

Using wave signatures for identifying mechanical objects

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Abstract. The article provides a rationale for identifying objects based on wave signatures. Wave signatures in the article are limited to the acoustic range of vibration. The results of experimental studies based on modeling the dynamic processes of propagation of complex excitations in samples of various configurations and with the presence of various defects using the signature of acoustic oscillations excited in the objects of study are presented. As such objects are presented parts of engineering production. These studies confirm the possibility of complex diagnostics of objects with their subsequent use in product quality control systems, in particular, to reduce the level of peak values of residual stresses in body parts during multi-frequency vibro-processing.

1, Introduction

The creation of identification objects implies, most often, their use in control systems. Requirements for such models ensure compliance with the criteria of accuracy and accuracy of the objectives of the application [1,2]. Control by reference models allows control systems to provide a corrective effect on the control object, thanks to which the tasks of increasing the accuracy of the performance of the control function by the object or working out the optimal control in accordance with the objective function are solved [3,4].

Creation of identification models is preceded by the formation of an array of precedents. The reliability of the object depends on their volume and quality.

One of the features of the identification of objects is the statement about the dependence of the response function on the complexity of the disturbing influence on the object. The essence of this statement is that the complexity of the nature of the disturbing influence is proportional to the volume of the individual properties of the object, which can be fixed as a function of the response to this disturbing influence. From the theory of automatic control, it is known that single functions make it possible to identify the transfer functions of typical links of dynamic models of objects. This becomes possible due to the formation of the natural oscillation functions of the object, including its elements.

2. Basic part

The aim of the presented work is to substantiate and confirm the expediency of identifying objects based on wave signatures (in particular, acoustic), excited by disturbing influences in the object, whose amplitude-frequency characteristic has the same amplitudes of wideband oscillations in the range available for fixation (“white noise”). The signature of such signals should be understood as the amplitude-frequency characteristic of a certain state of the object. Thus, each identified state of the

object corresponds to a certain signature. Many such signatures are capable of describing a variety of object states. (1).

$$\begin{aligned}
 &1\text{-st state of the object} - F(S)1; \\
 &2\text{-nd state of the object} - F(S)2; \\
 &\dots \dots \dots \dots \\
 &n\text{-th state of the object} - F(S)n.
 \end{aligned}
 \tag{1}$$

Since technical and technological objects can be described by a set of material M , energy E and informational I components, then it is the signature of objects having a wave character that contain the most complete amount of information about the object. It can be assumed that the range of the spectrum of signatures is directly proportional to the completeness of the identification models of objects. Moreover, the discreteness of signatures can solve the problem of boundedness of the array of source data.

3. Methodology of experimental studies

To confirm the applicability of wave signatures in the diagnostic systems of objects in order to identify any defects, the following conditions have been adopted. The database of sample signatures consists of valid (reference) and defective products, the type of which is shown in Figure 1 in the following sizes (Table 1).

Table 1. - Dimensions of samples, where L - sample length, mm; $d1$, $d2$ and $d3$ - diameter at the initial, middle and final cross sections of the samples, mm.

Sample number	Sample sizes			
	L , mm	$d1$, mm	$d2$, mm	$d3$, mm
1	200,10	Ø30,01	Ø30,23	Ø30,19
2	200,05	Ø30,23	Ø30,20	Ø30,17
3	199,95	Ø30,22	Ø30,24	Ø30,28
4	201,00	Ø30,25	Ø30,32	Ø30,29

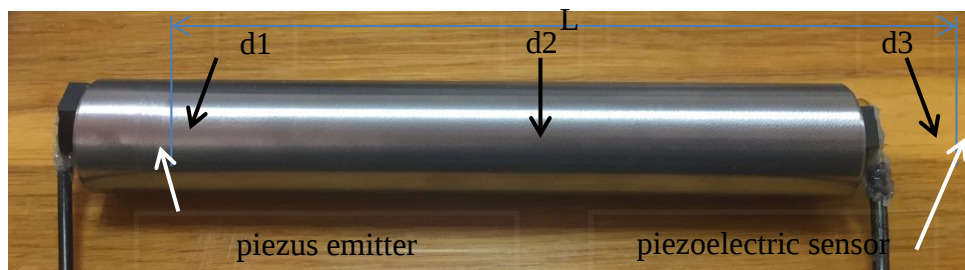


Figure 1. - Example of experimental samples with dimensions L , $d1$, $d2$ and $d3$ mm.

One sample is defective, has a specially made groove with a depth of 0.95 mm and a width of 2.75 mm at a distance of 27.4 mm.

Wave (acoustic) signatures created with the aid of a piezo emitter of a wave packet in the form of a broadband acoustic signal in the range of 20 Hz-20 kHz of constant amplitude ("white noise"), which is received and converted into an analog-digital device into an array; part which in the form of spectrographs is presented in Figure 2.

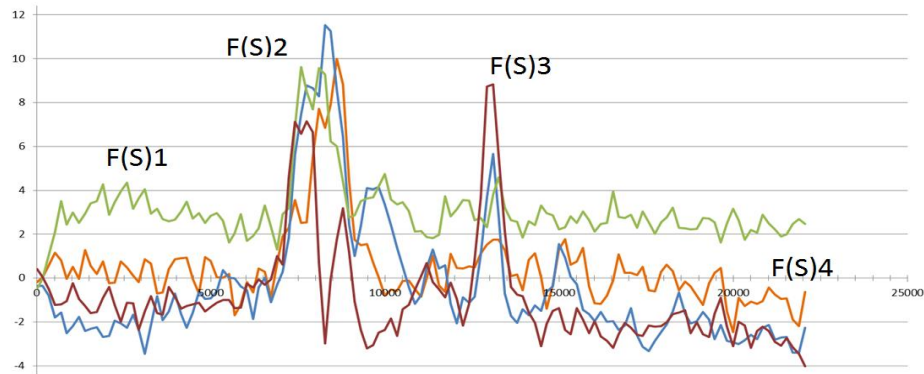


Figure 2. - Wave signature of experimental samples F(S)1, F(S)2, F(S)3, F(S)4.

Based on the data set of digitized signatures, neural network identification models were constructed for diagnosing the validity of samples by analogy with the authors' works [5-8]. The peculiarities of neural network modeling were that the number of implementations of signatures was taken by 10 for each sample. The difference in signatures was that for each measurement of signatures, the installation of a piezo emitter and piezo sensor was reinstalled. Thus, the invariance condition was ensured - the recognition of suitable and defective samples at any position of the emitter and sensor. To ensure the constancy of the clamping force of the emitter and sensor to the end surfaces of the samples, magnetic substrates of piezoelements were used (Table 2).

Table 2. The result of the analysis of spectral characteristics (wave signatures) of samples

Quality sign (1-quality, 0 defective)	Network forecast	Quality sign (1-quality, 4 defective)	Network forecast	Quality sign (1-quality, 4 defective)	Network forecast
1	1,028	1	1,036	1	1,036
1	1,007	1	1,039	4	3,859
1	1,034	4	3,859	1	1,039
0	0,013	1	0,961	1	0,961

Testing of samples with a random sequence of test sample presentation showed 100% recognition of the defective sample. Another example illustrates the capabilities of signatures for diagnosing technological regimes for improving the quality of engineering products. Production experience has shown that in case designs made of simple low-carbon steels and having a fairly high precision after welding, after further machining or stacking within two to three weeks, the tolerance limit was changed and they required additional processing. The main reason for such changes was the presence of residual stresses [9,10]. Changes in geometric sizes are increased under the influence of mounting, transport and operating loads, as well as with increasing temperature. In order to increase the stability of the geometric dimensions of foundry and welded structures, they are often subjected to general heat treatment, which requires additional energy costs. The urgent task of solving the problem of improving accuracy is the process of reducing the peak residual stresses by means of vibration stabilization treatment at resonant frequencies as this process is less energy intensive, but in most cases it is carried out at the resonant frequencies of the whole case. Vibration processing is carried out by means of excitation in the construction of low-frequency mechanical oscillations. In terms of energy consumption, vibration stabilization is tens of times lower than heat treatment, and in terms of performance significantly exceeds it. Approximately an order of magnitude decreases capital costs for the introduction of such processing technology. Vibration treatment is subjected to the construction not only of carbon steels, but also made of aluminum and titanium alloys. Widely used vibration processing of cast iron and steel castings [9,11,12].

Despite the presence of many discrete publications on the problem of vibration processing, summary information is inadequate [10,13,14]. Therefore, there is a need to propose a method for more efficient

vibration stabilization processing by simultaneously processing individual parts of the body part at their own resonant frequencies.

Example of method implementation: using piezo elements and software "Signal Generation" reproducing "white noise", the signal turns into mechanical oscillations using a piezoelectric actuator affects the body of the workpiece [15]. Spectrum Analyzer software is used to fix resonant oscillations [16]. The piezoelectric sensor converts mechanical vibrations into an analog signal, which converts into a digital signal of the resonant frequencies of individual parts of the body component using an analog-to-digital converter (ADC). This ADC is a computer sound card.

Excitement in the form of "white noise" causes wave signatures separately for each element of the complex profile. Converted by the hardware part of the experimental complex, the "white noise" signal is capable of generating the amplitude-frequency characteristics of the spectra of individual elements of the body detail in a tense state (diagnostic wave signatures) (Figure 3, $F(S)1$, $F(S)2$, $F(S)3$).

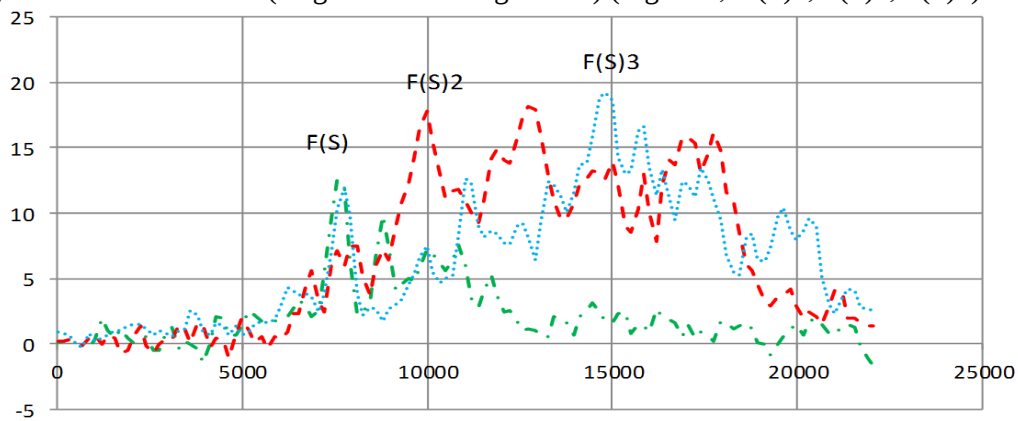


Figure 3 - Amplitude-frequency characteristics of the spectra of elements of the body detail in a stressed state

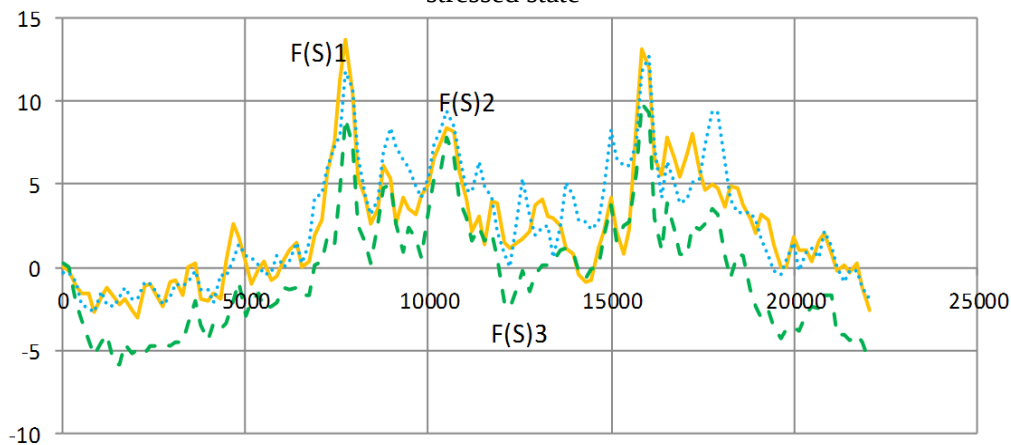


Figure 4 - Amplitude-frequency characteristics of the spectra of elements of the body detail after 30-minute processing at resonant frequencies

The graph of the amplitude-frequency characteristics of the spectra of plates in the stress state confirms that the signatures of each element are individual, despite the coincidence of some auxiliary ones.

The experimental booth is designed in such a way that it can excite each piezoelectric element on the surface of the body part with a spectrum of frequencies in accordance with its own diagnostic signature. Figure 4 shows the amplitude-frequency characteristics $F(S)1$, $F(S)2$, $F(S)3$ of the casing after 30-minute multifrequency machining.

Polyfrequency, according to signatures, simultaneous processing of all elements of body parts allows to significantly reduce the required vibration time and reduce the amplitudes of residual stresses. The technical result is an increase in precision due to vibrational stabilization of residual stresses in body parts, which increases productivity and reduces energy costs.

4. Conclusions

The simulation of dynamic processes for the propagation of complex excitations in samples of different configurations and the presence of various defects confirmed the possibility of complex diagnostics of objects. This means that, based on the data of one implementation of the diagnostic procedure, one can draw conclusions about the size, physical and mechanical properties, microheometry of the surface layer, the presence and nature of defects in products. Such products can have separate parts, and such knots and mechanisms of machines. The practical implementation of the use of wave signatures is the diagnosis of product quality and diagnostics with subsequent multifrequency effects on the product in order to change its complexity of stress.

References

- [1] A.M. Vendrov. Proektirovanie programmogo obespecheniya e'konomicheskix informacionny'x sistem. [2-e izd., pererab. i dop.]. Moscow: Finansy' i statistika, 2006. – 544 pp.
- [2] V.M. Tomashevs'kij. Modelyuvannya sistem. Kiev: Vidavnychy grupa VNV, 2007. – 352 pp.
- [3] A.A. Zhilenkov, S.G. Chyorny'j. Modelirovanie adaptivnogo upravleniya v slozhny'x raspredelenny'x sistemax s identifikaciej parametrov. *Visnik Xmel'nic'kogo nacional'nogo universitetu*. 6 (2013) 253-260.
- [4] S. Mirjalili, S.M. Mirjalili, A. Lewis. Grey wolf optimizer. *Advances in Engineering Software*. 69 (2014) 46-61. doi: [10.1016/j.advengsoft.2013.12.007](https://doi.org/10.1016/j.advengsoft.2013.12.007).
- [5] O.S. Kovalevska, S.V. Kovalevskyy. Application of acoustic analysis in control systems of robotic machine tools. *Naukovij zhurnal «Radioelektronika, informatika, upravlinnya» / «Radio Electronics, Computer Science, Control»*. 2 (45) (2018) 51-59.
- [6] S.V. Kovalevskij, E.S. Kovalevskaya, V.I. Tulupov. *Razvitie metodov akusticheskoy diagnostiki v mashinostroenii*: Monografiya. Kramatorsk : DGMA, 2014. – 91 pp.
- [7] S.V. Kovalevskii, O.S. Kovalevska. *Diagnostics of technological systems and engineering products (using neural network approach)*. Scientific Monography. Vrnjačka Banja: SaTCIP, 2016. – 169 pp.
- [8] S.V. Kovalevs'kij, O.S. Kovalevs'ka, E.O. Korzhov, A.O. Koshevoj. *Diagnostika texnologichnix sistem i virobiv mashinobuduvannya (z vikoristannyam nejromerezhevogo pidxodu)*. Monografiya. Kramatorsk: DDMA, 2016. – 186 pp.
- [9] R.G. Rizvanov, A.M. Fajrushin, D.V. Karetnikov. *Vliyanie parametrov vibracionnoj obrabotki v processe svarki na svojstva svarny'x soedinenij*. Kramatorsk: DDMA, 2016.
- [10] V.M. Semenov, A.Yu. Den'shnikov, S.V. Podlesny'j. Issledovanie vliyaniya termicheskoy i vibracionnoj obrabotki na deformacii svarny'x konstrukcij. *VISNIK Donbas'koï derzhavnoi mashinobudivnoi akademii*. 2 (19) (2010) 260-263.
- [11] A.F. Bulat, G.A. Shevchenko, V.A. Lenda. *Povyshenie e'fektivnosti texnologii vibracionnoj stabilizacii ostatochny'x napryazhenij i geometricheskix razmerov v svarny'x konstrukciyax*. Kiev: Institut geotexnicheskoy mexaniki im. S. Polyakova NAN Ukrainy', 2012, pp. 84-87.
- [12] G.I. Lashhenko. Texnologicheskie vozmozhnosti vibracionnoj obrabotki svarny'x konstrukcij. *Avtomaticeskaya svarka*, 7 (754) (2016) 28-34.
- [13] P.I. Yashhericy'n, E'.V. Ry'zhov, V.I. Averchenko. *Texnologicheskaya nasledstvennost' v mashinostroenii*. Minsk: Nauka i texnika, 1977. – 256 pp.
- [14] V.A. Kolot, S.V. Kovalevskij. «Sposob stabilizacii ostatochny'x napryazhenij» *Progressivnaya texnologiya v mashinostroenii*. Tezisy' dokladov. – Simferopol', 1994. – 121 pp.
- [15] Web page: <https://www.tek.com/signal-generator-software>. Available on the 23.04.2019.
- [16] Web page: <https://www.consultixwireless.com/>. Available on the 23.04.2019.