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Graphs and structural numbers in analysis and synthesis of mechanical systems

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Analysis and modelling

ABSTRACT

Purpose: The main purpose of this work is the introduction the algorithm of a analysis and synthesis of mechanical systems. The systems containing passive and active elements reducing of vibrations. In result of conducted synthesis was received structures and parameters of a discrete model meeting the defined requirements concerning the dynamic features of the system, in particular, the frequency spectrum.

Design/methodology/approach: In this paper was used a non-classical method of polar graphs and their relationship with algebra of structural numbers. The use of such a method enables the analysis and synthesis of mechanical systems irrespective of the type and number of the elements of such a system.

Findings: Presented approach simplifies the process of selecting the dynamical parameters of systems in view of their dynamical characteristics. The application of active elements to eliminate vibration enables overcoming limitations which occur if passive elements are used.

Research limitations/implications: The scope of discussion is analysis and synthesis of passive and active mechanical systems, but for this type of systems, such approach is sufficient.

Practical implications: The practical realization of the analysis and synthesis 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, introduced in this work, can be conducted as early as during the designing of future functions of the system as well as during the construction of the system. Using method and obtained results can be value for designers of mechanical systems.

Keywords: Process systems design; Polar graphs; Structural numbers; Reduction of vibrations

1. Introduction

Classical design methods of systems consist in searching for values of elements meeting specified requirements. If a given system does not meet the requirements, it needs further analysis and modification [1-9]. Such an approach can be called a method of successive trials and produces desirable results in the design of simple systems. In case of complex systems, such an approach has proved very time-consuming and unreliable as far as obtaining desirable effects is concerned. For that reason it is necessary to apply non-classical design methods such as an inverse operation called ”synthesis” [1, 4, 5, 8, 10-14]. This method consists in searching for a system structure with such values of elements which meet required frequency characteristics.

Nowadays, already at the stage of designing modern machinery, one attempts to eliminate phenomena which may adversely affect the operation of a machine or create hazard in its surroundings. In some devices vibration may be related to their fundamental operation, in other cases, however, vibration could be highly undesirable. Detrimental vibrations occurring in machines negatively affect their operation as well as reduce machine reliability and user’s comfort of work. Many methods exist to preventing excessive vibration of machinery elements. It is possible to divide them into passive, active and semi-active measures of reducing vibration [15].

2. Analysis and synthesis of mechanical systems

To solve the problem of reducing the vibration of mechanical system [1, 12, 14, 16-19], it is necessary to execute the synthesis or identification of a system.

Approaching to synthesis of mechanical system one should was act according to following scheme:

Step 1

Synthesis by means of a selected method or system after identification.

Step 2

Qualification acting on system kinematic and dynamic excitation.

Step 3

Set of structures of system containing one or more active elements and determination of value of force or forces generated by active elements or determination of value of damping elements.

Step 4

Checking frequency and time-related results obtained.

Depending, on a structure and parameters as well as input functions affecting the system, to appoint the structure of a system containing active or passive elements. Mechanical systems can be described at using dynamic characteristics in form of dynamic slowness and mobility [1, 12, 14], about following figures:

$$U(s) = H \frac{d_l s^l + d_{l-1} s^{l-2} + \ldots + d_1 s}{c_k s^k + c_{k-1} s^{k-2} + \ldots + c_0} \tag{1}$$

$$V(s) = H \frac{c_k s^k + c_{k-1} s^{k-2} + \ldots + c_0}{d_l s^l + d_{l-1} s^{l-2} + \ldots + d_1 s} \tag{2}$$

Polar graph of mechanical system of *n*-degree of freedom with kinematic, dynamic and active excitation was introduced in Figure. 1.

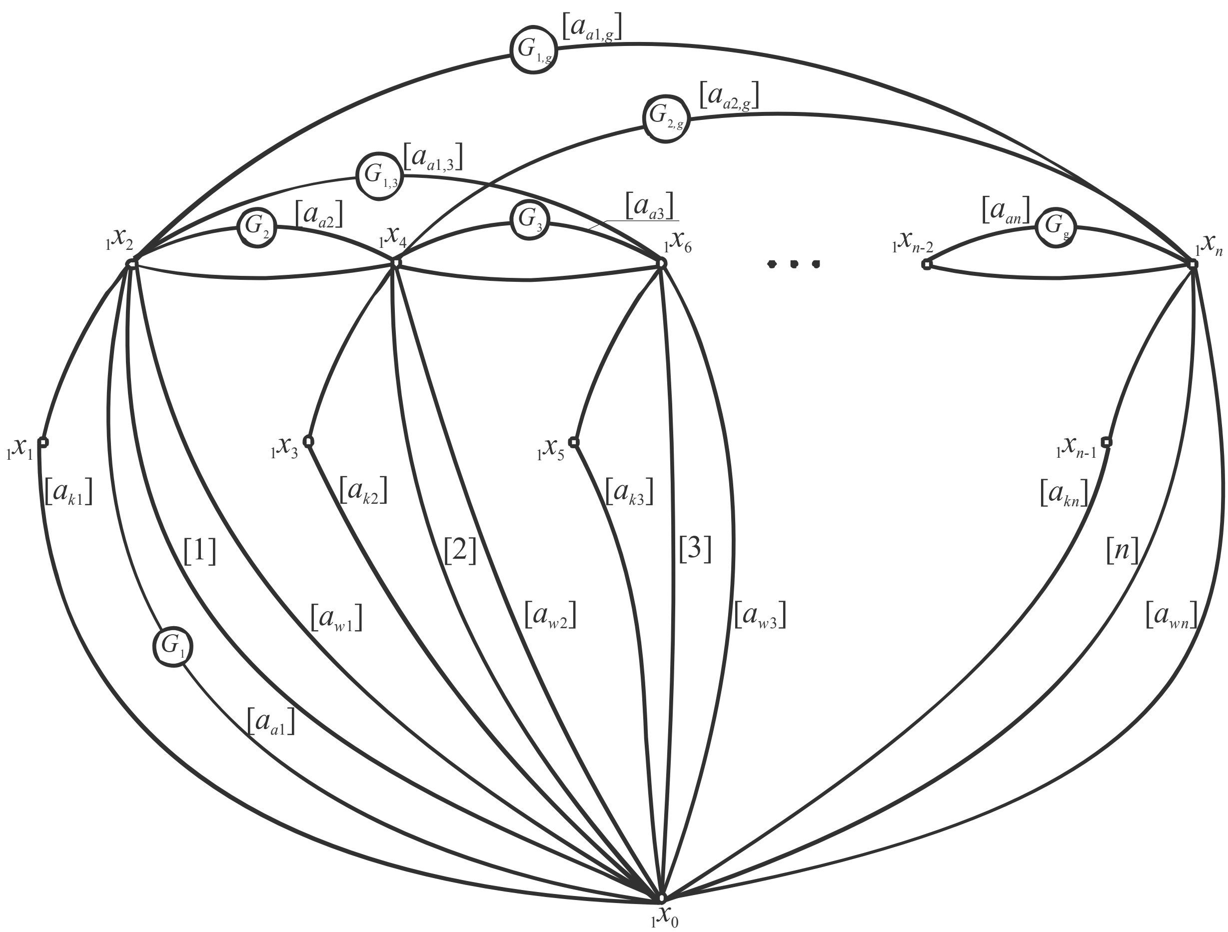

Fig.1. Polar graph of mechanical system

The above elements of polar graph (Fig. 1) are numbered according to the following standard:

$1,\dots,n$ - edges of inertial elements,

$a_{w1},\cdots,a_{wn}$ - edges of dynamic excitations,

$a_{k1},\cdots,a_{kn}$ - edges of kinematic excitations,

$a_{a1},\cdots,a_{an}$ - edges of forces generated through active elements.

Kinematic and dynamic excitations acting on mechanical system cause dislocations and vibrating of inertial elements. Using active elements it is possible to reducing this dislocations and vibrating.

Applying the theory of polar graphs and their relation to structural numbers [1, 8-10, 12, 17, 20-22], it is possible to determine the values of amplitudes of forces generated by active elements.

A general formula for amplitude value is as follows:

$$A_n = \frac{\left(\underset{z}{Sim}\left(\frac{\partial D(\omega)}{\partial[1]};\frac{\partial D(\omega)}{\partial[n]}\right)\left(F_1+F_{k1}+G_1\right)\right)+}{} \frac{+\left(\underset{z}{Sim}\left(\frac{\partial D(\omega)}{\partial[2]};\frac{\partial D(\omega)}{\partial[n]}\right)\left(F_2+F_{k2}+G_2\right)\right)+}{D(\omega)} \frac{+\dots+\left(\left(\frac{\partial D(\omega)}{\partial[n]}\right)\left(F_w+F_{kl}+G_g\right)\right)}{} \tag{3}$$

where:

$D(\omega)$ - characteristic equation,

$\frac{\partial D(\omega)}{\partial[1]}$ - derivative of structural number the in relation to of edge [1],

$\underset{Z}{Sim}\left(\frac{\partial D(\omega)}{\partial[1]};\frac{\partial D(\omega)}{\partial[2]}\right)$ - function of simultaneousness of structural number,

$F_{k1},F_{k2},\dots,F_{kl}$ - kinematic excitation,

$F_1,F_2,\dots,F_w$ - dynamic excitation,

$G_1,G_2,\dots,G_g$ - forces generated through active elements.

Solving a system of equations (5) leads to the obtaining of values of individual amplitudes generated by active elements G_1, G_2, …, G_g.

To solve problem of reducing vibration of mechanical systems it is possible to use passive elements in form of dampers.

A general formula for value of damping [12], when damping is proportional to elastic element, is as follows:

$$b_i = \lambda c_i \tag{4}$$

where:

b_i - damping elements

λ - modulus of proportionality $\left(0<\lambda<\frac{2}{\omega_n}\right)$

ω_n - the largest value of frequency

c_i - elastic elements

$$\begin{bmatrix} \left(\frac{\frac{\partial D(\omega)}{\partial[1]}}{D(\omega)}\right) & \left(\frac{\underset{z}{Sim}\left(\frac{\partial D(\omega)}{\partial[1]};\frac{\partial D(\omega)}{\partial[2]}\right)}{D(\omega)}\right) & \dots & \left(\frac{\underset{z}{Sim}\left(\frac{\partial D(\omega)}{\partial[1]};\frac{\partial D(\omega)}{\partial[n]}\right)}{D(\omega)}\right) \\ \left(\frac{\underset{z}{Sim}\left(\frac{\partial D(\omega)}{\partial[1]};\frac{\partial D(\omega)}{\partial[2]}\right)}{D(\omega)}\right) & \left(\frac{\frac{\partial D(\omega)}{\partial[2]}}{D(\omega)}\right) & \dots & \left(\frac{\underset{z}{Sim}\left(\frac{\partial D(\omega)}{\partial[2]};\frac{\partial D(\omega)}{\partial[n]}\right)}{D(\omega)}\right) \\ \vdots & \vdots & \vdots & \vdots \\ \left(\frac{\underset{z}{Sim}\left(\frac{\partial D(\omega)}{\partial[1]};\frac{\partial D(\omega)}{\partial[n]}\right)}{D(\omega)}\right) & \left(\frac{\underset{z}{Sim}\left(\frac{\partial D(\omega)}{\partial[2]};\frac{\partial D(\omega)}{\partial[n]}\right)}{D(\omega)}\right) & \dots & \left(\frac{\frac{\partial D(\omega)}{\partial[n]}}{D(\omega)}\right) \end{bmatrix} \cdot \begin{bmatrix} \left(F_{K1}+F_1+G_1\right) \\ \left(F_{K2}+F_2+G_2\right) \\ \vdots \\ \left(F_{Kl}+F_W+G_g\right) \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \vdots \\ 0 \end{bmatrix} \tag{5}$$

3. Conclusions

During designing a machine it is necessary to take into consideration various factors which may affect its operation. Proper modelling enables appropriate optimisation of machine construction as early as at the design stage. Using non-classical design methods (synthesis) make possible to obtain system parameters and structure meeting previously adopted requirements in relation to dynamic properties.

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References

[1] A. Buchacz, K. Żurek, Reverse task of active mechanical systems depicted in form of graphs and structural numbers. Monograph 81, Silesian University of Technology Press, Gliwice 2005 (in Polish).
[2] K. Żurek, Design of reducing vibration machatronical systems, Proceedings of the 7th International Scientific Conference "Computer Integrated Manufacturing - Intelligent Manufacturing Systems" CIM'2005, Gliwice–Wisła, 2005, 292-297.
[3] K. Białas, Comparison of passive and active reduction of vibrations of mechanical systems, Journal of Achievements in Materials and Manufacturing Engineering 18 (2006) 455-458.
[4] K. Białas, Synthesis of mechanical systems including passive or active elements reducing of vibrations, Journal of Achievements in Materials and Manufacturing Engineering 20 (2007) 323-326.
[5] K. Białas, Reverse task of passive and active mechanical systems, Journal of Achievements in Materials and Manufacturing Engineering 23/2 (2007) 51-54.
[6] A. Buchacz, J. Świder, Computer support CAD CAM. Support for construction of systems reducing vibration and machine noise. WNT Warsaw 2001 (in Polish).
[7] A. Buchacz, Hypergraphs and their subgraphs in modelling and investigation of robots, Journal of Materials Processing Technology 157-158 (2004) 37-44.
[8] A. Buchacz, The expansion of the synthesized structures of mechanical discrete systems represented by polar graphs, Journal of Materials Processing Technology 164-165 (2005) 1277-1280.
[9] A. Buchacz, Modifications of cascade structures in computer aided design of mechanical continuous vibration bar systems represented by graphs and structural numbers, Journal of Materials Processing Technology 157-158 (2005) 45-54.
[10] A. Buchacz, Sensitivity of mechatronical systems represented by polar graphs and structural numbers as models of discrete systems, Journal of Materials Processing Technology 175 (2006) 55-62.
[11] A. Buchacz, Modelling, synthesis, modification, sensitivity and analysis of mechanic and mechatronic system, Journal of Achievements in Materials and Manufacturing Engineering 24/1 (2007) 198-207.
[12] A. Dymarek, Reverse task of damping mechanical systems depicted in form of graphs and structural numbers. Doctoral thesis, Silesian University of Technology, Gliwice, 2000.
[13] A. Dymarek, T. Dzitkowski, Modelling and synthesis of discrete–continuous subsystems of machines with damping, Journal of Materials Processing Technology 164-165 (2005) 1317-1326.
[14] T. Dzitkowski, A. Dymarek, Synthesis and sensitivity of machine driving systems, Journal of Achievements in Materials and Manufacturing Engineering 20 (2007) 359-362.
[15] S. Michałowski, Active systems in machines construction. Cracow University of Technology Press, Monograph 171, Cracow 1994 (in Polish).
[16] A. Buchacz, Influence of piezoelectric on characteristics of vibrating mechatronical system, Journal of Achievements in Materials and Manufacturing Engineering 17 (2006) 229-232.
[17] A. Buchacz, A. Wróbel, Piezoelectric layer modelling by equivalent circuit and graph method, Journal of Achievements in Materials and Manufacturing Engineering 20 (2007) 299-302.
[18] A. Buchacz, S. Żółkiewski, Dynamic analysis of the mechanical systems vibrating transversally in transportation, Journal of Achievements in Materials and Manufacturing Engineering 20 (2007) 331-334.
[19] A. Buchacz, S. Żółkiewski, Mechanical systems vibrating longitudinally with the transportation effect, Journal of Achievements in Materials and Manufacturing Engineering 21/ 1 (2007) 63-66.
[20] A. Sękala, J. Świder, Hybrid graphs in modelling and analysis of discrete–continuous mechanical systems, Journal of Materials Processing Technology 164-165 (2005) 1436-1443.
[21] G. Wszołek, Modelling of mechanical systems vibrations by utilisation of GRAFSIM software, Journal of Materials Processing Technology 164-165 (2005) 1466-1471.
[22] J. Świder, G. Wszołek, K. Foit, P. Michalski, S. Jendrysik, Example of the analysis of mechanical system vibrations in GRAFSIM and CATGEN software, Journal of Achievements in Materials and Manufacturing Engineering 20 (2007) 3919-394.