About diagnostics of technical condition of metal-cutting machines

M A Vernezi*, A D Lukyanov, V V Dolgov, V V Zotov
Don State Technical University, Rostov-on-Don, Russia

*e-mail: slavikvernezi@mail.ru

Abstract. At present, scheduled maintenance prevails at production enterprises without taking into account its actual technical condition. This approach leads either to overspending of maintenance costs in the case of rare use of equipment, or vice versa, if maintenance is delayed, there is a risk of an emergency failure. Losses from the sudden failure of critical elements of machine equipment are costly for both the company's budget and its image. Therefore, the main task of technical services is to control and ensure a given level of reliability of metal-cutting machines by detecting faults at the early stages of occurrence, tracking the dynamics of the development of faults, determining and planning rational terms of repairs. This article discusses the most effective operational methods for diagnosing the technical condition of metal-cutting machine components.

1. Introduction
Reliability - the property of an object to preserve in time the ability to perform the required functions in the specified modes and conditions of use, maintenance, storage and transportation. To improve the performance of automated equipment, ensure the specified dimensional accuracy of manufactured products with a sufficiently low roughness of the processing surface, as well as reduce the risks of emergency failures of production equipment, it is planned to introduce a device for diagnosing the cutting process.

Research has shown that a significant part of the costs of manufacturing enterprises falls on the maintenance and repair of machine equipment. According to experts, they reach 7 ... 8 % of the total production costs [1]. Thus, one of the most promising methods of monitoring the state of technological equipment is real-time monitoring.

In addition, as a result of untimely maintenance of machine equipment, the quality of manufacturing parts decreases.

One of the reasons for this is:

1. wear of tools, accessories, or clamping chucks. When equipped with a blunted cutter or other substandard tool, it begins to remove the required amount of material worse. As a result, the reference dimensions of the product are not included in the tolerance field. When the Cams in the cartridge wear out, the vibration and beating increases, which in certain conditions are noticeable to the naked eye. If the workpiece is poorly fixed in the slot screws, it may shift under strong mechanical impact from the tool. This ensures that the geometry of the final product is broken relative to the planned parameters;

2. wear of guides, gears, bearing units, the appearance of backlash in the "lead screw – nut" pair. Visually, these problems are almost impossible to detect. To fix the problem, you must either change
the worn-out components, or adjust the operation of the machine at the program level by the amount of output;

3. Violations in the systems of control and management of the movement of the cutter. The reasons for these violations can be caused by various reasons. Accordingly, this diagnostics of CNC machines is already quite complex and requires special equipment.

2. Methods of dynamic diagnostics
One of the main requirements of the diagnostic system is the ease of integration into existing production facilities. The main control methods that meet these requirements are the following:

- Vibration method
- Electromagnetic diagnostics
- Temperature method
- Control of the consumed electric current

Diagnostics using the vibration method is performed using vibration sensors (accelerometer) installed on the diagnosed equipment components (bearings) [2]. The analysis of the obtained data consists in identifying the values of the amplitude of certain harmonic frequencies that indicate the nature of the fault. This method allows you to analyze a wide range of processes that occur in working machines: wear processes, propagation of shock pulses and electromagnetic effects. Using this method, you can diagnose about 23 parameters of mechanical wear and malfunctions of machine components and parts. Defects of each bearing are determined, including wear of the outer or inner ring, misalignment of the outer ring, wear of balls or rollers, runout or misalignment of shafts and spindles, wear of each gear, error of engagement of each transmission, wear of parts of a ball-screw pair: nuts, screw, balls, skewed ballscrew.

Methods of electromagnetic diagnostics allow you to diagnose the condition of the main drives of machine equipment. The principle of operation of this method is to measure electrical and magnetic values that are directly dependent on the progressive wear. These methods allow for accurate diagnostics, since the measured values directly depend on the defect [3]. One of the methods of electromagnetic diagnostics is the ESC method, in which the eccentricity is determined by the value of the EMF, by means of two measuring coils installed in the air gap of the stator and designed to measure the harmonics of the field with the number of pairs of poles. Diagnostics using this method is not possible without serious intervention in the design of the equipment, which is often impossible.

The method of thermal control consists in monitoring the temperature determined by the equipment node, which indirectly can be used to judge faulty and overloaded sections of equipment [4]. During the operation of the mechanism, increased heating occurs in the movable joints. These include bearing units and gears, power electrical contacts, Converter semiconductor installations, etc. Especially dangerous are the electrical connections in traction motors, between the transformer and switching devices. The introduction of infrared thermography reduces the monitoring time and increases its reliability.

Of the existing diagnostic methods, the most optimal is the current monitoring method, which consists in a dynamic analysis of the electric current consumed by the entire CNC system. The results of equipment monitoring are used to study the state of the controlled object and then evaluate it; continuously compare the state of the controlled object with the state of the reference (system model in computer memory); provide information to personnel about the fault location; organize the continuation of the system in the mode of gradual degradation, i.e. partial functioning of the system.

3. Spectral analysis of the current consumed by the main drive
Most modern diagnostic methods involve placing measuring devices directly on electric motors or taking the engine out of service for periodic routine maintenance, which is often difficult. The widespread method of vibration diagnostics is quite expensive and time-consuming, requiring the use of special measuring equipment and complex software. Recently, methods for diagnosing the state of electric machines based on monitoring the current consumed, followed by a special spectral analysis of the received signal, have been intensively developed in the EU countries, which allows determining the
technical condition of various engine elements with a high degree of reliability and predicting the remaining life [5].

The principle of operation of this method of diagnosis is that any perturbation to the electric or mechanical part of the motor and associated mechanism lead to changes in the magnetic flux in the gap of the electric machine and, therefore, to change the spectrum of consumed electric current.

This diagnostic method allows you to identify such malfunctions in the machine operation as:

* inter-turn short circuits of the stator windings;
* partial and complete breakdown of stator winding insulation;
* damage to bearing units; misalignment and runout of shafts;
* imbalance of the rotor;
* defects (conductor defects, casting defects) of the rotor;
* the weakening of the fastening elements of the motor;
* defects in the mechanical part of devices connected to the electric motor [6].

The data analysis presented in fig 1 and fig 2 clearly shows the effect of a certain type of fault on the harmonics of the electric current consumed by the main electric motor [7].

**Figure 1.** Current spectrum of an electric motor with a damaged rotor

![Figure 1. Current spectrum of an electric motor with a damaged rotor](image)

**Figure 2.** Current spectrum of an electric motor with defects in the belt drive

![Figure 2. Current spectrum of an electric motor with defects in the belt drive](image)
4. Application of neural networks for the diagnosis [8]

The method of diagnostics based on artificial neural networks consists in using a software and hardware complex consisting of a computing device and a digital device for collecting diagnostic data. Various system parameters, such as temperature, vibration level, electric current, and so on, can be used as diagnostic data. The program running on the computing device must process the input information in a certain way and determine the most likely type of malfunction of any element of machine equipment and draw a conclusion about its technical condition as a whole. To date, this approach is the most effective, since it logs large databases with information about the tracked dynamics of damage to any node of technological equipment, in order to predict its future.

It is known that the magnetic field of the rotating rotor asynchronous running motor operates on the magnetic field of its stator windings, which leads to periodic fluctuations in electrical quantities of the motor such as current, power or voltage of the stator winding. The period of these oscillations is proportional to the frequency of rotation of the rotor. Thus, by analyzing the shape of the signal graph of any of the electrical quantities for a given period, it is possible to detect damage in the drives of machine equipment and recognize their type. Many different approaches can be used to solve this problem. For example, you can build an approximation function based on several source points of a signal corresponding to a specific type of damage, and during diagnostics compare the current measured values with the values of this function with a certain degree of error. However, the approximation of complex nonlinear signals leads to large errors, which are compounded by additional interference from the electrical network with connected electric drives. Currently, the use of artificial neural networks for building mathematical models of complex nonlinear processes, pattern recognition, and signal prediction is widespread.

A neural network is a set of neurons, each of which is a model of a biological neuron. Each neuron has so-called dendrites, synapses, and axons. Dendrites coming from the body of the nerve cell to other neurons where they receive signals at connection points called synapses. The input signals received by the synapse are fed to the body of the neuron. Here they are summed up, and some inputs tend to excite the neuron, others - to prevent its excitation. When the total excitation in the body of a neuron exceeds a certain threshold, the neuron is excited, sending a signal along the axon to other neurons. This basic functional scheme has many complications and exceptions, however, most artificial neural networks model only these simple properties.

Currently, mathematical models of neural networks are widely used. There are also other neural network models, among which the most commonly used are Hopfield recurrent networks and Kohonen self-organizing networks. In the mathematical model of a neuron, all incoming arrows have weights, and the output is usually calculated as a non-linear function of the average sum of these weights with some additional arithmetic operations.

To use a direct propagation neural network to solve a specific problem, it must first be trained. To do this, any values are fed to the input of the neural network, and the output is taken from the resulting values, which are compared with the values that should be there. If the output values of the neural network differ from the required values, then the weights of the neural network are optimized by one of the mathematical algorithms until these values correspond to them with the specified accuracy. After that, the neural network can be considered trained.

Neural networks make it possible to effectively determine the causes and types of damage to elements of metal-cutting machine components, work with noisy data, eliminating the need to use intermediate electronic filters against interference or filtering using mathematical methods. In addition, artificial neural networks are widely used in forecasting tasks. In conclusion, it should be noted that with effective diagnostics of the technical condition of metal-cutting machines and timely adoption of preventive measures, maintenance and repair costs can be reduced by 20 ... 25 % [1], which in relation to the technological complexes of the enterprise will create significant savings.
5. Conclusion
In conclusion, it should be noted that with effective diagnostics of the technical condition of metal-cutting machines and timely adoption of preventive measures, maintenance and repair costs can be reduced by 20...25% [1], which in relation to the technological complexes of the enterprise will create significant savings.

References
[1] A.V. Barkov, N. A. Barkova, A. A. Borisov Vibration diagnostics of electric machines in steady-state operating modes: guidelines. Saint Petersburg: North-Western training center, 2006. 145 p.
[2] M. Kozlov, A. A. Kozlov Reducing the repair time of CNC machines based on fault diagnostics // Modern materials, equipment and technologies Kursk 2018 pp. 33-37.
[3] V. A. Rogachev, Diagnostics of the rotor eccentricity of asynchronous electric motors by the harmonic composition of the stator current: dis. ... Cand. tech. Sciences: 05.09.01 / Vyacheslav Rogachev. - Novocherkassk, 2008. - 173 p.
[4] V. Dmitriev Diagnostics of the thermal state of a metal-cutting machine // Universum: technical Sciences: electron. scientific. journal. 2014. # 5 (6). URL: https://7universum.com/ru/tech/archive/item/1310 (accessed: 23.10.2020).
[5] A Review of On-Line Condition Monitoring Techniques for Three-Phase SquirrelCage Induction Motors -Past Present and Future / W. T. Thomson Keynote address at IEEE Symposium on Diagnostics for Electrical Machines, Power Electronics and Drives, Gijon, Spain, Sept. 1999. – P. 3–18.
[6] Condition Monitoring Methods, Failure Identification and Analysis for High Voltage Motors in Petrochemical Industry / V Thorsen and M Dalva, Proc 8a 1EE Int Conf, EMD'97, University of Cambridge, № 444. – P. 109–113.
[7] V. Fedorov Diagnostics of electric motors based on the analysis of the current consumption spectrum. // electronic magazine "electrical engineering news" No. 1 (31) 2005.
[8] V. S. Petukhov, I. F. Suvorov Complex method of diagnostics of asynchronous electric motors based on the use of artificial neural networks // Electrical engineering news. SPb. 2014. №1(85). 45 C.