | −0.02346666 | 0.1345 | 0.003116667 |
| 40 | 0.2835 | 0.05125 | −0.951 | −0.0233875 | 0.1925 | 0.0037875 |
| 50 | 0.3125 | 0.00468 | −1.195 | −0.02359 | 0.25 | 0.00418 |
| 60 | 0.337 | 0.00430833 | −1.419 | −0.02339166 | 0.311 | 0.0045 |
| 70 | 0.356 | 0.00396428 | −1.657 | −0.02345 | 0.3625 | 0.004592857 |
| 80 | 0.3765 | 0.003725 | −1.9 | −0.02355625 | 0.419 | 0.004725 |
| 90 | 0.3935 | 0.0035 | −2.132 | −0.02351666 | 0.4795 | 0.004872222 |
| 70 | 0.3595 | 0.00401428 | −1.9105 | −0.0236875 | 0.422 | 0.0047625 |
| 60 | 0.342 | 0.00439166 | −1.6815 | −0.0238 | 0.3645 | 0.004621429 |
| 50 | 0.319 | 0.00481 | −1.448 | −0.023875 | 0.304 | 0.004383333 |
| 40 | 0.29 | 0.0052875 | −1.209 | −0.02387 | 0.248 | 0.00414 |
| 30 | 0.2595 | 0.00603333 | −0.979 | −0.0240875 | 0.184 | 0.003575 |
| 20 | 0.214 | 0.006775 | −0.7405 | −0.02416666 | 0.125 | 0.0028 |
| 10 | 0.16 | 0.00815 | −0.4975 | −0.0241 | 0.0645 | 0.001175 |

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