Synthesis of mechanical systems including passive or active elements reducing of vibrations

K. Białas*
Institute of Engineering Processes Automation and Integrated Manufacturing Systems, Faculty of Mechanical Engineering, Silesian University of Technology, ul. Konarskiego 18a, 44-100 Gliwice, Poland
* Corresponding author: E-mail address: katarzyna.zurek@polsl.pl
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ABSTRACT

Purpose: In this work there is presented basic method of synthesis of active and passive mechanical systems realization. The principal aim of the research is to work out a method of structure and parameters searching i.e. structural and parametric synthesis of a discrete model of mechanical system on the base of desired requirements. The requirements refer to dynamic features of the system, particularly its frequency spectrum.

The purpose of this paper is also comparison of reduction of vibrations in mechanical systems by use the passive and active elements.

Design/methodology/approach: In this work used unclassical method of polar graphs and their relationship with the algebra of structural numbers. This method enables analysis without limitations depending on kind and number of elements of complex mechanical system using electronic calculation technique.

Findings: Use of active elements into the elimination of vibration offers the possibility to overcome the limitations of the methods of passive elimination of vibration, such as, in particular, low efficiency in case of low-frequency vibration.

Practical implications: The results represented this work in form of polar graphs extend the tasks of synthesis to other spheres of science e.g. electric systems. The practical realization of the reverse task of dynamics introduced in this work can find uses in designing of machines with active and passive elements with the required frequency spectrum.

Originality/value: Thank to the approach, an unclassical method of polar graphs and their relationship with the algebra of structural numbers, can be conducted as early as during the designing of future functions of the system as well as during the construction of the system.

Keywords: Process systems design; Polar graphs; Structural numbers; Synthesis

1. Introduction

The occurrence of undesirable side effects in the operation of machinery may result from the factors, which may be related to a design and constructional process, manufacturing and manner of operating a machine. Designers, manufacturers and users also have to face problems of preventing unwanted effects in the operation of newly designed machinery or adapting already manufactured and operating machines to meet requirements resulting from current knowledge of hazards caused by machinery. Introducing the condition of vibration reduction into the set of constructional criteria substantially extends the scope of knowledge and qualifications required from designers and constructors [1].

There are many methods of preventing excessive vibration of machinery elements. The major division is that into passive and active measures of reducing vibration and active and passive forms of their execution. The term of passive measures of reducing vibration of machinery refers to such additional constructional elements of vibroisolation systems which do not constitute integral elements of a machine structure but are implemented additionally.
Properties of mechanical systems was it been possible to use dynamic characteristics in form of dynamic slowness and mobility \([1,3]\), about following figures:

\[ U(s) = H \frac{d_0 s^4 + d_1 s^3 + \ldots + d_5 s}{c_k s^4 + c_{k-1} s^3 + \ldots + c_0} \]

\[ V(s) = H \frac{c_k s^4 + c_{k-1} s^3 + \ldots + c_0}{d_4 s^4 + d_{3-1} s^3 + \ldots + d_4 s} \]

The synthesis of mechanical systems to be applied be able through distribution of characteristic function into partial fraction or continued fraction expansion.

2.1. Synthesis of mechanical system by means of continued fraction expansion method

The required frequency spectrum:

\[ \omega_1 = 0 \frac{\text{rad}}{s}, \quad \omega_3 = 19 \frac{\text{rad}}{s}, \quad \omega_5 = 31 \frac{\text{rad}}{s} \]

\[ \omega_0 = 0 \frac{\text{rad}}{s}, \quad \omega_2 = 13 \frac{\text{rad}}{s}, \quad \omega_4 = 25 \frac{\text{rad}}{s} \]

The structures of systems after accomplishment the synthesis was introduced in Table 1.

2.2. Qualification acting on system dynamic excitation

System number 1 (from Table 1) was selected to more far considerations. This system was weighted dynamic excitation (Fig.2). Polar graph of the system was introduced in Figure 3.
Table 1.
The structures of systems after accomplishment the synthesis

<table>
<thead>
<tr>
<th>No</th>
<th>FUNCTION</th>
<th>STRUCTURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$U(s) = s + \frac{1}{s + \frac{1}{564 + \frac{1}{2s + \frac{1}{500 + \frac{1}{2.08s + \frac{1}{s + \frac{1}{213}}}}}}$</td>
<td><img src="image1" alt="Structure 1" /></td>
</tr>
<tr>
<td>2</td>
<td>$U(s) = \frac{80}{s} + s + \frac{1}{s + \frac{1}{484 + \frac{1}{1.474s + \frac{1}{s + \frac{1}{250 + \frac{1}{1.01s + \frac{1}{s + \frac{1}{50}}}}}}}}$</td>
<td><img src="image2" alt="Structure 2" /></td>
</tr>
<tr>
<td>3</td>
<td>$U(s) = s + \frac{1}{s + \frac{1}{528 + \frac{1}{1.56s + \frac{1}{s + \frac{1}{227 + \frac{1}{1.72s}}}}}}$</td>
<td><img src="image3" alt="Structure 3" /></td>
</tr>
<tr>
<td>4</td>
<td>$V(s) = \frac{564}{s} + s + \frac{1}{s + \frac{1}{333 + \frac{1}{1.08s + \frac{1}{s + \frac{1}{250 + \frac{1}{2.68s}}}}}}$</td>
<td><img src="image4" alt="Structure 4" /></td>
</tr>
</tbody>
</table>

Fig. 2. Idea of synthesis of mechanical systems

Fig. 3. Polar graph of the system with dynamic excitation

2.3. Determination of value of damping elements

In order to solve the problem of reducing the vibration of system it is possible to implement passive elements.

A general formula for value of damping [15], when damping is proportional to elastic element, is as follows:

$$b_i = \lambda c_i$$

where:

- $b_i$ - damping elements
- $\lambda$ - modulus of proportionality $0 < \lambda < \frac{2}{\omega_n}$
- $\omega_n$ - the largest value of frequency
- $c_i$ - elastic elements
- $\lambda = 0.01$
- $b_1 = 5.64 \frac{Ns}{m}$; $b_2 = 4.32 \frac{Ns}{m}$; $b_3 = 2.29 \frac{Ns}{m}$

Systems with passive elements reducing vibrations they be introduced in figure 4 (polar graph in fig.5):

Fig. 4. The models of the system with passive elements
2.4. Determination of value of forces generated by active elements

In order to solve the problem of reducing the vibration of selected parts of a system it is necessary to implement active elements by „locating” them in optionally selected places of the system.

Applying the theory of polar graphs and their relation to structural numbers [10], it is possible to determine the values of amplitudes of forces generated by active elements.

Systems with active elements reducing vibrations they be introduced in figure 6 (polar graph in fig.7):

3. Conclusions

In this paper there are presented the basic methods of mechanical systems synthesis. The synthesis realization aims to achieving the optimum mechanical system meeting the basic and additional assumptions.

The received mathematic model as a result of synthesis allows to select mechanical system parameters for it to possess required dynamic features. The problem showed in such a way requires usage of synthesis methods, defined in categories adequate to the active and passive systems class being considered.

References