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Neural Networks For Diagnostics Of Metal Cutting Machine Modules

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***Abstract*—The work is devoted to solving the problem online diagnostics of machine tools modules using data-based models. The authors propose a diagnostic method that includes models based on long short-term neural memory networks as a repository of frequency reference values. Data for training neural networks is a frequency spectrum reflecting the oscillations of the tool and the workpiece normal to surfaces caused by the presence of a manufacturing defect in the module element of a metalworking machine. Neural network model with long short-term memory are used for approximation the nonlinear frequency characteristics. For classification of module defects proposed a second neural network that compare the neural network model of the reference spectrum with the spectrum obtained from the actual quality parameters of the part in real time, determine the sources of defects. To evaluate the effectiveness of the method, a series of experiments were carried out with the definition of defective machine modules. An experimental result of the application of proposed method is given.**

Keywords—cutting machining, operational diagnostic, long short term memory, deep neural networks

I. Introduction

In modern metalworking, various structurally complex equipment is used, consisting of expensive components. The cost of repairing such equipment is high, so research on the implementation of measures to maintain the operable condition of the machines and quickly find defective modules are relevant. The performance degradation assessment and localization of defect modules an important role in guarantee reliability in industrial processes [1-3].

There is a large number of works devoted to the diagnosis of machine tools. A known method for diagnosing the state of metal-cutting equipment due to the study of the profilogram of the surface of the machined part [4] and the method for diagnosing the elements of a closed dynamic system [5]. Both of these methods consist in determining, when processing a detail, the vibration indices of machine tools and subsequent processing, and comparing information with calculated ones in order to determine defective nodes. The disadvantage of these methods is the lack of automation in making decisions about the state of the machine, since the methods suggest performing diagnostics using computational tools after completing the part processing and do not assume the application is directly in the machine's operating mode, that is, on-line diagnostics.

There is a method for diagnosing the elements of a closed dynamic system of a lathe [6]. In this method the machine is diagnosed by measuring static compliance, natural frequency and vibration decrements of the main elements of the machine dynamic system. Next steps are determining their transfer functions in the form of oscillatory links and then constructing a transfer function equivalent elastic machine systems, which identify the main links that cause unstable operation of the machine.

The disadvantage of this method is limited diagnostic capabilities, because the method is based on the analytical construction of the equivalent system of the machine and does not take into account the frequency of vibration perturbations that occur in the machine nodes, and the action of the cutting process. This diagnostic method does not allow detection of defects in machine modules.

The device for diagnostics of lathes according to the accuracy parameters of the manufactured part [7] includes a spindle angle sensor, a non-contact displacement sensor used to measure movements of the tool tip in a plane passing through the tool tip and a spindle axis. A contactless displacement sensor is mounted on the tool head of the caliper and configured to measure the distance to the cylindrical surface of the cartridge. After recording the readings on the computer, experimental data are processed using mathematical statistics methods. The constructed geometric image of the surface in three-dimensional space allows us to determine all the necessary indicators of the accuracy of the part before its final processing. The method is aimed at predicting the parameters of accuracy and quality of manufactured parts.However, this device does not allow to determine the technical condition of the machine elements according to the constructed geometric image.

For spindle units of machine tools there is a diagnostic method using neural networks [8], which provides for the determination of the spectra of vibration signals taken from spindle units using vibration transducers (accelerometers) installed near the bearings. Directly for diagnosis, the neural network of the "multilayer perceptron" architecture is used, the input elements of which are supplied with vibration spectra, and the output elements are fault classes. The disadvantage of this method is the limited diagnostic capabilities associated with the size of the training set — in the event of malfunctions that are not present in the training set, it is impossible to accurately determine the state of the node and use the diagnostic algorithm in real time.The closest to the proposed method in the paper is a method for diagnosing a spindle unit [9]. This method involves the application of external load to the mandrel installed in the spindle, and measuring the distance from the surface of the mandrel to displacement sensors located in two cross sections of the mandrel at a given distance between the sections. The mandrel is machined with a chisel, and non-contact sensors are used as displacement sensors, according to the signals of which the cross sections of the mandrel are determined at the installation sites of displacement sensors. The cross sections define the geometric image of the mandrel in three-dimensional space. After machining the mandrel with a cutter, for the resulting geometric image, an error of radial size, geometric shape, total error of shape and relative position of surfaces in the radial and end directions is estimated, the deviation from cylindricity and the evaluation results determine the parametric reliability of the spindle assembly. The disadvantages of this method are limited functionality, because the method is intended for diagnostics of the spindle unit and does not allow diagnosing faults of other elements of the machine according to the constructed geometrical pattern does not take into account the dynamics of the machining process.

The closest algorithm used for diagnostics is the algorithm used to determine the state of the technological process of electrochemical machining machines [10]. In this algorithm, the determination of the defect during processing is based on a comparison of the current indicators of the state of the technological process (current, position of the processing elements) with the reference ones recorded in the neural network model. The disadvantage of this method is the limited use of the neural network architecture used to form a reference model based on a multilayer perceptron [11]. The information capacity of the multilayer perceptron is limited, which leads to significant limitations when trying to implement a reference model of the amplitude-frequency characteristics of the vibration indicators.

II. Description of the method of on-line diagnostics

The paper proposes a method of on-line diagnostics, which allows extending the functionality of diagnosing the technical state of each module of a metalworking machine.

The technical result of such a diagnosis is to determine the presence and location of the defect in the machine module.The proposed method of on-line diagnostics implies the achievement of the technical result due to the following actions. First step is according to information from the sensor, determine the geometrical image of the surface of the machined part. Next step is estimate the total error in the shape of the surface of the machined part, and represent the geometrical image as a frequency spectrum reflecting the oscillations of the tool and the workpiece normal to surfaces caused by the presence of a manufacturing defect in the module element of a metalworking machine. After that the geometric image are compared with the operation geometric image with the reference and the deviation from the reference it determine the presence and location of defects in the machine tool module.

The formation of a reference geometric image is carried out by fixing the vibrometric information during machining with metal-cutting machines and using the accumulated information to train neural network models representing an approximation of nonlinear characteristics. As a neural network architecture that implements reference models, it is proposed to use recurrent neural networks with long short term memory (LSTM) [12].

According to the geometrical image of the surface being processed, vibrometric information is obtained, that is, when comparing the shape errors (waviness) and the surface roughness, the frequency spectrum is given.

This representation allows you to compare the geometric image of the surface with the relative oscillations of the machine elements, which gives a number of advantages - the ability to quickly assess the technical condition of the machine modules directly from the results of its work, as well as using relatively simple measuring devices for this purpose: vibrometer, profilometer, profilograph, etc. . Search for the cause of failure is carried out in a certain frequency range by identifying the disturbance frequency with the dominant frequency causing a failure in this frequency range. The discrepancy between the reference neural network model and the current process characteristics is calculated, the magnitude and dynamics of change of which determine the nature of the defect through the use of the second neural network model - the classifier. On the basis of the requirements for the metal-cutting machine, a generalized spectrum is compiled, in which the specified shape deviations (waviness) and the surface roughness of the part are not exceeded, subject to specific processing conditions. Such a spectrum is a reference and determines the allowable level of amplitudes and the range of frequencies corresponding to the permissible errors of shape (waviness) and roughness of the processed surface of the part [13]. The calculated spectrum is determined by modeling the oscillations of the tool and the workpiece, taking into account the technical conditions for the accuracy of manufacturing and assembling the modules of the metalworking machine.

When using the reference spectrum in the process of diagnosing the technical state of the machine modules, the characteristic spectrum is distinguished according to the calculated spectrum, in which the manufacturing errors of the metalworking machine modules appear. During the operation of the machine, spectrum is permanently fixed in the form of amplitude-frequency characteristics. If new types of defects that were previously undetectable occur, the neural network of the classifier is further trained according to new data. In the diagnostic process, two main causes of parametric failure are established:

- Failure due to changes in the technical requirements for the manufacture of drive components, as a result of which the amplitudes of the individual harmonics of the calculated spectrum exceed the permissible level of the reference spectrum.
- Failure due to non-observance of technical conditions of the machine assembly, as a result of which the amplitudes of the individual harmonics of the calculated and actual spectrum of the shape error (waviness) and roughness of the machined surface of the part exceed the amplitude of the reference spectrum.

The essence of the proposed method is presented in figures 1 to 4.

Figure 1 shows a block diagram of a method for on-line diagnostics of modules of a metalworking machine.

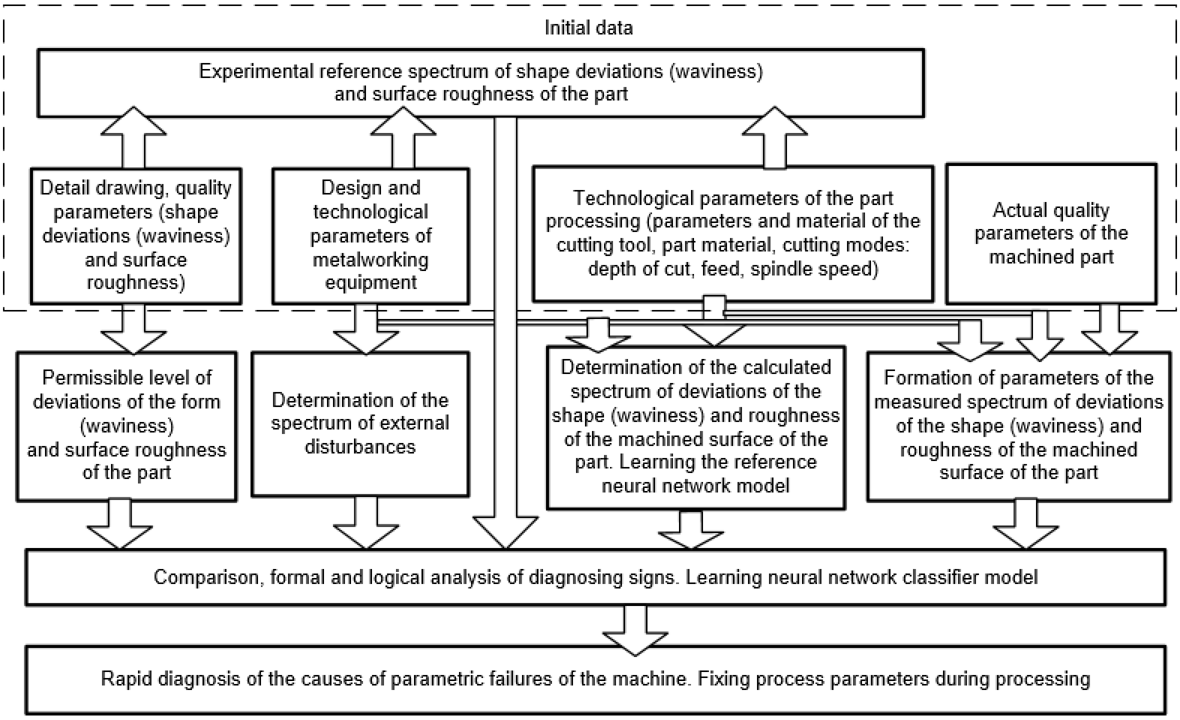

Fig. 1. Block diagram of a method for on-line diagnostics of modules of a metalworking machine.

Operational diagnostics of the technical condition of the drives of metalworking machines are proposed to be carried out in the sequence shown in Fig. 2, which consists of several steps.

To obtain the calculated spectra of the irregularities of the surfaces of the part, using a multifactorial dynamic model of the metalworking machine, the input effects of which are the parameters of precision manufacturing and assembly of the elements of its drives.On the basis of the measured indicators of the quality of the surface of the part to obtain the actual range of irregularities of the treated surface.

By calculation, determine the sources of vibration perturbations and rank them by frequency ranges.

To fix reference characteristics (spectrum) during the technological processing repeated many times in the conditions without failures and with refusals in the form of a neural network model with a long short-term memory;

Carry out the procedure of training and verification of neural network models of classifiers implemented in the form of multilayer perceptrons, with a preliminary partitioning of the training set to perform the classification of the state of the technological process;

Comparing the neural network model of the reference spectrum with the spectrum obtained from the actual quality parameters of the part in real time, determine the sources of defects.

If several sources of defects are revealed that appear at the same frequencies, carry out an additional analysis of the obtained spectrum according to the reference spectrum, which characterizes one of the found defects, and conduct additional training of the neural network classifier model.

Conduct a formal and logical analysis of certain defects, vibration-disturbing spectra and identify the defective element of the metalworking machine.

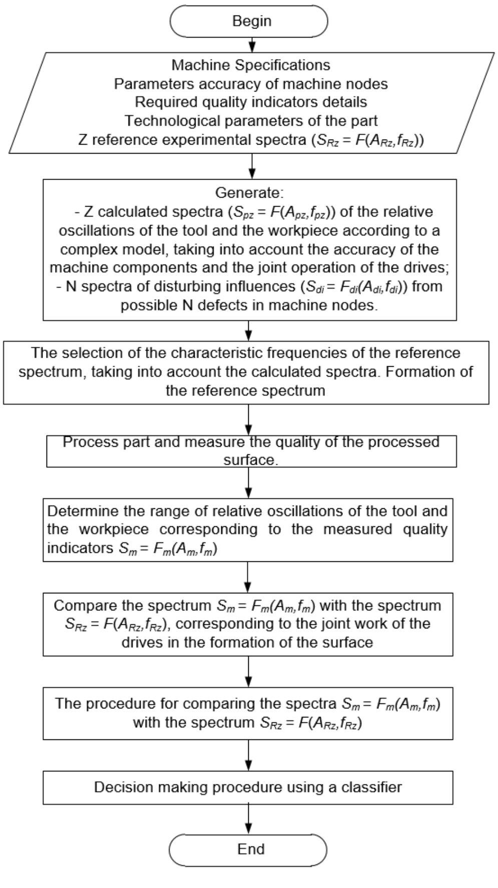

Fig. 2. Operational diagnostics sequnce.

Figure 3 presents the process of comparing the reference spectrum with the current one.

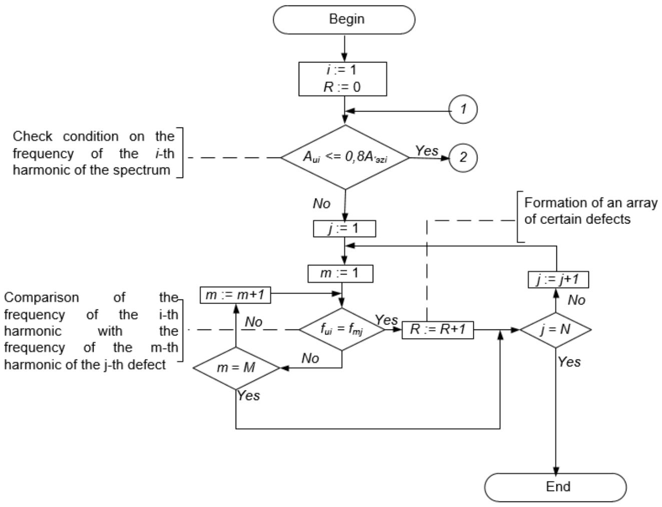

Fig. 3. Comparing the reference spectrum with the operational spectrum.

In figures 3 and 4, the following notation is used: *S* is the spectrum, indices: “*m*” is the measured value, “*r*” is the reference, *i* = 1..*K* is the number of harmonics of the reference spectrum, *j* = 1..*N* is the number of defects, *m* = 1..*M* is the number of harmonics of the vibration perturbation spectrum, *r* = 1..*R* is the number of defects found, *z* = 1..*Z* - *i* = l..*K* is the number of reference spectra.

Figure 4 is the decision to identify the defect.

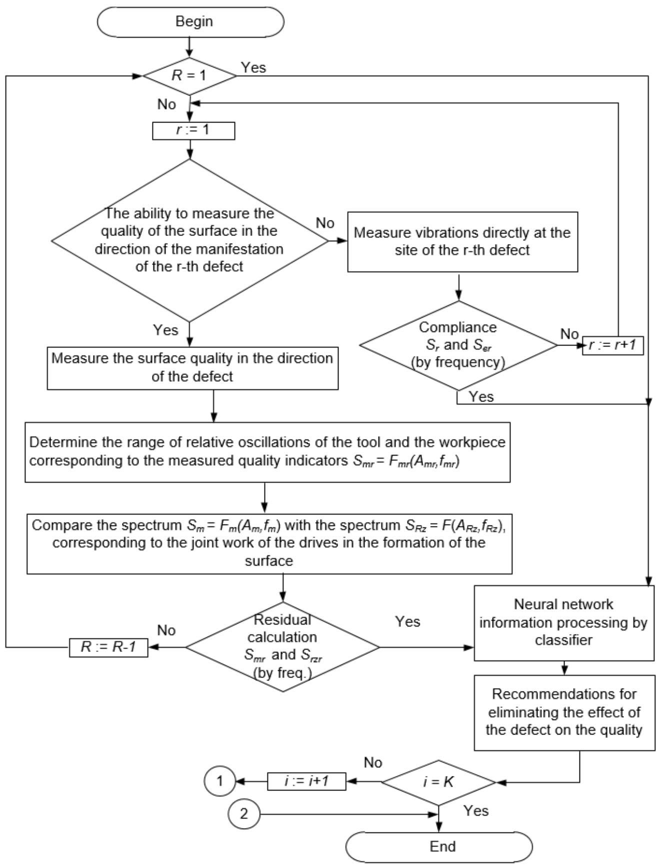

Fig. 4. Defect identification.

The figure 5 presents the architecture of the neural network with a long short-term memory used to fix the reference model. The neural network architecture with a long short-term memory allows recording the input vector x, which is a set of harmonics of the reference spectrum at discrete points in time, to change the spectrum during the process and get the reference harmonics for the next discrete time point at output.

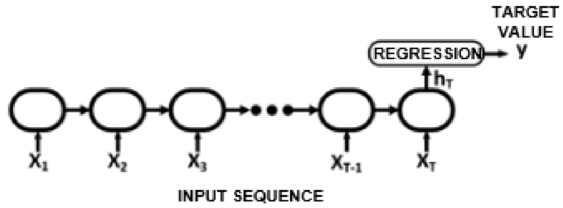

Fig. 5. Long short-term memory nural network.

The initial data for on-line diagnostics are: the actual errors in the quality of the machined surface of the part; manufacturing parameters of machine components, which are determined by the sources of vibration perturbations.

III. An Example of the Practical Implementation of the Method

Evaluation of the technical condition on the example of the machine model 500VS [14, 15] was carried out on the quality of the machined surfaces of the part. For the workpiece type "pyramid" checked the accuracy of the manufactured equipment. The part was machined using an end milling cutter in the next mode: depth of cut *t* = 0.1 mm, feed S = 200 mm/min, spindle speed 600 Hz [16].

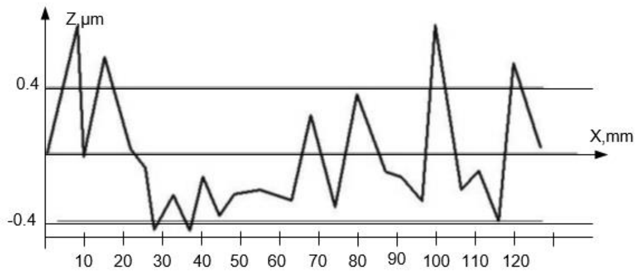

Fig. 6. The spectrum of deviations of the shape (waviness) and roughness.

The evaluation was carried out in the sequence shown in Fig. 2.

The spectrum of deviations of the shape (waviness) and roughness (Fig. 6) was obtained according to the data of Fig. 3, using the ratio fi/n = fH, where fi is the frequency of occurrence of relative oscillations of the tool and workpiece, fH is the frequency of manifestation of shape deviations (waviness) and roughness, and n is the tooth frequency of the tool rotation (for this case it was determined that fi = 75 Hz).

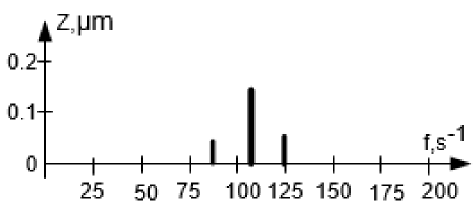

Fig. 7. The reference spectrum when processing the surface.

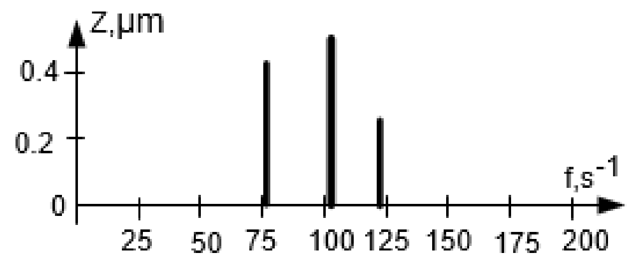

Fig. 8. The actual spectrum of the treated surface.

In the course of comparing the actual spectrum with the reference one in the frequency range of possible errors, it was established that the obtained frequency spectrum corresponds to the errors in the manufacturing of the screw paths of the drive for the vertical movement feed and the drive for the longitudinal movement. To uniquely identify a node defect in this case, additional diagnostics of the machine is necessary. Fig. 6 shows deviations of the shape (waviness) and surface roughness when machining a part in the XOZ plane; Fig. 7 shows the reference spectrum when processing the surface of a similar component; Fig. 8 shows the actual spectrum of the treated surface of the part in the XOZ plane; in Fig. 9 - deviations of the shape (waviness) and surface roughness when machining the surface of a part in the XOY plane; Fig. 10 shows the actual spectrum of the machined surface of the part in the XOY plane.

When machining a part in the XOY plane (the feed drive along the Z axis does not work) in a certain frequency range, the influence of errors in the feed drive along the X axis on the quality of the workpiece surface has been analyzed. It is established that in this case the deviations of the form (waviness) and roughness on the surface under consideration do not exceed the permissible values (Fig. 7).

In the course of comparing the actual spectrum (Fig. 8) with the reference one in the frequency range of occurrence of the screw manufacturing error, it was established that the amplitude of the spectrum does not exceed the permissible level.

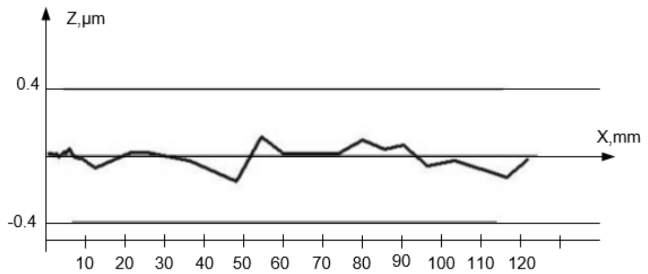

Fig. 9. Deviations of the shape (waviness) and surface roughness when machining the surface of a part.

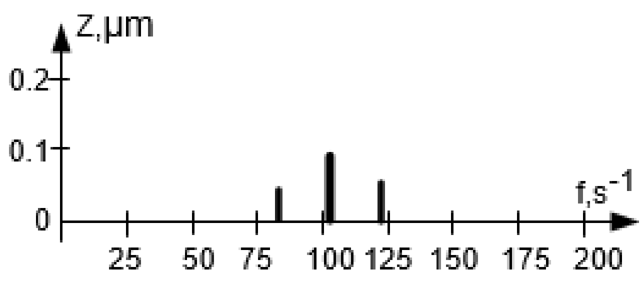

Fig. 10. The actual spectrum of the machined surface of the part.

Consequently, the defect that generates deviations of the shape (waviness) and surface roughness is in the drive of vertical displacement and belongs to the screw-nut rolling transmission.

IV. Conclusion

Diagnostics of the technical condition of drives of metalworking machines in accordance with the proposed method allows you to:

- To quickly identify the sources of defects in the machine modules and develop measures to eliminate them;
- When detecting new types of defects, correct the operational classifier of defects by further training or retraining of a multilayer perceptron;
- To give recommendations for the development of scientifically based technical conditions for the manufacture and assembly of nodes of a multi-purpose machine at the design stage;
- To recommend rational cutting conditions when machining a part on a multi-purpose machine, taking into account the quality indicators of the workpiece, allowing to reduce the mutual influence of defects in the drives of a multi-purpose machine;
- to recommend the parameters of the correction of movements in the computer numerical control machine tool in the case of rejected.

The proposed method allows to determine the sources of defects in the drives of the machine, with its short-term stop and minimal disassembly, as well as to develop measures to eliminate them.

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