Identification and Technological Impact of Broadband Vibration on the Object

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Abstract. The research presents the approach consisting of resonant excitation of objects – elements of technological systems, including the machine tool, fixture, cutting tool, and part. Resonant Nano amplitude vibrations of the object under the action of broadband perturbation, which has a spectrum characteristic of "white noise", are sources of information about the geometric characteristics of objects and indicators of their physical and mechanical properties. The latter is important for the materials of the workpieces. When a constant uniform field of magnetic or thermal nature is applied to an object, the introduction of Nano amplitude vibrations acquires the properties of technological influence, as a result of which the properties of the material from which the object is made may change. Experimental studies of resonant excitation of an object placed in a strong constant, uniform magnetic field on the physical and mechanical properties of materials of objects, particularly on increasing their hardness, are presented. The universality of this approach is shown under the condition of application of neural network models, which allows establishing the relationship between the parameters of the frequency spectra of resonant oscillations of objects and their geometric and physic-mechanical properties. Based on the presented materials, fundamentally new innovative technological processes can be developed, which have the prospect of wide application in the conditions of resource-saving highly automated production of products of various industries.

Keywords: Innovative technology · Resonant vibration · Broadband influence · Technological system · Diagnostics · Neural network

1 Introduction

Object identification is a problem, the solution of which is actualized in the systems of optimal management of these objects. Therefore, the requirements for such models are regulated by their compliance with the criteria of reliability and accuracy for the purposes of application [1]. Based on such models, reference models can be created, used by automated control systems for corrective action on the control object [2].

The creation of identification models is based on the choice and justification of the information source with the subsequent formation of an array of precedents. The reliability of the identification model of the object depends on their volume and quality. One of the features of such identification of objects is the statement about the dependence of the object's reaction on the complexity of the disturbing effect on this

V. Tonkonogyi et al. (Eds.): InterPartner 2021, LNME, pp. 78–87, 2022.
https://doi.org/10.1007/978-3-030-91327-4_8

object [3]. The essence of this statement is that the amount of information about the individual properties of the object is proportional to the complexity of the perturbing function and can be identified as a response to this effect [4]. In the research studies [5, 6], it has been proved that the design of technological equipment should be based on parameter identification for ensuring the reliability of manufacturing processes.

It is known from the theory of automatic control that step effects as an analog of single ones allow revealing the transfer characteristics of the links of dynamic models of objects. This example suggests that the natural oscillations of the object and its elements contain information about the defining set of its properties and characteristics.

2 Literature Review

A promising direction in increasing production productivity due to the flexibility of production is to equip it with equipment with mechanisms of parallel structure [7]. The capabilities of such equipment are based on the modularity of such structures, on the multiplicity and scaling of their configuration, on mechatronic nodes, and on adaptive control algorithms. However, the mechanical part and drive system of actuators of such equipment with mechanisms of a parallel structure requires systematic improvement of the principles of design, control, and monitoring of objects due to the complex relationship of the trajectory of actuators with mechanisms of parallel structure and dynamic processes accompanying work processes [8]. The conclusions of domestic and foreign researchers in improving the accuracy of positioning, kinematics, and dynamics of objects based on the mechanisms of parallel structure confirm the thesis of the complex nature of control of the mechanism. However, the constant development of production and technological systems continues to pose new challenges. Purely systemic approaches based on the principles of synergy are inherent only in complex systems' integrity properties [9]. Therefore, further improvement of equipment systems with parallel structure mechanisms can be achieved by developing and implementing structural and parametric optimization of equipment with parallel structure mechanisms. The control of this equipment is based on dynamic identification mathematical models of positioning the executive unit of such equipment [10]. Principles of harmonization of levels of improvement of structural components of equipment systems with mechanisms of the parallel structure require the creation of appropriate means of providing technological processes of manufacturing machine-building products with technological tools with increased operational properties, corresponding principles of complex active control of dimensional and separate physical and mechanical characteristics of products mechanical assembly production [11].

The prospect of creating competitive technological equipment must be accompanied by structural optimization to ensure structural and technological flexibility of technological equipment [12]; creation of a system of normalized actuators based on the minimum number of energy conversions to expand technological work areas; creation of a system of normalized mechanisms for rapid change of technological tools to increase technological flexibility [13]; creation of technological equipment for the organization of the working space of technological operations based on equipment with parallel kinematics [14]; creation of the reconfigured sites of machine-building production which are quickly adjusted, from the normalized knots of the equipment with application of mechanisms of parallel structure [15]. According to the research study [16], the design of the manufacturing system should be realized based on "The Ontology on Flexibility".

This development of technological equipment and systems based on it allows to dramatically increasing the efficiency of multi-item production, including repair production for various areas of economic activity. However, using such equipment and its systems cannot but require intervention in the reliability of the technological processing and diagnostic tools. Therefore, it is justified to use special processes to improve the machining properties of metal-cutting and other technological tools, based on various effects of power, electrical, magnetic, wave, pulse, chemical, nanoscale, and their combinations.

3 Research Methodology

Based on such conclusions, we have developed and tested promising design solutions according to the Research Program of the Problem Laboratory of Mobile Intelligent Technological Machines of the Institute of Artificial Intelligence of the Academy of Sciences of Ukraine and Donbas State Machine-Building Academy of the Ministry of Education and Science of Ukraine.

The problem of dynamic identification of objects is to develop a mathematical modeling apparatus that would have the capabilities to provide the necessary characteristics of the accuracy of d (t) and the adequacy of A (t) of the dynamic model. The authors [17] proposed methods for determining all sample sizes by an acoustic signal, which is an amplitude-frequency characteristic of their own oscillations (frequency spectrum or signature). The accuracy of such dimensional diagnostics reaches 0.1 mm. The same estimates of the coordinates of the configuration of objects with mechanisms of parallel structure [18]. To implement this approach, the following is adopted: W (f) – excitation signal of the object "white noise"; R [W (f)] – the object's response to excitation by "white noise"; X_k, X_l…, X_r… – properties and parameters of the object (configuration, speed, deformation, force, stress, velocity, acceleration, temperature, etc.) R[W (f)] = F {X_k, X_l X_r …}.

The task of diagnostics and creation of a reference model of the object is to determine the properties and parameters of the object X_k, X_i…X_r… by reaction R[W (f)]R[W(f)]R[W(f)]. Information model for determining the properties and parameters of the object Eq. (1):

$$W(f) - \text{Object} - R[W(f)] - F_y[A_i(f_i)] - X_k, X_l \ldots X_r \tag{1}$$

The emitter and receiver of the diagnostic device are reversible piezoelectric elements, which are fed (emitter) and from which are removed (sensor) signals. Since the diagnostics of the object is performed relative to the reference signal "white noise", this approach allows you to normalize the output diagnostic signals relative to the reference signal. Transformation solution X_k, X_l…, X_r… = F {X_k, X_l …X_r …} is recommended to perform using neural network modeling. The solution is proposed based on the entropy index of the histogram that corresponds to the samples of Table 1 according to Eqs. (2) and (3):

$$H_a(x) = -\sum_{i=1}^{n} p_i(x) \bullet log_a p_i(x) \quad (2)$$

$$H_{ai}(x) = \frac{H_a(x)}{n} \quad (3)$$

Where, $H_a(x)$ – the index of entropy of the distribution of pixels of images of samples on brightness;

$p_i(x)$ – probability of the i-th degree of the histogram of the distribution of pixels of images of samples on brightness; n – the number of degrees of the histogram of the pixel distribution of the images of the samples by brightness.

The construction of the model on a neural network basis was performed in NeuroPro-0.25 using Microsoft Access to generate input and output data in *.dbf format. When training and testing the model according to the structure of the metal at different heating temperatures, the same exposure time, and cooling conditions of the samples, it was found that a significant part of the signature is the seventh interval ×7 (150 to 175 on the pixel brightness scale) for each image histogram. The verbal description of the model is given as follows: Solving the inverse problem of the ability to determine the structure (ferrite and perlite) from the values of the interval ×7 of the signature images of micro sections allows obtaining an expert assessment of the elementary heat treatment of samples. The paper formulates the hypothesis that the normalized gradual effect on the controlled part is accompanied by its response, which has specific characteristics. A combination can diagnose the size and accuracy of the size of parts and other characteristics of their quality (Fig. 1).

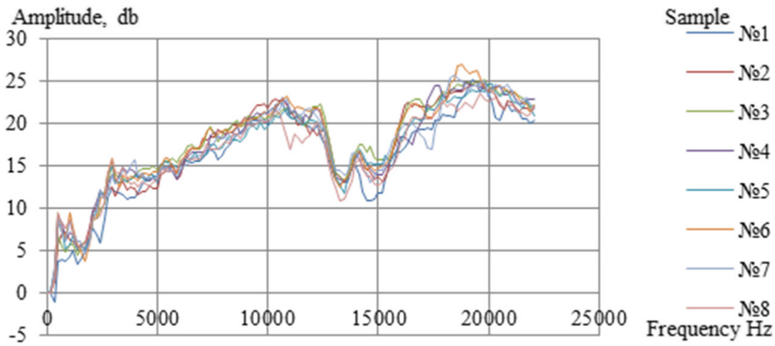

Fig. 1. Frequency spectra of samples.

Studies have shown that the smallest number of synapses is characteristic of a single-layer network. The authors propose a method for assessing the quality of objects based on the spectrum of the acoustic signal given in the cutting tool due to the response to forced oscillations in the form of “white noise”. The authors performed research, the objectives of which were working out of a technique of definition of the spectral characteristic of own acoustic fluctuations of the cutting tool; assessment of the quality of batches of cutting tools by the degree of similarity of their properties; the formation of similar acoustic spectrum groups of cutting platinum, in a multi-blade prefabricated tool. The method of determining the spectral characteristics of the acoustic oscillations of the cutting tool is developed on the example of non-grinding cutting plates, Pramet acoustic response signal, software package “spectrum analyzer”. The normalized acoustic signal has an amplitude-frequency characteristic of the constant amplitude of the signal in the frequency range 10–20000 Hz (Fig. 2).

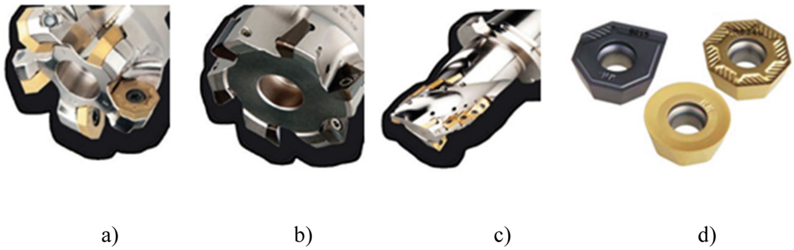

Fig. 2. Samples of prefabricated cutters (a, b, c) and cutting inserts for their assembly (d) Pramet.

For example, the results of processing the digitized spectra of a batch of cutting inserts (30 pieces) in increments of 172.3 Hz, frequencies range 10–20000 Hz. using the Detector Studio Academic package. Figure 3 shows the results of grouping the cutting inserts into three groups formed on Kohonen maps.

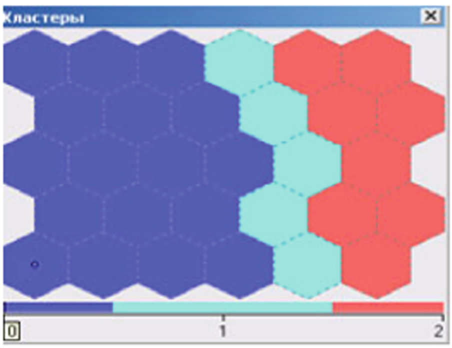

Fig. 3. Grouping of non-grinding cutting inserts in the similarity of the spectra of acoustic signals of the “white noise” response.

The presented example illustrates the uneven distribution of the properties of the cutting inserts of one batch. The plates in the batch are distributed according to the numbers presented in Table 1.

Table 1. The results of grouping cutting inserts on Kohonen maps.

Clusters of cutting inserts for complete sets of prefabricated cutters, identical in a similarity of spectra of acoustic signals, the response of “white noise”		
1 group	2 group	3 group
2,3,4,6,7,9,11,14,16,17,18,19,21,22,25,26,28,30	5,10,13,20,23	1,8,12,15,24,27,29

Tests of stability of the final mills completed with plates from the 1st and 3rd groups showed an increase in stability of combined mills by 31–35%. Plates of the 2nd group were not used.

In the study [19], the possibility of using a broadband vibration flux to influence the volume of the material of the magnetic field formed by powerful permanent magnets is shown. The process of influencing the material volume of the experimental samples was that the effect of a uniform magnetic flux permeating the sample was initiated by resonant oscillations of the sample caused by a broadband effect of equal amplitude using a white noise generator and a peso emitter [20]. The possibility of obtaining a positive effect of a positive change in the physical and mechanical properties of the material of the experimental samples is based on the following provisions [21].

It is well-known [22] that the modulus of elasticity E and the density of the material of the sample ρ are associated with the resonant frequency f_0 of the sample by the following dependence Eq. (4):

$$f_0 = K_f \bullet \sqrt{\frac{E}{\rho}} \quad (4)$$

Where, K_f- coefficient depending on the size of the sample.

Here it is necessary to consider the three-dimensional nature of vibrations (deformations) in the resonance of each element of the volume of the material. To do this, we use the dependence Eq. (5):

$$E = 1,64 \bullet m \bullet L^3 \bullet f^2/d^4 \quad (5)$$

Where: m is the mass of the sample, L is the length of the sample, d is the diameter of the sample.

Based on these initial conditions, the determination of the resonant frequency of the experimental sample placed in a uniform magnetic field and subjected to resonant vibrations using a piezoelectric emitter and a piezoelectric sensor is made based on the frequency spectrum of the sample in the magnetic field according to Eq. (6):

$$f_0 = \frac{\sum_{i=1}^{n} f_i \bullet A_{1i}(f_i)}{\sum_{i=1}^{n} A_i(f_{1i})} \quad (6)$$

where: $A_{1i} = A_i - A_{0i}$; A_{0i} – amplitude i—the degree of the frequency spectrum of the hardware of the experimental stand in the absence of the excitation signal of the generator “white noise”; A_i - amplitudes of the i-th degree of the frequency spectrum of the sample, installed in the zone of the uniform magnetic field of the experimental stand and excited by the signal of the generator “white noise” using a piezoelectric element that is part of the experimental stand; A_{1i} - natural amplitudes of the i-th degree of the frequency spectrum of the sample placed in a uniform magnetic field.

4 Results

Testing of duralumin sample: before vibration treatment in a uniform magnetic field, the hardness of the sample with a diameter of 15 mm and a height of 8 mm is 60 ÷ 80 HB; after vibration treatment for 20 min, the hardness of the sample was 208 ÷ 212 HB: an increase in the sum of the individual sites of amplitudes indicates that the sample becomes changing the viscosity of the material. The increase in the resonant frequency, which indicates a change in the physical and mechanical properties, is Δf_0 = 225 HB.

Copper sample test: before vibration treatment in a constant magnetic field, the hardness of the sample with a diameter of 20 mm and a height of 5 mm is 60 ÷ 100 HB: after vibration treatment for 20 min, the hardness of the sample was 220 ÷ 222 HB. A change in the resonant frequency of the sample may indicate a change in the density of the material, leading to an increase in hardness. The change in the resonant frequency of the samples is Δf_0 = 150 Hz, which indicates a change in the physical and mechanical properties.

Testing of a non-grinding plate of a cutting tool made of hard alloy HS123: increasing the resonant frequency of the sample (Δf_0 = 120 Hz) may indicate an increase in the material’s modulus of elasticity while increasing its viscosity. It is typical for polycarbonates, polyamides, composite materials.

Tests of plates at turning a batch of parts ∅95,5 mm from steel 42Cr4 at giving of 0,5 mm/rev and cutting speed of 150 m/min dimensional wear of plates HS123 decreased by 40–42%. It is an argument in favor of vibration resonant processing of cutting inserts in a uniform magnetic field.

Non-grinding test of the cutting tool plate made of hard alloy HG30: increasing the resonant frequency of the sample ((Δf_0= 70 Hz) may indicate an increase in the material’s modulus of elasticity while increasing its viscosity.

Testing of gray cast iron with cutters made of hard alloy HG30 with a hardness of 200–220 HB when turning the sample with a cutting depth of 1.8 mm with a feed rate of 0.2 mm/rev and a cutting speed of 114 m/min wear of plates with HG30 decreased by 32–37% It is shown that with increasing duration of such processing the increase in its efficiency decreases. In addition, the process of changing the properties of the materials continues after vibration resonance treatment in a uniform magnetic field for the next 3–5 days. The change of these properties is subject to exponential nature and for different materials has a different time constant. Then the indicators $\sum_{i=1}^{n} A_i(f_{1i})$ and f_0 are stabilized, which indicates the termination of the process of changing the properties of the material of the samples.

Magnetic resonance treatment in a magnetic field of non-grinding cutting plates, CNMA120408E-KD5ACK15A; WNMG080408E-MC3AP301M; WNMG080412E-PD3AC250P, and SNGX1206ANN-MM3AP351U were accompanied by observations of the dynamics of changes in the indicators $\sum_{i=1}^{n} A_i(f_{1i})$ and f_0. It is emphasized that the increase in hardness is inversely proportional to the decrease in the resonant frequency of the cutting plate. For different types of cutting inserts, the correspondence of hardness to resonant frequencies is different and depends on the design features. Therefore, on average, the change in resonant frequency is determined by the formula: Δ HB = –(0, 65…0, 75) • Δf0.

For plates of group SNGX 1206ANN-MM3 AP351U) the result is described by formulas:

f0 = –1, 27 · HB + 11802;
HB = –0, 79 · f0 + 9317.

The generalized result can be described by the dependence:

f0 = –1, 53 · HB + 11981;
HB = –0, 66 · f0 + 7856.

5 Conclusions

Making samples of materials placed in a uniform magnetic field, resonant poly frequency vibrations with Nano-dimensional amplitude in the range of 20–80 nm allow changing the viscosity of the material, the modulus of elasticity of the material, and the hardness of the material samples. Thus, nanoscale amplitudes of natural oscillations of objects of complex shape in energy fields, which include uniform magnetic fields, can correct the physical and mechanical properties of materials of such objects to achieve their identity or add strictly defined properties. The study of this effect can be extended to many materials, their atomic-crystalline structures, ranges of magnetic fluxes, frequency ranges, and estimates of the materials' obtained physical and mechanical properties thus treated. It has been confirmed that image pixel signatures allow communication with previous technological transformations. It allows you to examine the technology by which the samples were machined or speed up the receipt of metallographic research data, and speed up the analysis of the material on the composition of structures.

The proposed approach, which consists of the resonant excitation of objects, allows abandoning the traditional schemes of equipping technological systems with many sensors that read information about objects. The frequency spectra of objects can perform this role. It is shown that the frequency spectra of resonantly excited objects are sources of information about the macro geometric characteristics of objects and indicators of their physical and mechanical properties. Experimental confirmation of the influence of the resonant excitation of an object placed in a strong constant, uniform magnetic field on the physical and mechanical properties of the materials of objects, in particular, on the increase of their hardness, is presented. The universality of the approach to the resonant excitation of the object is shown, illustrated by pixel signatures of images of micro sections of material structures. A special role in the information support of the processes of diagnostics of objects and changes in their physical and mechanical properties is given to intelligent computing and neural network models. The materials of the article have the prospect of wide application in the conditions of resource-saving highly automated production of products of various branches.

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