Real-Time Diagnosis and Forecasting Algorithms of the Tool Wear in the CNC Systems

Georgi M. Martinov, Anton S. Grigoryev, and Petr A. Nikishechkin(✉)

FSBEI HPE, MSTU "STANKIN", Moscow, Russia
pnikishechkin@gmail.com

Abstract. The article proposes concept of solution development for diagnosis and control of real-time cutting tool in for edge cutting machining. The functional model of a diagnosis subsystem based on data reading from sensors of various types established in a cutting zone is developed. Algorithms of subsystem accepted signals processing and averaging, allowing define condition of cutting tool with defined preciseness and it's condition forecast in future are offered. Architectural features of subsystem program realization are exposed and solutions for integration into CNC system are described. Testing results of the diagnosis subsystem and its main algorithms during manufacturing processes control on turning machine tools are presented.

Keywords: Diagnosis · Forecasting · Cutting tool · Sensor · Signal processing · Algorithm · CNC system

1 Introduction

One of the most important aspects of modern automated manufacturing is reliability and process control of machining. Operating experience of the technological systems that are based on automated machines shows that their reliability is often insufficient. Dimension wear or chipping of the cutting tool are the most common damage, which reduces the accuracy of the technological system.

Today, similar problems in EU countries and the USA are solved, mainly based on statistical methods, tracking the work tool and using tool resource for 80-90%. The main problem is that, even within a single batch, tool life of Russian production may vary widely by 15–40%. In this case, the use of a statistical approach the risk of defects in products or tool breakage is significantly higher. It can lead to big financial losses, especially during prolonged treatment of the critical parts [1].

In this regard, during operation of the technological systems solved the problem of increasing the reliability due to the technical diagnosis. Diagnosis provides timely termination of machine operation or making corrections in his work, at the expense of an operational definition of condition failure. Diagnosis of tool wear provides an operating time of each tool to the actual refusal. Besides, a problem of diagnosing is not only definition of technical condition in which there is an object at present, but also forecast of technical condition, in which the object will appear in the following

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interval of time. Implementation of solutions, allowing to determine the current state of the cutting tool and to predict its state in the future, will reduce the percentage of defects, to increase productivity and reliability of all technological system. This solution should provide a guaranteed ending process of transition, the ability to determine the critical situation and to make the necessary actions to stop the process of processing or removal tool and ensure maximum resource utilization of the cutting tool [1,2].

2 Analysis of Modern Diagnosis Systems of the Cutting Tool

Most of realized systems for diagnosis can recognize the current condition and cutting tool failure. For today, there are many diagnosis systems, which realize control of machining process products in the automated manufacturing. Table 1 summarizes commercially available diagnosis systems.

Table 1. Analysis systems for the diagnosis tools wear from international manufacturers

Characteristic	Diagnosis system			
	PROMETEC Promos (Germany)	**Nordmann** (Switzerland)	**ARTIS Orantec** (USA)	**Brankamp CMS** (Germany)
Real-time diagnosis	+	+	+	+
Diagnosis data	Force, acoustic emission, power, vibration	Force, acoustic emission, power, vibration	Force, power, vibration	Acoustic emission, longitudinal deformation
Real-time forecast of the cutting tool state	–	–	–	–
Capability of the integration in CNC system	SINUMERIK 810D/840D	SINUMERIK 840D, IndraMotion MTX, Fanuc	SINUMERIK 840D	– (autonomic module)
Capability of the using of different algorithms	–	–	–	–

Commercial systems mainly focus on the diagnostics and monitoring of tools, without remaining life forecasting, and can only be used with the numerically controlled systems for which they were developed. Also, there are no Russian commercial systems for real-time tool diagnosis. Our analysis permits the formulation of various requirements for a system capable of real-time diagnosis and forecast of the tool's wear in turning [3].

An actual task is developing a universal solution that operates in real time and allows the diagnosis and forecast of the residual resistance of the cutting tool, as well as having the ability to integrate in the control without changing the core of CNC system.

3 Constructing a Functional Model of the Solution for Tool Forecast and Diagnosis

Correct work of the diagnostic system requires the definition its basic modules, their functioning and interaction with each other. Fig. 1 shows a developed functional model solutions for the diagnosis and forecast of the cutting tool state, reflecting the architecture of its construction and the sequence of actions for it to work properly [2].

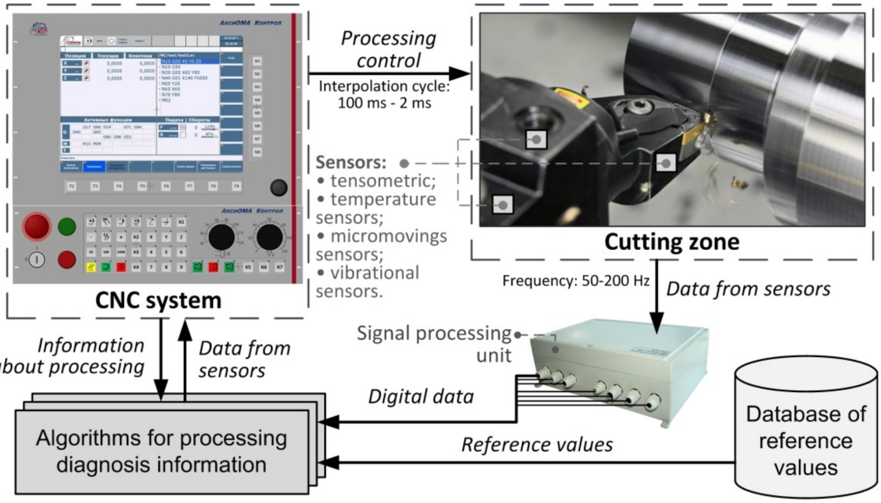

Fig. 1. Functional model of the solution for forecast and diagnosis of tool wear

The basis of the developed diagnostic solutions provided the use of a method based on the use of various types of sensors mounted in the cutting zone, and determining the current state of them, and the cutting tool in the forecast its remaining life (Fig. 2).

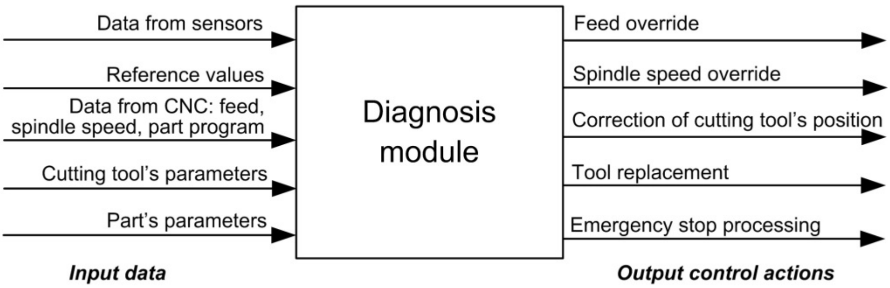

Fig. 2. Functional model of the solution for forecast and diagnosis of tool wear

The diagnostics and forecast of tool wear may be divided into four phases. The first involves data collection from the cutting zone, by means of sensors, which can characterize the current state of the cutting tool [4-6].

At present, it is proposed the use of four types of sensors:

– tensometric sensors – are used to determine the load on the cutting tool during machining in three axes;

– temperature sensors – are used for measuring temperatures in the cutting zone, as well as basic units of the machine;

– microsupply sensors – determine the deflection and displacement of the basic units of the machine during operation;

– vibration detector – are used to determine the level of vibration of the cutting tool and the basic units of the machine.

The second phase is digitization and preliminary analysis of the signals, by means of autonomous devices or circuits built into the computer.

Determination of the current condition of the cutting tool and forecast its of future condition is performed using specialized algorithms for information processing. The input data for diagnostic algorithms is a wide range of parameters and factors on which the algorithm determines the condition of the cutting tool and, if required, generates an output control signals, which are transmitted to the NC (Fig. 2).

Basic information are signals that come from the cutting zone and measured by various types of sensors. Calculations are based on previously obtained the reference values used to calculate the diagnostic coefficients, which in turn uses an algorithm. The data sets are stored in a database, where in block directly received diagnostic algorithms [7].

Control signals transmitted to the CNC system from diagnosis solutions could be:

– feed correction – is realized to maintain a constant load on the elastic elements of the machine in order to stabilize the elastic deformation and to reduce the risk of breakage of the cutting tool;

– spindle speed adjustment – to maintain the cutting speed in the optimal range for stabilizing the surface quality, stability of the cutting tool and to simplify procedures for the preparation of control programs;

– cutting tool's position correction – to improve the machining accuracy by compensating for the size of the cutting tool wear, thermal and elastic deformations of the machine manufacturing errors affecting the accuracy of movement of workers;

– tool replacement command– the command is executed when a critical tool wear to ensure the required quality of the product and to prevent accidents;

– emergency processing stop – the command is required to prevent damage to the mechanism of the machine and marriage details.

The proposed functional model allows diagnosis and monitoring of the cutting tool in accordance with various algorithms of data processing and transfer of control in the control system.

4 Development of Algorithms for Diagnostics and Forecast of the Cutting Tool State

Describing the operation of the cutting tool can be identified such a thing as its residual resistance, which is defined as the time it works until it reaches the limit value of wear. Work of the tool is possible and after time, however the probability of its refusal becomes high and unacceptable for the automated production. For determination of this parameter it is required to develop and realize the algorithm, allowing to estimate residual firmness of the tool at serial processing of a large number of the same details and, in case of impossibility of further processing with the set accuracy, to give out a signal to the operator and to stop processing.

In the presented work is offered the consideration of algorithm for determination of current state and forecast of residual firmness of the cutting tool by measurement of force operating on it at fair processing of a large consignment of the same products on machines of turning group.

When finishing the parts of details control algorithm should be applied only after detecting that the residual tool life is enough for the surface treatment once the details of the required accuracy and a given roughness.

Otherwise, the tool needs to be replaced before the end of treatment, leading to defects because of the trace left on the surface of the insertion of a new tool. Therefore, at fair processing, the algorithm of diagnosing, besides control, has to include actions of forecast of changes of a condition of the tool during processing of the following detail of the parts. Developed procedures necessary to control the cutting tool and forecast its residual resistance is presented in the Fig. 3.

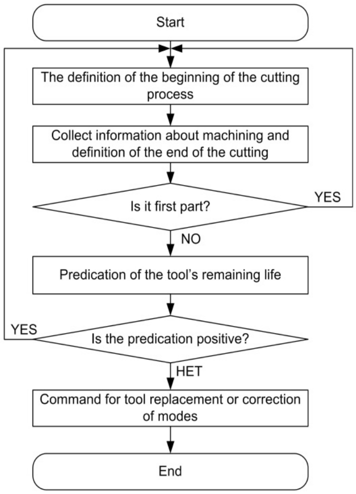

Fig. 3. Algorithm of the tool's monitoring and predict its remaining life

The processing of any part consists of the main periods: idling, digging, lead-out, and operating period – contact of cutting tool with part (Fig. 4). To solve the problem of determination of remaining life of cutting tool is necessary to analyze information from the sensors from the machine cutting zone during full contact of cutting tool with part (working period of machining). Processing data from the other zones is not required and can lead to significant errors in forecast of remaining life of cutting tool. To exclude unnecessary data from other processing zones are proposed algorithms to determine of the beginning and end of cutting another part.

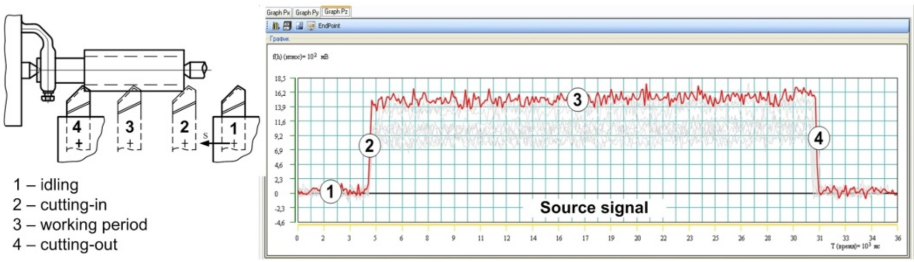

Fig. 4. Main periods of processing

Determination of the working period of the cutting tool requires finding zones change of a condition of the tool. To solve this problem, the received signal is approximated by the method of least square (OLS) and then made its differentiation. Approximation is performed by groups of digital signal values within the established period of time Δt_a, which are determined experimentally (Fig. 5, A). Group digital offset values for determining Δt_{a_1} produced by an amount equal to $1/f$ (f is a frequency of data collection). Then, the angular coefficient k is determined for each group. The set of all coefficients (k) is a differential signal from the originally received signal (Fig. 5, B).

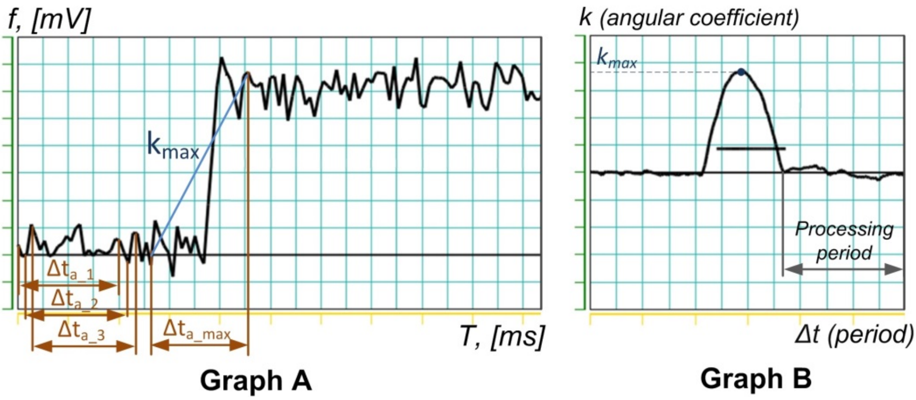

Fig. 5. Definition of the total working period of the signal by the method of least squares

Then, the diagnosis system receives two set points from the database: the minimum and maximum. If the value of the differentiated graph goes beyond of set points, the algorithm detects the initial and final positions of the entry and exit in the specified range of the signal level. During the received period of time is determined maximum and minimum signal level according to the cutting-in or cutting-out of the tool. The obtained values of the maximum and minimum suggests that the group of digital signal values for the period of time $\Delta t_{a\_max} - \Delta t_{a\_min}$ extreme values are in various states of the cutting tool [5,8].

The working period of the machining approximated by least-squares method and the general equation of a straight line is determined. Using of the slope of this straight line and the processing time of one part, remaining life of the cutting tool is determined.

When the level exceeds the limit value, the command a tool change is made. If the forecast for the next part is higher than a predetermined level adjustment mode, made a correction processing mode (Fig. 6).

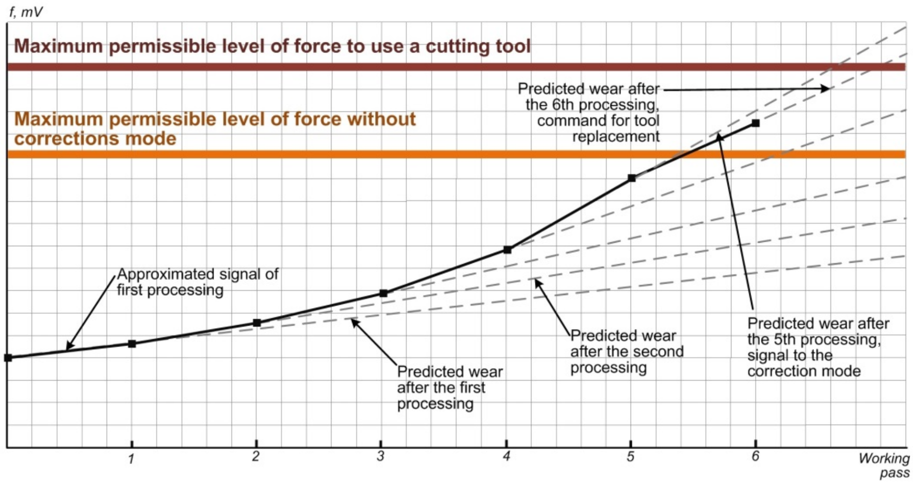

Fig. 6. Forecast of the state of the cutting tool using the approximate signal processing work periods

The developed algorithm of signal processing realizes the possibility of determining the current state of the cutting tool and forecast its resistance life in the future.

5 Software Implementation of Solutions for the Diagnosis of Tool Wear and Forecast it's Remaining Life

The variety of process equipment, types and modes of processing, types of cutting tools and materials of workpieces involves the development of a universal software solution with open architecture that allows the flexibility to modify the data processing algorithm, and integrate own algorithms. The proposed solution provides independence of external devices and data processing algorithms [2,4,9-11].

Software implementation of solutions for diagnosis and forecast of the resistance life of the cutting tool requires the determination of the basic modules and their interactions with each other. Develops solutions is offered to divide into four main modules: components manager, input module, the main diagnostic module, and output module. The UML class diagram of solution is presented in Fig. 7.

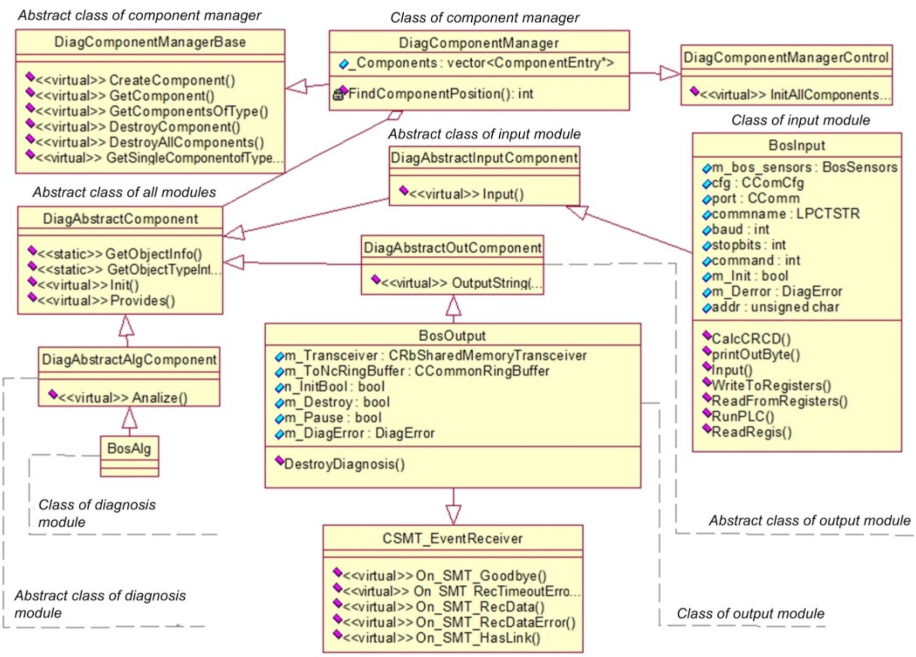

Fig. 7. The UML class diagram of diagnosis solution

Components manager is designed is intended for initialization of all modules solutions, and is configured by modifying the XML file. It allows to reconfigure the solution without changing the program code and recompiling the system.

Input module implements the interaction with external devices and produces initial processing of the received data. To facilitate communication system diagnostic modules produced cast data from the signal processing unit, to an internal format solutions.

Diagnostic module allows to process received from the input module information by diagnostic algorithms. Configure the diagnostic algorithm is also stored in the configuration XML-file, which allows to flexibly reconfigure the system without changing its programming code.

Output module implements the transfer of the core information and commands, received from the diagnostic module. In addition, it’s able to receive data and instructions from the kernel the control system. This is required to be able to control the system through a terminal diagnosis of CNC system, as well as to provide data on the current operation of the system.

Diagnostic solutions can be implemented as integrated in the CNC system solution and as the external solution. Integrated solution involves the processing information of algorithms of diagnosing and forecast directly in the control system, by integrating into it all the software components. External solution provides independence from the CNC system [3].

The integration process involves the separation of the terminal part (machine time), and real-time component that implements the diagnostic algorithms and adaptive control of the machining process by interaction with the core of the system. Computing module of diagnostic solution operates on the same computer as the kernel of the CNC system and communicates with it using shared memory. The solution allows to transfer to the kernel of CNC system all the commands: processing modes correction, the tool replacement or emergency stop processing [7,11,12].

In the terminal part of the CNC system “AxiOMA Control” was implemented specialized diagnostic mode that allows to visualize the diagnostic process operator to make management of diagnostic solutions, as well as display the main parameters of the treatment process (Fig. 8).

Fig. 8. The interface of terminal part of the diagnostic mode in the CNC system

The main terminal screen diagnostic solutions include visualization module signals coming from the cutting zone from different types of sensors, visualization component current command values of the coordinate axes, as well as a component to display the feed override / spindle speed override. The correction may be standard, and additional calculated in integrated in the core module according to the diagnostic algorithm [12-14].

6 Practical Tests of the Diagnosis Module Integrated into the CNC System

For justification of the practical importance of the developed solution, a series of tests, which included machining by pass-through cutter on the modernized lathe SA-700 (manufactured by Machine Tool "SASTA"). The machine is equipped with a complete control system: CNC system AxiOMA Control, the servodrives, the programmable-logic controller of electrics (PLC) and the developed in MSTU "STANKIN" data collection device (Fig. 9).

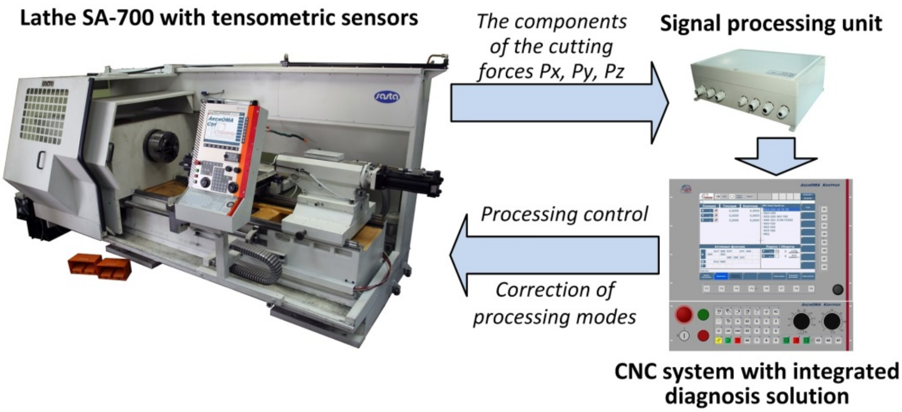

Fig. 9. Modernized lathe SA-700 with a diagnosis module integrated into the CNC system

Tensometric sensors were installed on the machine tool holder and that allow reading information about cutting forces in three axes. This information allows to carry out monitoring of the tool with high probability. For correct determination of the cutting force components is realized calibration of the sensors and the compilation of tables for conversion from the sensor readings to values of the forces [3,7,15].

Experiments consisted in serial processing of party of identical preparations until the message is displayed on the critical condition of tool wear. In this case, to demonstrate the efficiency of the system was made 12 passes to the full development of a resource tool (Fig. 10).

The graph shows that the loading which influence on the cutting tool is increased with time and indicating that the increasing tool wear. All the data were processed using the described diagnostic algorithm, and after the 12th pass was diagnosed the high level of tool wear.

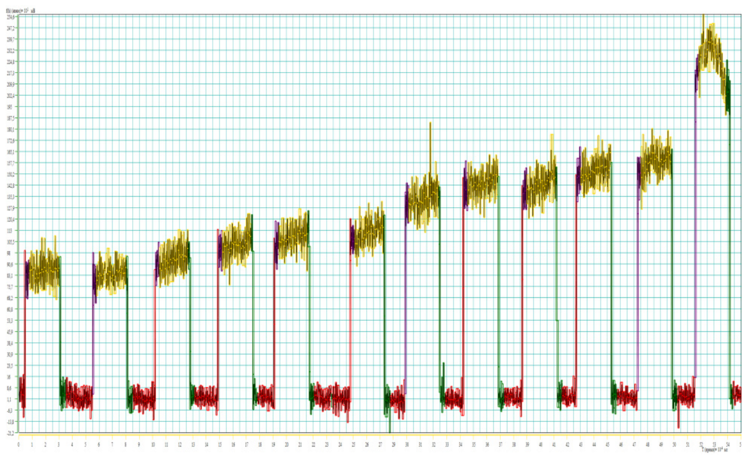

Fig. 10. Data from tensometric sensors during turning processing

To check the correctness of the tool wear definition after each pass measurement of tool wear was made by optical method and made the tables which confirmed association between wear size of a cutting tool and the received data from the sensors representing the making the cutting force.

Performed tests have clearly shown the accuracy of previously developed diagnostic algorithms and algorithms for forecast of the remaining tool life. The tests, which includes 12 passes, demonstrated that the operability of system and the predicted critical tool wear at the last pass [5,7,16].

7 Conclusions

The proposed solution for the real-time diagnosis and forecast of the remaining life of the cutting tool improves the dimensional precision of the machined blank and the final surface quality, with significant reduction in the rejection rate at quality control. The task of developing solutions for the real-time diagnosis and control of the cutting tool, and its integration to the CNC is solved. The chosen architecture is open and allows to expand the system to and integrate into it new algorithms for diagnosis and predicate of resistance tool life [7].

Integration of solution for cutting tool diagnosis in the CNC system “AxiOMA Control” extends its functionality and allows continuous monitoring the tool condition, predicting its resistance life, correction processing in real-time as well as the visualize diagnostic processes for operator.

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