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THE METHODOLOGY OF THE SYNTHESIS OF ADAPTIVE CONTROL SYSTEM OF ACTIVE CANCELLATION OF VIBRATIONAL LOADING

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Abstract. *The paper describes the sequence of the stages of experimental synthesis of digital adaptive control system of active vibration cancellation. The methodic of plant's identification that allows the system to work in a linear range is being proposed.*

Keywords: active methods; adaptive control system; compensation of vibration.

1. Introduction

The object of the research is the console beam. The aim of the research is the synthesis of adaptive control system of active cancealltion of vibrational loading on the console beam using active methods. The methodology of the research is the experimental investigation of adaptive technologies in active methods of optimisation of materials' acoustic charachteristics.

The self-tuning of the control system in response to changes in the parameters of vibration is difficult to implement due to the nonlinear nature of these changes. Another problem is the accurate identification of an experimental model of the plant, which is used to configure the controller.

This problem is covered in a number of publications and papers. Fundamental researches are [Hansen 2001; VanDoren 2003], that are focused on the baseline principles of active cancellation and adaptive control.

This paper covers experimental identification of the plant and digital synthesis of adaptive control system of active compensation on the basis of PID controller in Matlab and Simulink.

2. Materials and methods

As a basis of researches the model-based method is chosen (Fig. 1).

PID controller (proportional-integral-derivative controller) is used as a controller (Fig. 2).

PID controller is a device in the feedback loop used in automatic control systems for control signal management. PID controller generates a control signal which is the sum of three components, the first of which is proportional to the input signal, the second is the integral of the input signal, the third is the derivative of the input signal.

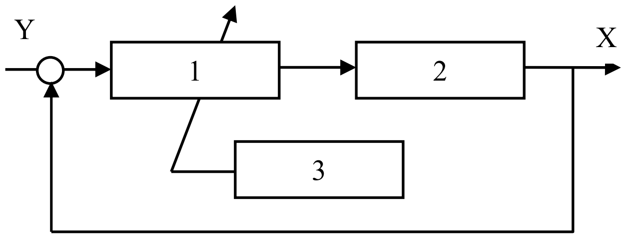


Fig. 1. Functional scheme of the control system based on the model of the plant:
1 – controller;
2 – plant;
3 – model of the plant;
Y – input of the control system;
X – output of the control system

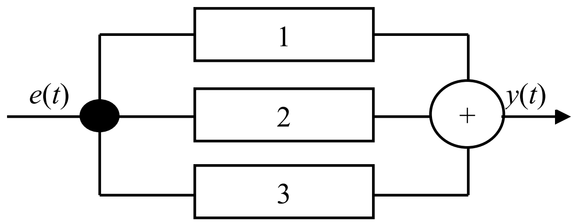


Fig. 2. Functional scheme of PID-controller:
1 – proportional block;
2 – integral block;
3 – derivative block;
e(*t*) – error signal;
y(*t*) – control signal

The relationship between output and input signals is described by the following equation:

$$y(t) = K_p e(t) + K_i \int_0^t e(t)dt + K_d \frac{de}{dt},$$

assuming K_p, K_i, K_d are the gains of proportional, integral and derivative block respectively.

Using PID controller requires experimental identification of the plants' model. The plant is console steel beam with the length 300 mm. The experimental setup is given on a Fig. 3.

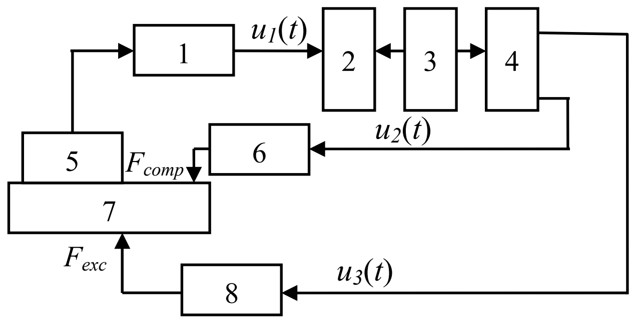


Fig. 3. Experimental setup:
1 – pre-amplifier of the accelerometer signal;
2 – ADC;
3 – PID controller;
4 – DAC;
5 – accelerometer;
6 – pre-amplifier of the control signal;
7 – steel beam;
8 – pre-amplifier of the excitation signal;
$u_1(t)$ – accelerometer signal;
$u_2(t)$ – control signal;
$u_3(t)$ – excitation signal;
F_{comp} – compensating force;
F_{exc} – excitation force

3. Results and discussion

In order to implement adaptive control based on the PID controller the identification of the plant is needed. In other words, a mathematical expression that describes its transfer function. In order to reliably identify the plant the sequence of the following steps is proposed:

1. The optimal placement of the executive device and vibration sensor.

1.1. Investigation of the plant's frequency spectrum.

1.2. Determination of resonant frequencies that occur on a spectrum of frequencies 50...150 Hz.

1.3. The excitation of the plant at the resonant frequencies to detect oscillation modes

2. Investigation of the relationship between the output voltage of the DAC and acceleration created by it in order to detect linear ranges of this dependence.

2.1. Obtaining the relationship $A = f(U)$ for the frequency spectrum 50…150 Hz, given U – voltage value, coming from the DAC output to the execution device, A – vibrational acceleration value on the coordinate of execution device.

2.2. Obtaining $U_{\min}$ – minimal value of U, at which the linearity is kept in the $A = f(U)$ dependency.

2.3. Obtaining $U_{\max}$ – maximal value of U, at which the linearity is kept in the $A = f(U)$ dependency.

2.4. Limiting the range of operating voltages of the control system to $U_{\min}$ and $U_{\max}$.

3. Identification of the plant.

4. Actual synthesis of the control system and configuration of the PID controller according to obtained plant's model.

In order to obtain the optimal coordinates for executive device and sensor placement the beam is being excited for 60 s at a frequency value that increases linearly within the frequency range 50...150 Hz to determine the beam's response. From the obtained data a conclusion of the resonance frequency of the beam is being made.

Five experiments with different coordinates of the sensor (30, 99, 148, 264, 337 mm) were held. The results are presented in Table.

Resonant frequencies of the beam's frequency spectrum

Sensor coordinate, mm	30	99	148	264	337
Resonant frequency, Hz	125	135	141	138	141

Obviously, the measurement results are different, while the deviation is not critical (<16 Hz). In this case, there are two approaches in determining the final result: the average value (136 Hz) or the maximum value (141 Hz).

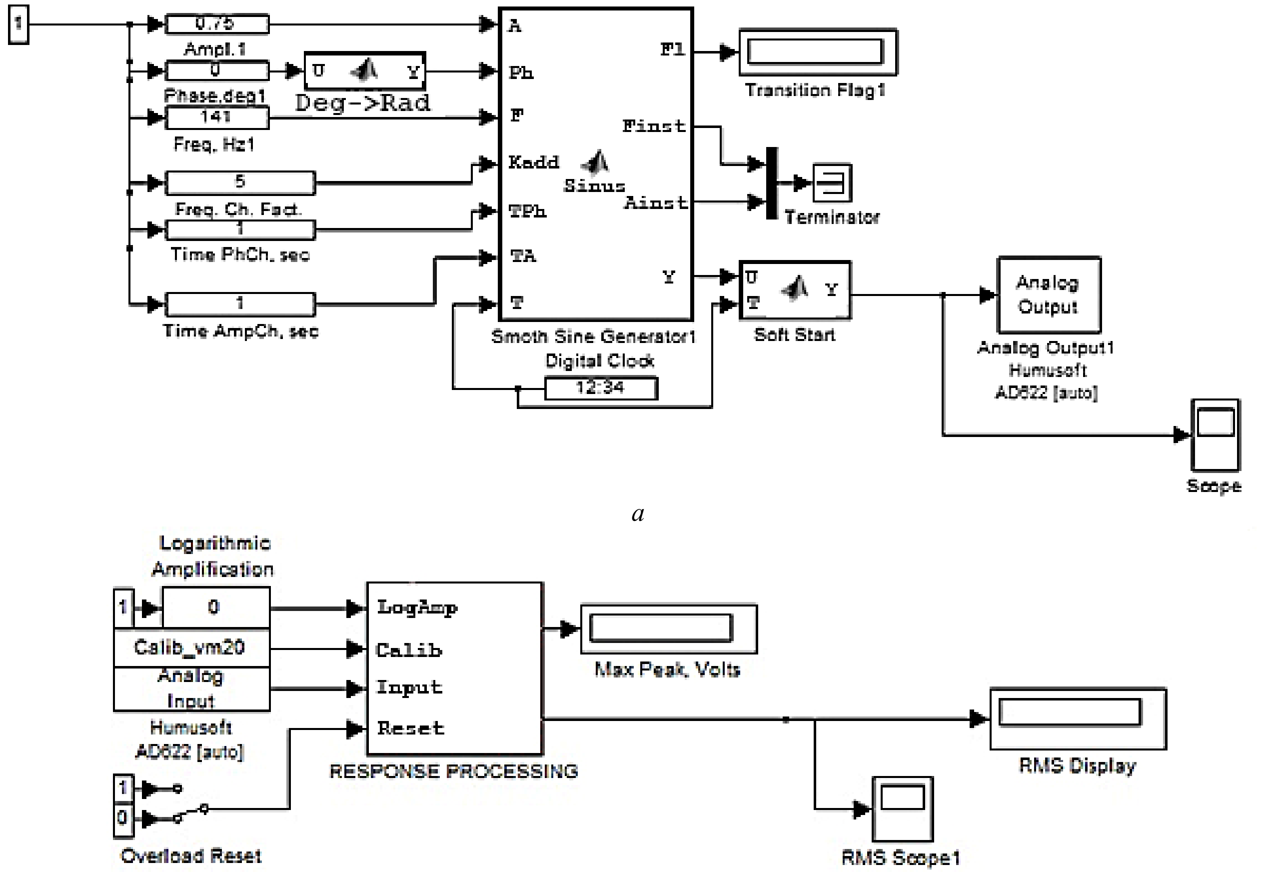
However, putting additional masses on the plant tends to lower the value of the resonant frequency, so following the second approach is more precise. Thus, the resonance frequency of the plant was assumed equal 141 Hz.

The idea of the research of the beam oscillation modes is that sensor should be placed in the modes that appear on the range 50...150 Hz (the first mode), and compensating executing in the node the second mode, for maximum lowering of its influence in an operating range.

The researches have shown next coordinates for placing the sensor installation and executive device:

1. Sensor: 264 mm.
2. Compensating executive device: 99 мм.

It is necessary to investigate the relationship between the output voltage of the DAC and acceleration it creates on the plant. For the experiment Simulink model was built, entitled UArelate.mdl. Its block diagram is shown in Fig. 4.



a

b

Fig. 4. Model UArelate.mdl:
a – output group of blocks;
b – input group of blocks

Thus, on the frequency spectrum 50-150 Hz, with increments in frequency equal to 5 Hz, the research of vibration acceleration value at voltages 0.125 V, 025 V, 0.375 V, 0.5 V, 0.625 V, 0.75 V, 0.875 V and 1 V, is being held. The values of vibration acceleration are recorded and eventually the $A = f(U)$ dependency is constructed for each frequency dependence. It is impractical to cite this characteristic for each frequency, so we give only typical cases of 50 Hz, 60 Hz and 65 Hz (Fig. 5).

It is evident that the range of operating voltages in adaptive control system should be restricted on the frequency spectrum 55...70 Hz.

It is necessary to determine the identification signal that meets these restrictions. Determined dependency for the identification signal ($U_{ident} = F(f)$), as well as minimum (U_{min}) and maximum (U_{max}) voltage restrictions are shown in Fig. 6.

At identification process 4 dependencies are displayed: Plant Input (input of system), Frequency (straight line, indicating the change in frequency of the excitation signal), Amplitude (amplitude change)

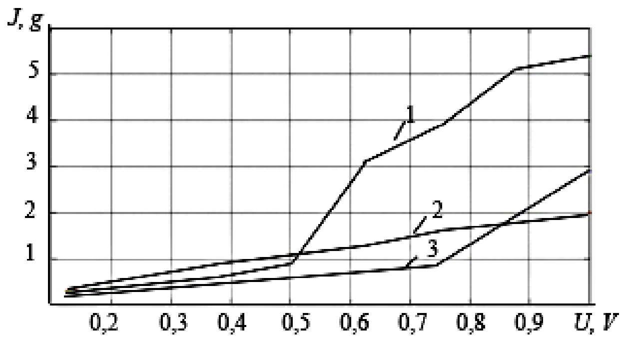


Fig. 5. The $A = f(U)$ dependency for different frequencies:
1 – 65 Hz;
2 – 50 Hz;
3 – 60 Hz

and Plant Output (measured response of the beam). All the data is stored in the structure entitled MeasRes in the Matlab workspace, from which it is possible to get the value needed for further estimation of the data using Matlab System Identification Tool.

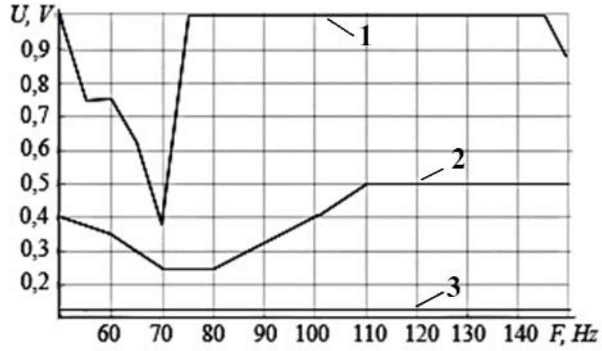


Fig. 6. The voltage restrictions and the dependency for identification signal:
1 – $U_{max} = f(F)$;
2 – $U_{ident} = f(F)$;
3 – $U_{min} = f(F)$

Since this tool needs two sets of data, it is necessary to obtain Plant Output in experiments held in modes: forward (frequency of identification signal increases linearly from 50 Hz to 150 Hz) and reverse (frequency of the identification signal linearly decreases from 150 Hz to 50 Hz).

The plant's model was estimated using Matlab System Identification Toolbox. The beam's model was evaluated with 87.7% certainty.

Before the actual synthesis of adaptive control system, the optimal values of K_p, K_i, K_d of the PID controller should be obtained. This was done using the block Discrete PID Controller from the Simulink library. The obtained values are:

$K_p = 0{,}0053$;
$K_i = 0{,}0051$;
$K_d = -0{,}0127$.

It now becomes possible to synthesize the adaptive control system.

The experiment was held in two stages. At first, control system operates with the compensating signal not applied to the beam, and then experiment is repeated with compensation signal applied to the beam.

The beam's responses on both stages are given on Fig. 7.

It is evident from Fig. 7 that the operation of control system results in reducing the beam's vibrational loading.

The estimation of the effect should be held using the values of the loading on the resonant frequency using next equation:

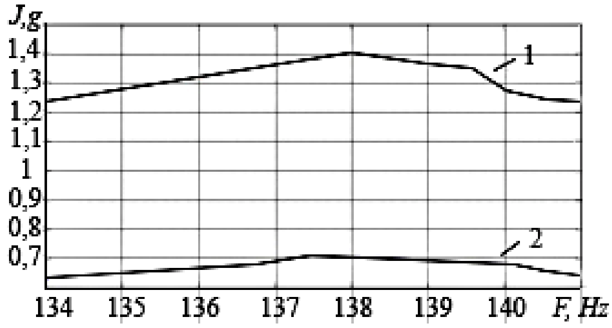


Fig. 7. Beam's response:
1 – with compensating signal not applied to the beam;
2 – with compensating signal applied to the beam

$$L_a = 10\lg\frac{A_1}{A_0} - 10\lg\frac{A_2}{A_0} = 10\lg\frac{A_1}{A_2},$$

given A_1 – RMS value of the vibrational loading with compensating signal not applied to the beam;

A_2 – RMS value of the vibrational loading with compensating signal applied to the beam;

A_0 – reference minimum value of vibration acceleration.

For the resonant frequency 141 Hz the reduction effect is:

$L_a = 2.9$ dB.

Respective Simulink model PID_BEAM_ FSETTER.mdl is shown on Fig. 8. Principally it consists of 4 basic blocks: Excite Generator, Reference Generator and Discrete PID Controller, RMS Evaluation.

4. Conclusions

The methodology of synthesis of adaptive control system of steel beam's vibrational loading reduction using active methods is proposed. As a result of experimental researches the optimal values of the controllers' gains were obtained, that allowed to successfully tune the PID controller according to obtained plant's model. The synthesis of the adaptive control system allowed to reduce the vibrational loading of the plant for 2.9 dB.

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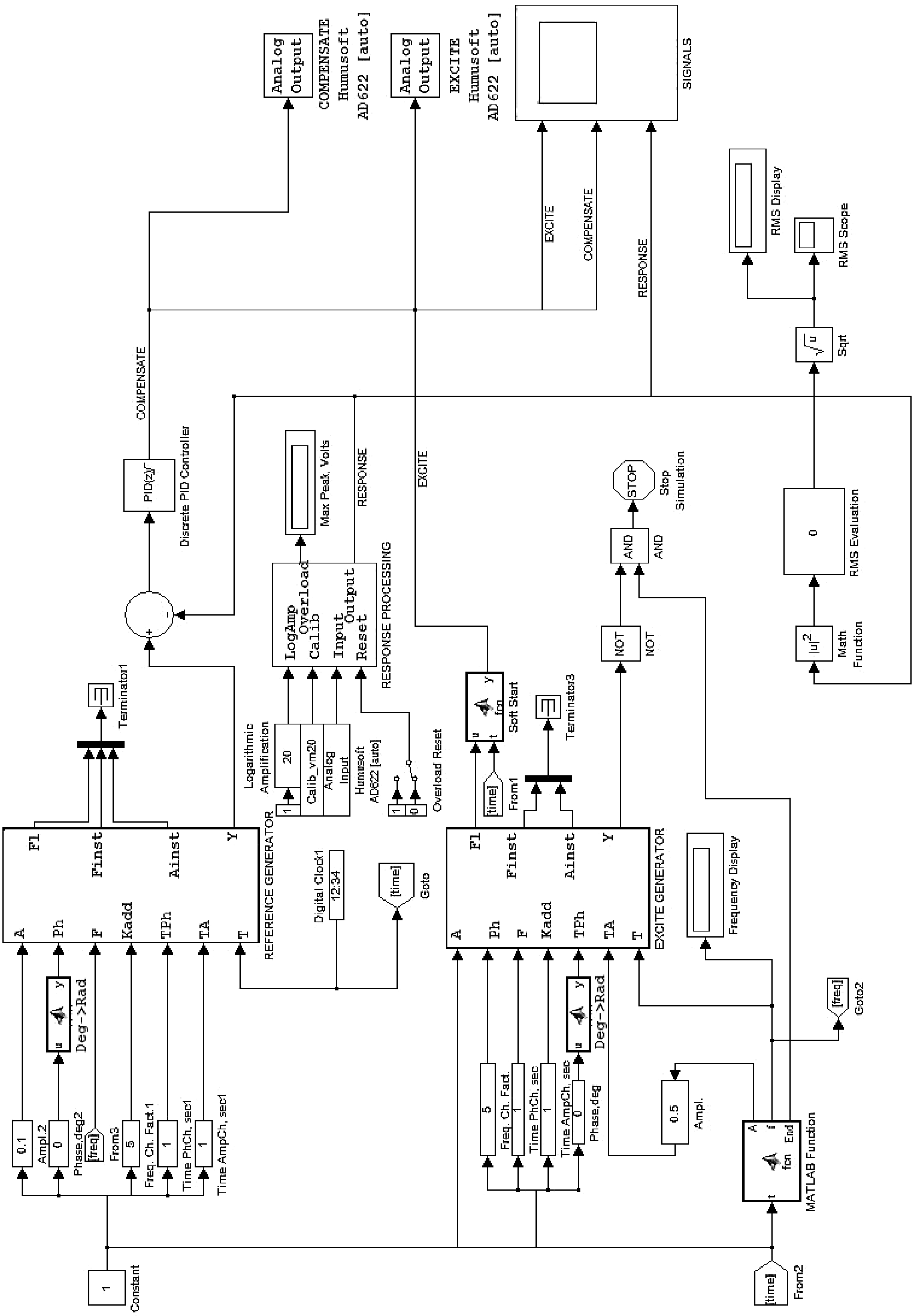

Fig. 8. Model PID_BEAM_FSETTER.mdl

Г.В. Пекуровський. Методика експериментального синтезу адаптивної системи автоматичного управління активною компенсацією вібрації

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Досліджено синтез адаптивної системи автоматичного управління зниженням вібрації на сталевій балці за рахунок використання активних методів. Описано послідовність стадій при синтезі цифрової адаптивної системи автоматичного управління активною компенсацією вібрації. На основі експериментальних досліджень адаптивних технологій при використанні активних методів оптимізації акустичних характеристик матеріалів визначено, що застосування активних методів зниження вібронавантаження може бути реалізовано на базі ПІД-регулятора з оптимальними коефіцієнтами підсилення в пропорціональному, інтегруючому та диференційному ланцюгах. Розроблено методику синтезу адаптивної системи автоматичного управління на основі активних методів зниження вібраційного навантаження, яка відрізняється від існуючих необхідністю визначення оптимальних координат розміщення сенсорів і виконавчих пристроїв, а також ідентифікацією об'єкта управління в лінійному діапазоні, що дозволило отримати з високою достовірністю параметри моделі об'єкта управління. Розглянуто методику налаштування параметрів ПІД-регулятора, яка дозволяє забезпечити адаптивність запропонованої системи автоматичного управління вібраційним навантаженням. Показано, що функціонування синтезованої адаптивної системи автоматичного управління дає можливість знизити рівень вібрації об'єкта управління за рахунок оптимального налаштування параметрів ПІД-регулятора системи автоматичного управління, наприклад, на резонансній частоті 141 Гц рівень вібрації знижується на 2,9 дБ.

Ключові слова: адаптивна автоматична система управління; активні методи; компенсація вібрації.

Г.В. Пекуровский. Методика экспериментального синтеза адаптивной системы автоматического управления активной компенсациией вибрации

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Исследован синтез адаптивной системы автоматического управления снижением вибрации на стальной консольной балке за счет использования активных методов. Описана последовательность стадий при синтезе цифровой адаптивной системы автоматического управления активной компенсацией вибрации. На основе экспериментальных исследований адаптивных технологий при использовании активных методов оптимизации акустических характеристик материалов определено, что применение активных методов снижения вибронагрузки может быть реализовано на базе ПИД-регулятора с оптимальными коэффициентами усиления в пропорциональной, интегрирующей и дифференциальной цепях. Разработана методика синтеза адаптивной системы автоматического управления на основе активных методов снижения вибрации, отличающаяся от существующих необходимостью определения оптимальных координат размещения сенсоров и исполнительных устройств, а также идентификацией объекта управления в линейном диапазоне, что позволило получить с высокой достоверностью параметры модели объекта управления. Рассмотрена методика настройки параметров ПИД-регулятора, позволяющая обеспечить адаптивность предложенной системы автоматического управления вибрационной нагрузкой. Показано, что функционирование синтезированной адаптивной системы автоматического управления позволяет снизить уровень вибрации объекта управления за счет оптимальной настройки параметров ПИД-регулятора системы автоматического управления, например, на резонансной частоте 141 Гц уровень вибрации снижается на 2,9 дБ.

Ключевые слова: адаптивная автоматическая система управления; активные методы; компенсация вибрации.

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