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Synthesis and sensitivity of machine driving systems

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Analysis and modelling

ABSTRACT

Purpose: The paper presents algorithms of synthesis and sensitivity analysis of dynamics characteristics applicable for aiding the process of designing of machine driving systems. The objective of the paper was to develop algorithms for selecting of design features of physical systems so that dynamic characteristics described in the frequency domain might be shaped in the best possible manner.
Design/methodology/approach: In this work used method of polar graphs and their relationship with algebra of structural numbers. This research method of mechanical systems allows quickly and exactly calculates the impact of individual factors on his dynamic properties.
Findings: Presented approach simplifies the process of selecting the dynamical parameters of machine drive systems in view of their dynamical characteristics.
Research limitations/implications: The scope of discussion is the synthesis and sensitivity of machine drive systems as models of torsional vibrations, but for the kind of systems the approach is sufficient.
Practical implications: The developed algorithm of shaping of the dynamics characteristics make it possible to formulate the problem of optimization when making use of the objective functions constraints described in the frequency domain.
Originality/value: A process of researching the structure of a system, meeting certain conditions, is inverse to the process of analyzing it. In other words, it's a synthesis. We should emphasize that the considered problem varies from other issues met in classic mechanics or control theory. The research has been undertaken on the basis of topological methods, developed in scholar environment of Gliwice, and on the basis of algebraically methods closely related to these topological ones – that is, methods of graphs and structural numbers.
Keywords: Constructional design; Dynamic flexibility; Polar graphs; Structural numbers

1. Introduction

The selection of the dynamical properties of machines is one of the methods enhancing their durability and reliability. Such task may be accomplished with the use of the analysis and synthesis algorithm. The scope of this paper is a method of selecting the dynamical parameters of machine drive systems on the grounds of the synthesis algorithm.

The determination of such structure of the system and its parameters that meets the requirements concerning the assumed dynamical phenomena is a task inverse to analysis [17÷20, 24], therefore, it is a synthesis [3÷16,]. Such task may be regarded as a support of the stage of designing mechanical systems, where an essential element is the fulfillment of the required dynamical properties. These properties may be represented in a graphic or analytical form, or in a form of sequential zeros and poles, which shall be considered in the paper.

Modern information technologies enable the analysis and synthesis of mechanical systems on the grounds of algebraic methods, easy for programming. Such methods (apart from rigid final elements methods and boundary elements methods, on which the following packets are based: ADAMS, DADS, MESA, VERDE, SIMPAC, MEDYNA, COSMOS, BEASY, PRO-MES, ANSYS, ALGOR) include network methods of graph bonds, polar graphs, flow graphs, hybrid graphs and hyper-graphs and structural numbers [1, 2]. The applications of graphs and structural numbers developed in Gliwice research institute [3÷19, 21÷24] have inspired the subject of this paper.

The scope of discussion is the synthesis of machine drive systems as models of torsional vibrations. Such vibrations are more difficult to detect than flexural ones, which are accompanied by noise and vibrations of the adjacent elements (for example, shaft frames). Due to the absence of symptoms, torsional vibrations are particularly dangerous, as they may be unnoticeable until the destruction of subsystems occurs. Therefore, the determination of basic frequencies of the drive system free vibration is of crucial importance, as it makes it possible to avoid the operation under resonance spheres which may hinder the durability and proper functioning of a machine.

The introduction to the synthesis of machine drive systems treated as torsionally vibrating systems was discussed in [16], where the presented method of the synthesis of the characteristics distribution into a continued fraction enables the derivation of the parameters and models of a uniaxial system. It should be emphasized, however, that the derived model may have a discrete, discrete-continuous or continuous form. In view of the form of the derive equations of the models and easiness of numerical solutions, the discrete distribution models have a wider practical application than the continuous and discrete-continuous distribution ones.

The derived models constitute the bases for further verification of complex models, and a starting point for the optimization of the dynamical properties of drive systems. Sensitivity analysis is a preliminary stage of optimization research. On the grounds of its results it is possible to assess the impact of the parameters on the change of the dynamical characteristics of the system.

2. Immobility synthesis by means of the continued fraction distribution method

Theoretical details of this method are presented in [3÷ 16]. In this paper, numerical examples of synthesized systems with constant segment intersection for n = 4 and a branched structure are provided, by the application of synthesizing program. The following requirements were subjected to synthesis:

- number of elements $n = 5$,
- furthermore, it was assumed that the resonance zones of the dynamical characteristic of the synthesized systems are in the neighborhood of poles, the values of which are: $\omega_0 = 0\ \mathrm{rad/s}$, $\omega_2 = 50\ \mathrm{rad/s}$, $\omega_4 = 100\ \mathrm{rad/s}$;
- the anti-resonance zones of the dynamical characteristics of the synthesized systems are in the neighborhood of zeros, the values of the characteristic frequencies are:. $\omega_1 = 25\ \mathrm{rad/s}$, $\omega_3 = 75\ \mathrm{rad/s}$.

Such formulation of the conditions of resonance and anti-resonance zones imply the boundary conditions of the synthesised structures. It is inferred from the assumptions that the system in question is a free system vibrating torsionally. On the grounds of the input data, applying Synan's program [4, 8, 14] and Synteza's [8] program for designating inertial, elastic and damping elements of a discrete system, the following parameter values were derived, as well as the geometric representation of a discrete structure.

As the results of numerical calculations, the inertial, elastic and damping parameters are obtained (see tables 1).

Table 1.
Inertial, elastic and damping parameters of synthesized discrete system

i	$(c)_{(i)}$ [Nm/rad]	$(b)_{(i)}$ [Nm/rad]	$(J)_{(i)}$ [kgm^2]
1			1.0E+00
1	6.31655E+03	3.05324E+01	
2z			2.22E+00
2z	4.91287E+03	1.93028E+01	
4z			3.89E+00

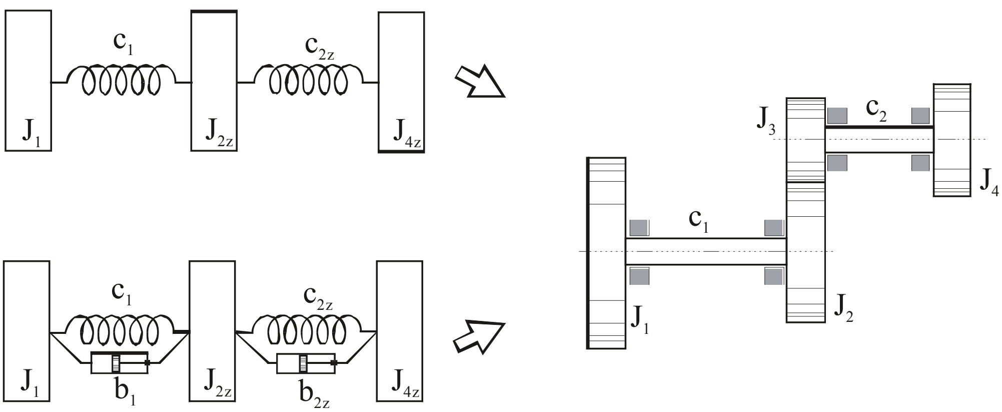

Fig. 1. Idea synthesis of machine driving systems

Applying the parameters of the discrete system (Table 1) it is possible to create two structures of a discrete system (see fig.1). The polar graphs of systems are presented in Fig.2, 3.

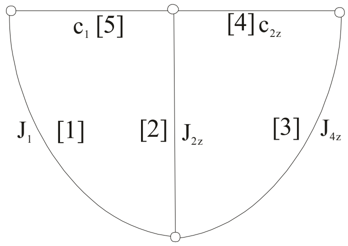

Fig. 2. Polar graph of vibration mechanical system without damping

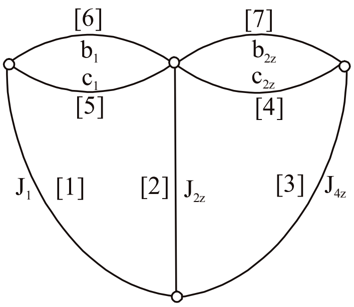

Fig. 3. Polar graph of vibration mechanical system with damping

Numerical calculations of the theoretical analysis are illustrated in Fig.4.

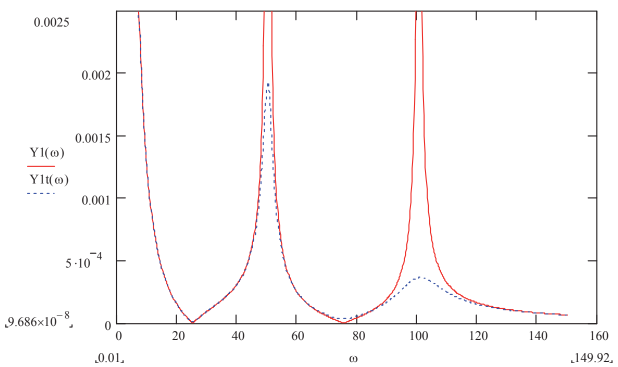

Fig. 4. FlexibilityY1 of system without damping

3. The sensitivity of discrete systems represented by polar graph and structural numbers

The way of examining the sensitivity of obtained discrete system, with respect to values of received parameters, as results of synthesis-by means the graphs and structural numbers methods-have been presented. Problems of examining the sensitivity in polar graphs categories and the structural numbers in a regard to discreet structures has been introduced in [23].

In this paper, it has been show how to nominate the sensitivity function in order to direct flexibility. The examination has been solved with a usage of graphs and their connections with structural numbers.

After following calculations, graphical representation of sensitivity functions is show in fig. 5 and fig.6.

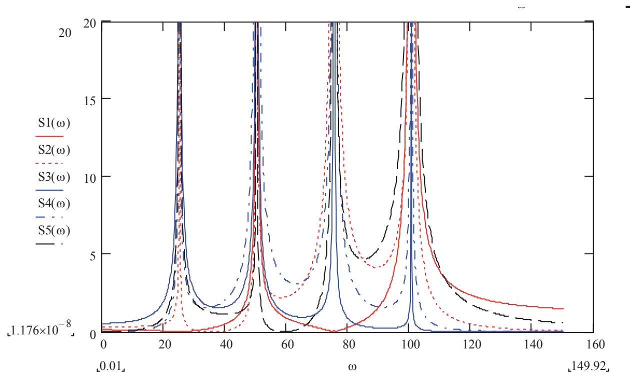

Fig. 5. The summary presentation of sensitivity function of examined mechanical system without damping

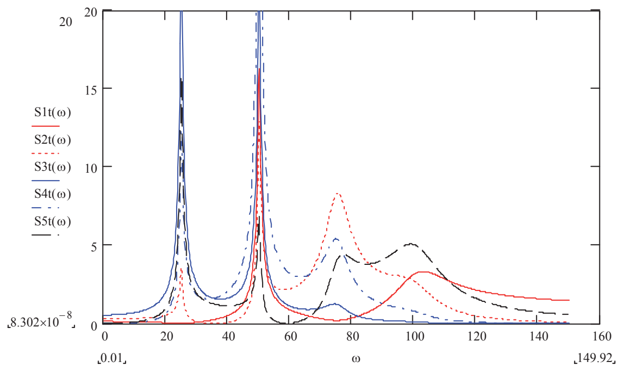

Fig. 6. The summary presentation of sensitivity function of examined mechanical system with damping

Analyzing the plots (see fig. 5 and 6) we can formulate following conclusions:

- the width of the resonance strand along the first frequency the biggest impact has the parameter J_{4z},
- comparing the width of an expanse of a sensitivity function along the second frequency it can be noticed that the parameter c_2 has a bigger influence on a width resonance section than the other parameters,
- the impact of all parameters on the width of the strand in order to the first and second frequency is comparable,
- observing the width of a section of a sensitivity function along the third frequency we can see that the more important parameter which has an influence on a width of a resonance strand along this frequency is stiffness J_2z,

- analyzing the width of the section of sensitivity function along which the fourth frequency we can notice that the most important parameter which has an impact on the width of this area has a parameter c_1, the other huge impact has the parameter J_1.

4. Conclusion

High durability and reliability of drive systems is associated with proper setting of system parameters – inertial, elastical and damping. Proper setting of these parameters is made possible by applying synthesis and sensitivity techniques. The derived parameters constitute the bases for further verification of complex models, and a starting point for the optimization.

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