COMPUTER SIMULATION OF STRENGTH TESTING OF AN OBJECT BASED ON SIGNAL SHAPED RESONANCE

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Abstract: Considered the problem of the effectiveness of the proposed and protected method for testing systems and structures, based on the use of the impulse response of the test object as an optimal test signal. The purpose of the study is to confirm the gain in the magnitude of the response of the test object to the optimal signal compared to traditional methods. To solve the considered problem, an approach based on the representation of the test object in the form of a matched filter is proposed. As a result of computer simulation of the procedure for the impact of various test signals on the test object, it was possible to show the advantage of the optimal test signal in the form of the maximum response of the test object to it.

Key words: optimal test signal, matched filter, object impulse response, computer simulation of tests, maximum object response.

1. INTRODUCTION

Before formulating the purpose of this study of computer simulation of the process of testing an object, it is necessary to indicate to which type of systems it belongs. The test object is a dynamic system, as “a structure into which something (substance, energy or information) is introduced at certain points in time and from which something is output at certain points in time.” Among dynamic systems, we will be interested in systems with an external description of the "input-output" type. The mathematical theory of dynamic systems and the use of the procedure for modelling processes in them are widely presented in the scientific literature [1].

Of interest is the problem of determining the type of the optimal signal at the input of a dynamic system, which would provide an extreme output response of the system in the presence of alternative signals at the input of the system. The search for signals that meet this problem is the subject of studying resonance in a generalized system of the “input-output” type when studying the phenomenon of resonance in such a system. This will solve the problem of determining the shape of the optimal test signal. Such a signal should provide an extreme response at the output of the test object, exceeding in magnitude the extreme responses of alternative systems.

2. RELATED WORK

Approaches to solving this problem were made in the form of proposed testing methods and studies carried out by domestic and foreign authors. These studies are a list of some methods and methods for testing systems and structures. These include testing, an expensive and time-consuming stage in the development of software systems [2], spectral analysis of diagnostic signals [3], ultrasonic sensing [4], pulse testing [5], integration of advanced CAE tools and test environments [6], model-based testing [7], micro-level computer processing [8], patterns for natural language translation in SQL queries [9]. Especially it should be noted the most common method of shock testing in all its diversity [10]. In the question of model-based testing, it should be noted that testing is an approach in which tests are built manually, in an automated way, or generated completely automatically based on a model of the behaviour of the system under test and a model of situations associated with its operation [11].

When considering the above methods of testing objects, the question arises of the reason for the variety of proposals in the approach to the testing process. This naturally raises the question of the optimal limit of the effectiveness of the method to which they strive.

The intrigue was that all the authors of the methods at the same energies of the test signals achieved a different intensity of the maximum response of the test object, all other things being equal. This should explain the variations in the forms of test exposure, such as vibration, spectral impact, noise impact, etc. With each proposed method, it is not possible to obtain an optimal test signal. At the same time, the corresponding maximum limit is not reached, which, with equal impact energies, would provide the maximum reaction of the test object in comparison with all other methods. Thus, the problem of testing arises, which requires its solution.

3. THE PROBLEM AND SUGGESTED SOLUTION DESCRIPTION

The solution to the problem came sequentially along with the concept of the signal shape, its formalization and the meaning of the form as a number, represented in the positional number system as a sequence of generalized digits. Each of the digits is determined by the corresponding waveform sample value. The basis of the number system should be the maximum possible number of quantized values in readings. The form unit 1FOR was proposed as its minimum number.

The possibility of the existence of a shape resonance in a linear stationary dynamic system with one or one n input and one output was shown under the action of a vector set of signals with complex structures at its inputs. A feature of this type of form resonance, called matrix resonance, is its consideration exclusively as a property of the external mapping of the system. At the same time, there is no need to involve information about its internal dynamics. This made it possible to consider the test object as a system in which form resonance can be observed, i.e. resonance under non-harmonic action. As such a system, a matched filter was used as an analogue of the test object. Using the feature of a matched filter to react extremely only to a signal matched with it made it possible to answer the question of the optimality of the test signal in relation to the test object. This optimality is determined by the properties of the impulse response of the filter, as a signal matched with it. Using the impulse response as the optimal test signal of all possible signal options, allows you to get the system response with the largest maximum. This is explained by the fact that the use of a matched signal eliminates those contradictions between the characteristics of the test signals and the characteristics of the test object, which took place in all previously proposed methods. The meaning of these contradictions is as follows:

1. There are quite definite relationships in intensity between all, and not just extreme, frequency components of the amplitude-frequency characteristic of the test object. They require the same matched ratios from all frequency components of the test signal spectrum. This is necessary to obtain an optimal test result, i.e. the maximum possible response of the test object to this signal. Therefore, the random nature of the intensity of the frequency components of the impact spectrum will not meet these requirements at all. However, if it does, then with a very small degree of probability, determined by the very randomness of the test process.

2. There are certain phase relationships between all, and not just the extreme, frequency components of the PFC of the test object. They require consistent phase relationships between all frequency components of the test signal spectrum. This is necessary to obtain an optimal test result, i.e. the maximum possible response of the test object to this signal. Therefore, the random nature of the phase relationships between the frequency components of the impact signal spectrum will not meet these requirements at all. However, if it does, then with a very small degree of probability, determined by the very randomness of this process.

Due to these reasons, the inconsistency of the impact parameters with could not provide such a response of the object that would make it possible to detect during the test the most dangerous deviations of the system or structure parameters that may occur during their operation. The problem was to determine such a form of the optimal diagnostic signal, the parameters of which are in the best agreement with the parameters of the test object at equal energies of different test signals.

The matched filter solves this problem. Therefore, in relation to the test object, obtaining the optimal test signal is reduced to obtaining the impulse response of the object as a result of the impact on it. Further, it becomes possible to form a mirror optimal test signal, which, ceteris paribus, provides the maximum possible response of the test object [12].

The proposed and patented method for testing systems and structures implements the optimal test signal by generating a shock excitation of the test object, fixing and discretizing the impulse response of the impulse response, obtaining a mirror sequence of impulse response readings and generating an optimal test signal based on these readings. Impact application points can be selected over the entire active surface of an object subjected to external influences in real operating conditions. This will provide a simulated impact equivalent to real loads. In this case, the maximum possible reaction of the test object is achieved in comparison with existing methods [13].

Therefore, the purpose of this work is to confirm the advantages of the proposed and patented optimal algorithm for generating a test signal when testing systems and structures.

The achievement of the goal is carried out by the method of comparative computer simulation of the test algorithm using the optimal signal, which has the form of a mirror impulse response of the object, on the one hand, and traditional harmonic and noise oscillations, on the other hand, with equal impact energies. The meaning of the advantage of the method is to obtain from the optimal test signal the greatest response of the test object, all other things being equal.

The authors hope that this circumstance will contribute to the introduction of the optimal method for testing systems and structures in engineering practice.

4. EXPERIMENT DESCRIPTION

Computational experiments in the work were performed by behavioural simulation of a dynamic system using the BMS library - "Block Model Simulator" [14] and the BPTK-Pyb library [15] Simple Python Library For System Dynamics. The simulation environment has been deployed in a Python Jupyter Notebook. The above graphs are visualized using the Plotly library.

The computer model of the optimal signal has the form of a Barker-7 function, discretized by 175 samples with a value from +1 to -1 in the first part of the interval (0-T), containing only 750 samples, Figure 1. Moreover, the remaining 750-175=575 readings located after the Barker function in the interval (0-T) are taken positive and equal to 0.043 to ensure a zero average over the entire sampling interval (0-T).

We consider this function in the interval T as continuously repeating with a period T, which gives us the right to consider the computer model of the test signal obtained with its help as periodic with a discrete spectrum of harmonics. It's mirror image is the computer model of the optimal test signal, shown in Figure 2.

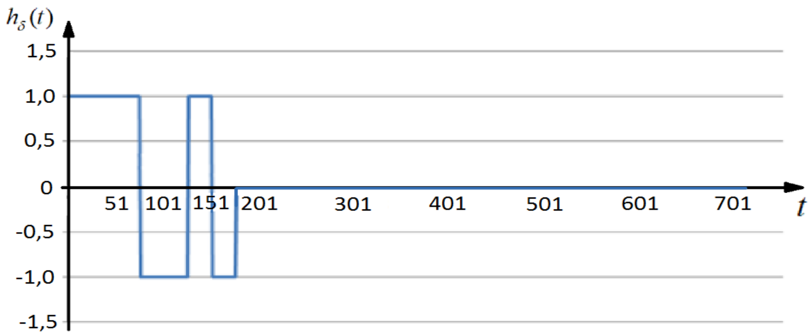

Figure 1. System impulse response

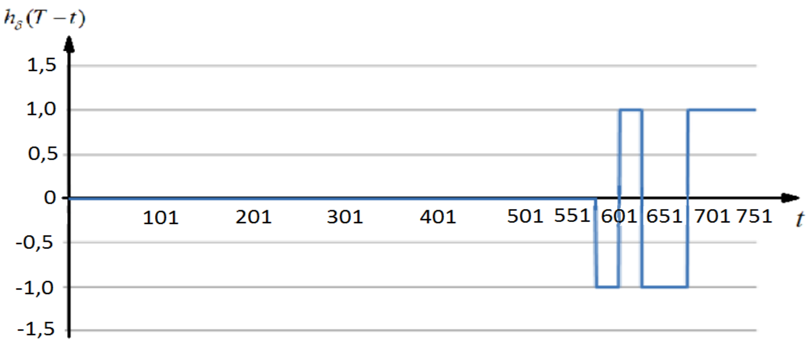

Figure 2. Optimal test signal

Consider the result of computer simulation of the convolution of the Barker function, which is a model of the impulse response of the system, with its mirror image, which is a model of the optimal test signal. As a result, we get the reaction of the object to this optimal signal (Figure 3). The maximum response of the system model to the optimal test signal model is 173.2.

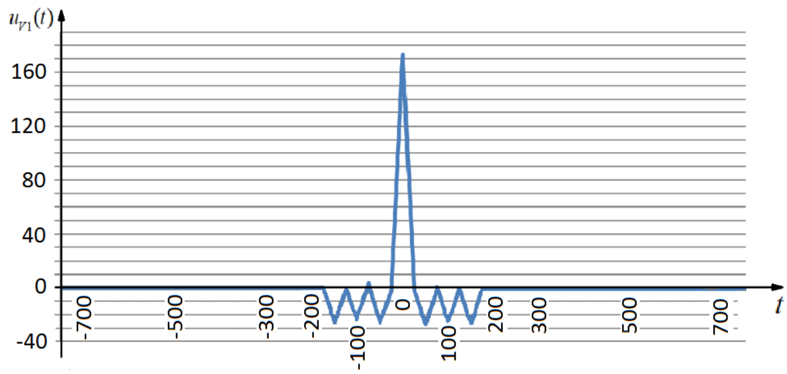

Figure 3. Object response to optimal signal

The spectrum of the impulse response of the object model, i.e. the envelope of the spectrum of harmonics n of the Barker function, similar in shape to the amplitude-frequency characteristic of the test object, has the form Figure 4.

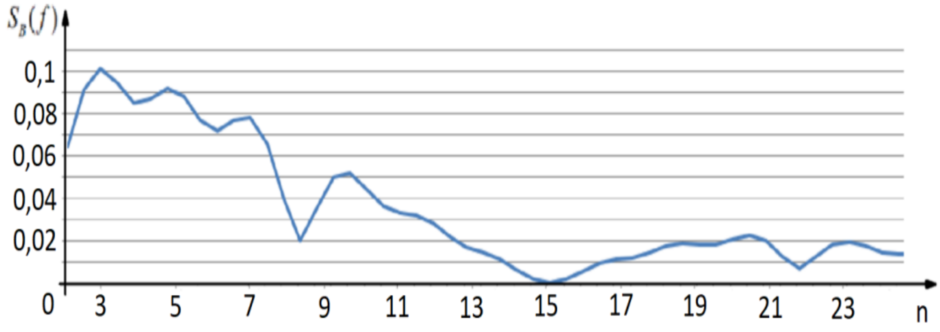

Fig. 4. Impulse response spectrum of the object model

Consider the maximum 3rd, 4th, 7th harmonics of the frequency response of the object, which, in accordance with the method of frequency testing, can be used as test signals, both individually and in a group. Let's conduct an experiment, forming from these harmonics a model of a test signal with an energy equal to the energy of the Barker-7 function in a given interval.

Let us first determine the energy of 750 signal counts in the interval (0-T):

$$W_B = N_B U_B^2 + N_0 U_0^2 = 175 \cdot 1^2 + 575 \cdot 0.043^2 = 176 \qquad (1)$$

where N_B - the number of non-zero counts of the Barker function, N_0 - the number of zero counts of the Barker function, U_B - the value of the non-zero reference of the Barker function, U_0 - the value of the zero reference of the Barker function.

When using the 3rd harmonic as a test signal model, 3 periods fit into the interval of 750 samples. This means that there are 750/3=250 readings for one period of the sinusoid. By equating the energy of the optimal signal to the energy of 3 periods of the energy of the third harmonic, one can obtain the value of the amplitude of the third harmonic from an equation of the form:

$$W_B = 3 \cdot U_{3m}^2 \sum_{k=1}^{k=250} \left[\mathrm{Sin}(k \cdot \frac{2\pi}{250}) \right]^2 \qquad (2)$$

Hence the amplitude of the harmonic signal U_{3m}=0,685B.

If the third, fourth and seventh harmonics are used together as a test signal, the total energy of which will be equal to the energy W_B, then the result of their in-phase action as a convolution with the impulse response of the object model will look like Figure 5. In this case, the maximum response of the object model to the test signal is 80. With respect to the response to the optimal signal 173.2, the gain is 2.16.

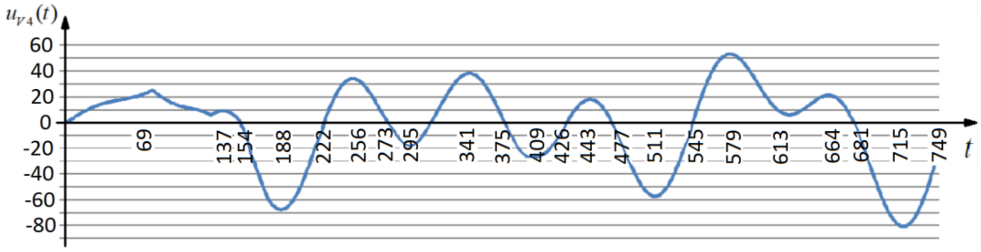

Fig. 5. The response of the object to the test signal in the form of the sum of the third, fourth and seventh harmonics

Consider as a test signal the implementation of normal (Gaussian) noise with duration and energy W_B equal to the duration and energy of the Barker function, respectively (Figure 6).

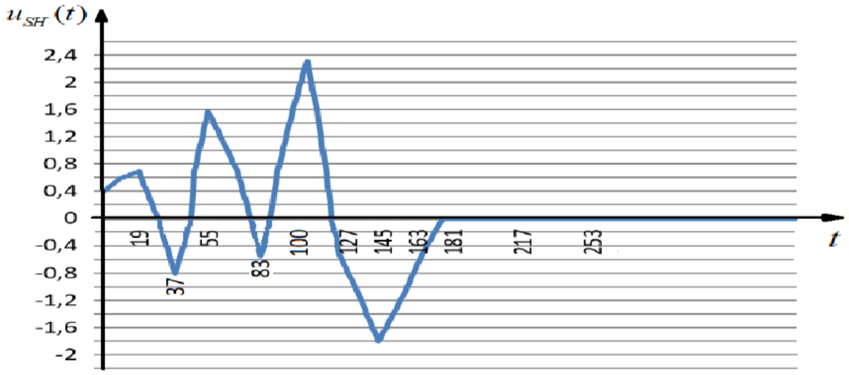

Fig. 6. Realization of normal noise as a test signal

Such test signals are often used in addition to the frequency method. The result of the convolution of the Barker system impulse response with the test signal model, a type of implementation of the Gaussian process, is shown in Figure 7.

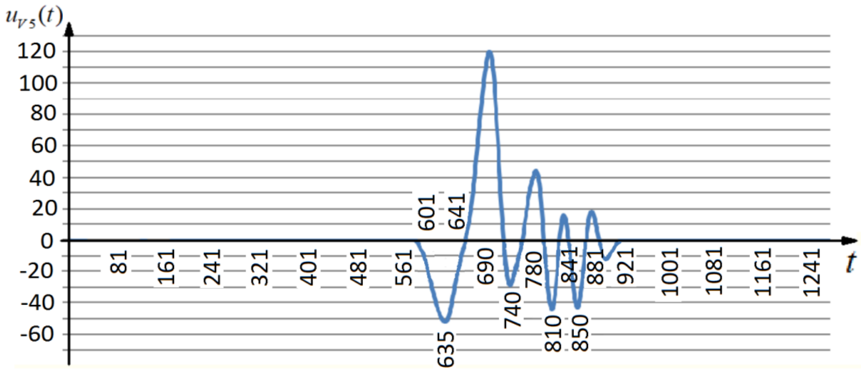

Fig. 7. Object response to a normal noise test signal

5. EXPERIMENTAL RESULTS DISCUSSION

The conducted experiment based on the simulation of the testing process using the mirror impulse response of the test object as models of test signals, as well as harmonic and noise signals, showed:

1. The test signal in the form of a mirror impulse response of the test object provides a twofold gain in the response of the test object compared to alternative signals.

2. As a result, the mentioned test signal can be considered optimal, solving the existing problem of testing systems and structures.

6. CONCLUSION

The computer simulation of the proposed optimal testing method made it possible to quantify the advantage of the method based on shape resonance in comparison with the traditional frequency testing method using the extremes of the frequency response of the object.

The optimal method is practically superior not only to the frequency method, but also to any other methods of generating a test signal, simply because it is based on the theory of a matched filter. Only this circumstance ensures the maximum response of any object to a signal of the type of impulse response matched with it.

The impulse response of the object is the optimal test signal. The reason is the fact that it contains all the features of the test object in the amplitude-frequency and phase-frequency senses.

Therefore, the arrival of the optimal method in engineering practice will not leave the slightest chance for alternative testing methods.

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