



Modelling, synthesis, modification, sensitivity and analysis of mechanic and mechatronic systems

A. Buchacz*

Institute of Engineering Processes Automation and Integrated Manufacturing Systems, Silesian University of Technology, ul. Konarskiego 18a, 44-100 Gliwice, Poland

* Corresponding author: E-mail address: andrzej.buchacz@polsl.pl

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Analysis and modelling

ABSTRACT

Purpose: The main purpose of this thesis is the research of the authors scientific problematic which were presented during the AMME and CAM3S conferences.

Design/methodology/approach: The main approach to the problem is to present the variety of the conferences and on this background – the abilities of the propositions for the potential participants. According to the author of this article these were the topics concerning - modelling, synthesis, design, examining the sensitivity, modifications of discrete, continuous, discrete continuous mechatronic systems and mechatronic active or passive and also taking into consideration the transportation.

Findings: The flexibility impact of the manipulators chains in fix position with the transportation was examined. The problem of the synthesis and examining the sensitivity of continuous and discrete continuous systems with the usage of method of examining this problem with discrete models was formulated and solved. The problem: of structural modification of different type of systems was formulated and solved; of active discrete structures. The methods of synthesis according to selected class of dynamical characteristic in order to generate the “new” structures – physical realizations in a shape of models of mechatronic systems were given.

Research limitations/implications: The various linear mechanical and mechatronic systems were modelled, synthesised, design and analysed.

Practical implications: Obtained results can be used as a field of improving and developing the modelling methods as far as design and examining the various class of vibrating mechanical and mechatronic systems are concerned. Mentioned results can be also useful for the engineers which are working with this or similar problems.

Originality/value: New modelling methods, synthesis, examination of sensitivity and modifications of selected class of mechanic and mechatronic systems represented by graphs and structural numbers were presented.

Keywords: Applied mechanics; Robotics; Sensitivity; Synthesis; Modification;

1. Introduction

Developing the modelling method, synthesis, projecting, examining the sensitivity and analysis of discrete, discrete – continuous and discrete continuous mechanical and mechatronic

systems analysis I had the opportunity to take part in the scientific conferences organized with participation of Prof., L. Dobrzański. Presented paper concerns the review of the problems which was presented during these conferences and in the publications which were the result of mentioned conferences.

2. Robotics [1, 5]

The problem of modelling and investigation of manipulator of robot were considered in [1,5]. A model of the manipulator of robot as mechanical system consisting of two links, with continuously dispersed parameters. Next, a hypergraph of two-blocks has been built to represent the model. The loaded and oriented skeleton of hypergraph was used to determine a matrix of rigidities for the system.

In Fig. 1 the robot diagram is presented.

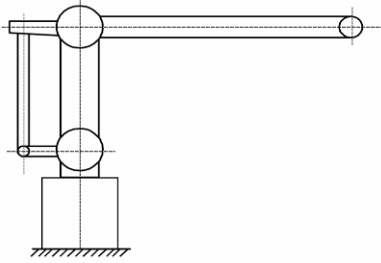


Fig.1. A scheme of the robot

As the manipulator model a system of two bars positioned in any spatial configuration is considered. We assume the possible existence of some constraints, which influence the system nodes. These constraints may appear in the form of harmonic forces (Fig. 2a) and moments (Fig. 2b) during the realization of a technological process.

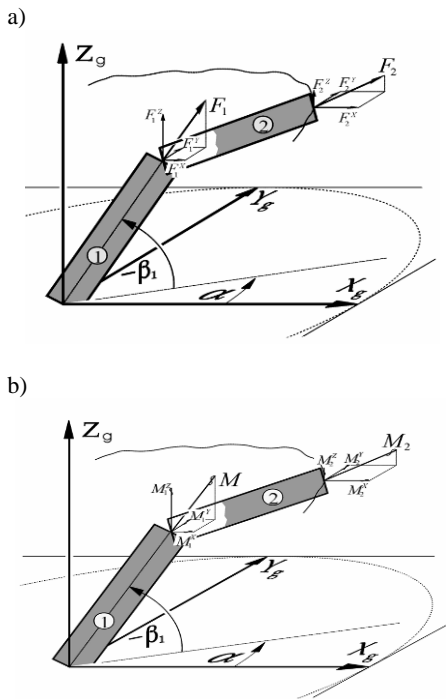


Fig. 2. Harmonical forces (a), moments of harmonical forces (b) applied to the ends of manipulator links

A completed graph of this hypergraph consists of edges, loaded with rigidities that describe connections between generalized dislocations and generalized forces working on ends of the manipulator (Fig. 3).

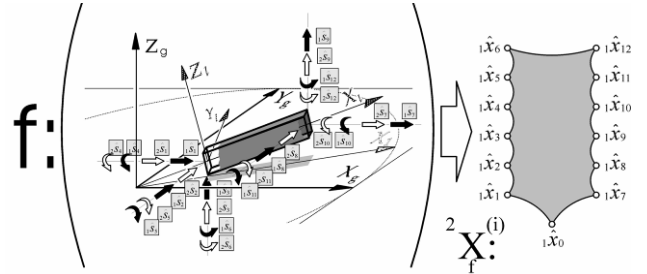


Fig. 3. Geometrical representation of the lengthwisely-flexibly-torsionally vibrating bar model projection into a hypergraph of 13 vertices

Examples of some amplitude characteristics of a manipulator links are shown in Fig. 4. Moreover examples of diagrams of trajectory and linear deflections in 3-D are shown in Fig. 5.

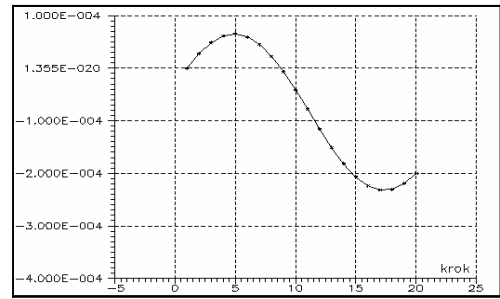


Fig. 4. The rotation displacement in relation to axis: X_g

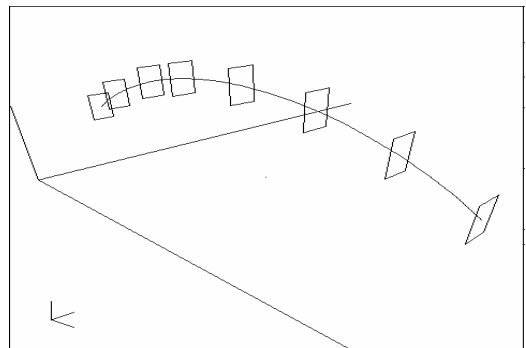


Fig. 5. Examples of linear deflections from the trajectory in 3-D

3.Sensitivity [4, 10, 13]

The design mechanical systems with certain requirements was presented in [4, 10, 13]. Then across sensitivity of parameters,

understood as quantitative measure of system, making easy estimation of influence of changes of size received in result of synthesis of computational parameters on changes of exit – size, one can estimate area resonance and to qualify which for parameters has decisive part on given resonance area. Number these of parameters limits oneself to basic unit's model of system that is to say to received coefficients of inertia and stiffness or pulps and stiffness. Then executing of correction values of parameters of system one can obtain reduction of level of amplitudes of twitches to founded values. One can so ascertain, that analysis of sensitivity of modification of parameters or of structural system fundamentally has in view as greatest adaptation of dynamic property received model to accepted criterions. System has to trellis not only definite requirements, relating of realising required of dynamic occurrences, but also required by charges statically and dynamic.

The analytical form of logarithm function, sensitivity from dynamical flexibility Y_{ik} , according to the weight of sensitivity edge can be appointed in a following manner

$$S_{a_r}^{Y_{ik}(r)} = a_r \left[\frac{\text{Sim} \left(\frac{\partial^2 A_{a_r a_k}, \partial^2 A_{a_r a_i}}{\partial a_r \partial a_k} \right)}{\text{Sim} \left(\frac{\partial^2 A_{a_i}, \partial^2 A_{a_k}}{\partial a_i \partial a_k} \right)} - \frac{\det^2 A_{a_r}}{\det^2 A} \right] = \frac{\det^2 A_{a_r}^{a_i}}{\det^2 A} \frac{\text{Sim} \left(\frac{\partial^2 A_{a_i}, \partial^2 A_{a_r}}{\partial a_i \partial a_r} \right)}{\text{Sim} \left(\frac{\partial^2 A_{a_k}, \partial^2 A_{a_i}}{\partial a_k \partial a_i} \right)} \quad (1)$$

In case of direct flexibility $Y_k(r)$ the formula number (1) can be wrote as

$$S_{a_r}^{Y_k(r)} = a_r \left[\frac{\det^2 A_{a_r a_k}}{\det^2 A_{a_k}} - \frac{\det^2 A_{a_r}}{\det^2 A} \right] = \frac{\det^2 A_{a_r}}{\det^2 A} - \frac{\det^2 A_{a_r}}{\det^2 A_{a_k}} \quad (2)$$

The polar graph of the as realisation of transforming characteristic [3,10] is shown in Fig. 6.

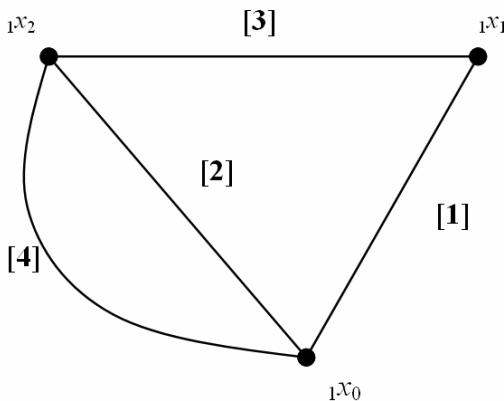


Fig. 6. Polar graph of vibration mechanical or mechatronic model of system

The sensitivity from flexibility Y_{rk} is nominated as

$$S_{a_r}^{Y_{ik}} = a_r \left[\frac{\text{Sim} \left[\frac{\partial A}{\partial [a_r][a_k]} \right]}{\text{Sim} \left[\frac{\partial A}{\partial [a_k]} \right]} - \frac{\det \frac{\partial A}{\partial [a_r]}}{\det A} \right] \quad (3)$$

The function of sensitivity according to (3) for the edge of graph, nominated as [4] it means the stiffness c_1 (Fig. 6) gets the shape of

$$S_4^{Y_{12}} = \frac{r^4 m_1 m_2 c_1 + r^2 (m_1 c_1 + m_1 c_2 + m_2 c_2) + c_1^2 c_2 - c_1 c_2^2}{r^4 (m_1 m_2) + r^2 (m_1 c_2 + m_1 c_1 + m_2 c_2) + c_2 c_1} \quad (4)$$

Graphical representation of sensitivity function (4) is shown in Fig. 7.

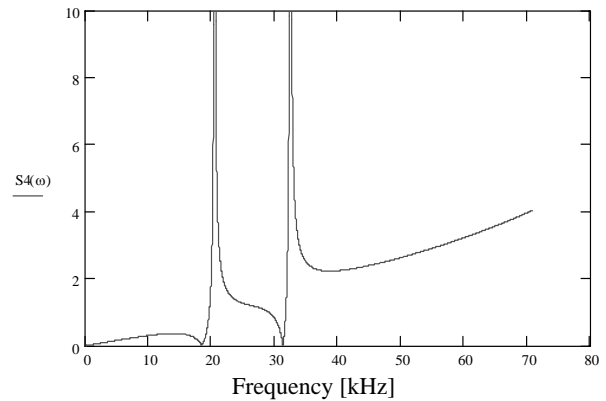


Fig. 7. The plot of sensitivity function $S_4(\omega) = S_4^{Y_{12}}(\omega)$ by the parameter c_1

4. Synthesis [14]

The problem of synthesising discrete physical, mechanical and, first of all, electrical and electronic systems is widely in scientific research. However, it is considerably to find examples of methods of synthesising discrete-continuous mechanical systems. Authors of the paper approaching these problems emphasise that the synthesis of systems with the discrete-continuous distributions of parameters is only beginning to be developed, so its exact formulation and solution is still to deal with. The partial fraction method of the synthesis of the dynamic characteristics distribution makes it possible to obtain branched structures of the discrete-continuous system [14]. The investigation into the structures of branched systems was conducted by means of the software method for distributing the dynamic characteristics to the partial fraction based on graphs and structural numbers.

5. Modification [2, 3, 6]

Basing on the design as the result of synthesis of continuous free systems with definite frequency spectrum, with cascade structure, the dynamical flexibility of such systems has the alternating: pole, zero, pole, zero, etc. Nevertheless, the frequency with the zero value is always a pole. On the other hand, in the case of systems with cascade structure but fixed at one side, the dynamical flexibility has the alternating: zero, pole, zero, pole, etc. respectively. The frequency with the zero value is always a zero. In those paper [2, 3, 6] the exactly method was applied in order to structural modification of the vibrating mechanical system with cascade structure as the task of synthesis these systems. This is the method called cascade one represented by hypergraphs and structural numbers.

Exemplary courses of characteristics of free systems as well as of systems fixed at one side, composed of seven elements with constant cross-section are presented in Fig. 8 and 9.

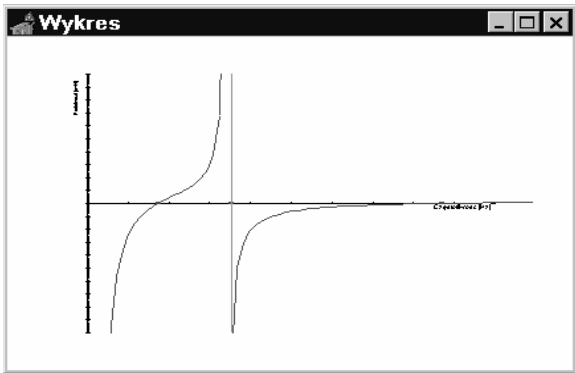


Fig. 8. Diagram of dynamical flexibility of free system with four constant segment intersection

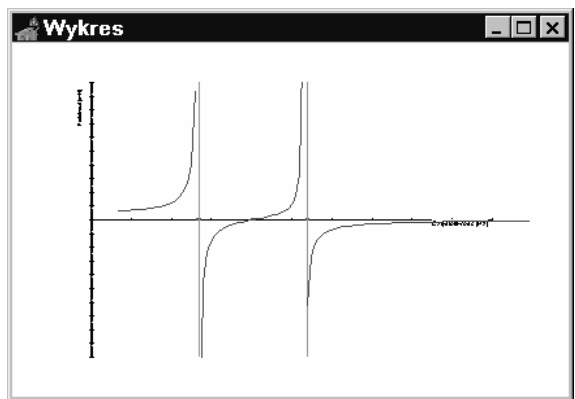


Fig. 9. Diagram of dynamical flexibility of clamped system on its end with four constant segment intersection

The mobility function as a continued fraction is obtained in form:

$$V(r) = \frac{r}{c_r^{(1)}} + \frac{1}{J_z^{(2)}r + \frac{1}{\frac{r}{c_r^{(3)}} + \frac{1}{J_z^{(4)}r + \dots + \frac{1}{\frac{r}{c_r^{(k-1)}} + \frac{1}{J_z^{(k)}}}}}} \quad (5)$$

The form (5) corresponds with mobility function of a polar graph X_{00} (see Fig. 10). The mobility determined at the point indicated by the arrow is identical with (5). This graph is a model of discrete system but after transformation it is a continuous system.

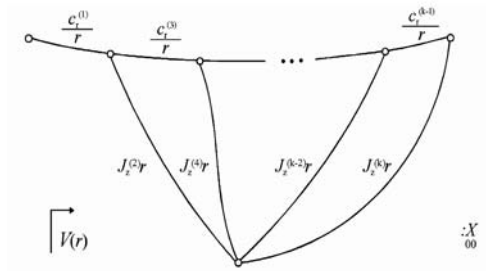


Fig. 10. Graphical illustration of equation (5)

In order to attain these function, the third category graph ${}^3X_1 = \{ {}^3X_1^{(i)}, {}^3X_1^{(i+1)} \}$ [4], as a model of longitudinally or torsionally transforming vibration system, is considered in Fig. 11 (hypergraph ${}^3X_1^{(i)} = {}^2X_1^{(i)}$ is a model of the "i" basic element, whereas hypergraph ${}^3X_1^{(i+1)}$ is a model of the other part the system contains elements from (i+1) to n).

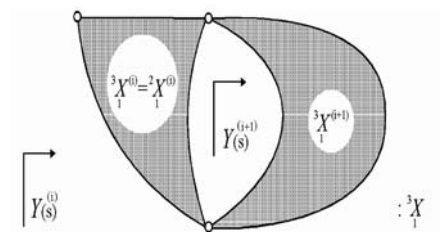


Fig. 11. Illustration of transformation of the dynamical characteristic and of the graph of a free bar and a clamped bar [2,3,6]

The construction scheme of the synthesized of transforming longitudinally or torsionally vibration system is obtained (see Fig. 12).

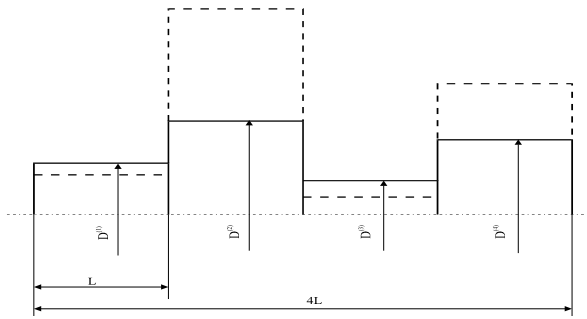


Fig. 12. Model of four-bar free system — torsionally vibrating, - - - longitudinally vibrating

6. Active systems [19, 20]

The modelling, analysis and synthesis of active mechanical systems incorporating the method of polar graphs and their relationships with structural numbers were considered in [19,12]. The work was an attempt at the comprehensive development of a reverse task of the dynamics of active mechanical systems. The introduction 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 and the impossibility to reduce the vibration of specific parts of machinery. In those works, the method of polar graphs and their relationships with structural numbers were used in order to derive equations determining the values of amplitudes of forces generated by active elements. The use of such a method enables the automation of calculation during the determination of dynamic characteristics of a system and the algorithmisation of calculations.

7. New structures [7, 8, 9]

The purpose of the papers was the application of the synthesis method according to realization of mobility or immobility function into partial fraction when the level of the denominator of characteristic is higher than the level of its numerator [7, 8, 9].

The problem of obtaining the “new” discrete vibrating mechanical systems with cascade and branched structures was formulated and formalized. The models of mechanical systems were represented by polar graphs. The reverse problem of dynamics of defined class of vibrating mechanical systems was also formalized and solved.

Findings those study were that the same class of polar graph is a model of mechanical system with “old” and “new” branched and cascade structure. Obtaining structures of graphs as models of mechanical systems are a physical realization of dynamical characteristics, which may be considered as the immobility or mobility function. Practical implications of these researches were that another approach was presented, which that means unclassical method of modeling of different structures of mechanical systems in form of polar graphs was used. The used

method of synthesis and the obtained results can be of some value for designers of designated class of vibrating mechanical systems. The results were obtained after distribution of two dynamical characteristics into partial fraction of finding structures of mechanical systems. This approach is other than those considered elsewhere.

Global case has been solved as a mobility, which is the next characteristic in the form

$$V(r) = \frac{c_k r^k + c_{k-2} r^{k-2} + \dots + c_0}{d_{k-1} r^{k-1} + d_{k-3} r^{k-3} + \dots + d_1 r}, \tag{6}$$

where: k – is even natural number.

This kind of distribution is being made by the lowest cubes of variable r . In this case the numerator and the denominator of sentence (6) have been divided into r in the highest potency

$$V(r) = \frac{c_k \frac{r^k}{r^k} + c_{k-2} \frac{r^{k-2}}{r^k} + \dots + c_0 \frac{1}{r^k}}{d_{k-1} \frac{r^{k-1}}{r^k} + d_{k-3} \frac{r^{k-3}}{r^k} + \dots + d_1 \frac{r}{r^k}} \tag{7}$$

Transforming equation (7) and introducing the new variable $r' = \frac{1}{r}$, we get

$$V(r') = \frac{c_k + c_{k-2} r'^2 + \dots + c_0 r'^k}{d_{k-1} r'^1 + d_{k-3} r'^3 + \dots + d_1 r'^{k-1}}. \tag{8}$$

When in (8) the level of the denominator is lower than the level of the numerator, which means that the reverse argument and function have to be synthesized. Finally the mobility $V(r')$ as a function of argument r' is concerned, that means

$$\frac{V(r')}{H} = \frac{(r'^2 + r_1^2)(r'^2 + r_3^2) \dots (r'^2 + r_{2n+1}^2)}{r'(r'^2 + r_2^2)(r'^2 + r_4^2) \dots (r'^2 + r_{2n}^2)}, \tag{9}$$

where: $H = \frac{c_0}{d_1}$.

Finally the formula (9) is given in the form

$$\frac{V(r')}{H} = m_z^{(\infty)} r'^1 + \frac{c_r^{(0)}}{r'} + \sum_{m=1}^n \frac{c_r^{(2m)} r'^1}{r'^2 + \frac{c_r^{(2m)}}{m_z^{(2m)}}}. \tag{10}$$

Form (10) corresponds with the mobility function of the polar graph X (see Fig. 13). The mobility determined at the point 00 indicated by the arrow is identical with (10). The graph (Fig. 13) is a model of a discrete system (Fig. 14).

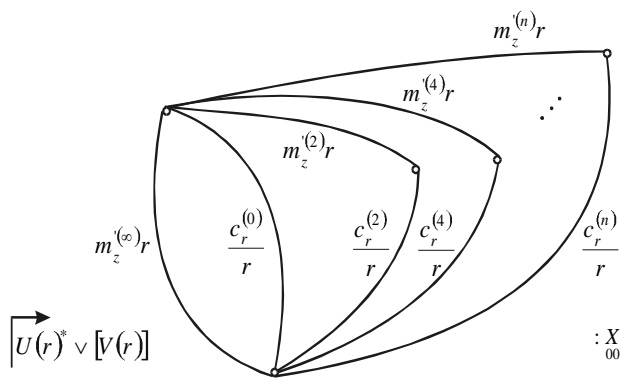


Fig. 13. Graphical illustration of equation (10)

For some edges it has to be qualify to dynamic characteristics according to order, which is a result of order of the characteristic implementation, the synthesized method of distribution the mobility $V(r)$ by partial the fraction method. The other cases of the synthesis function of an argument r and the same - r' have been presented in Table 1.

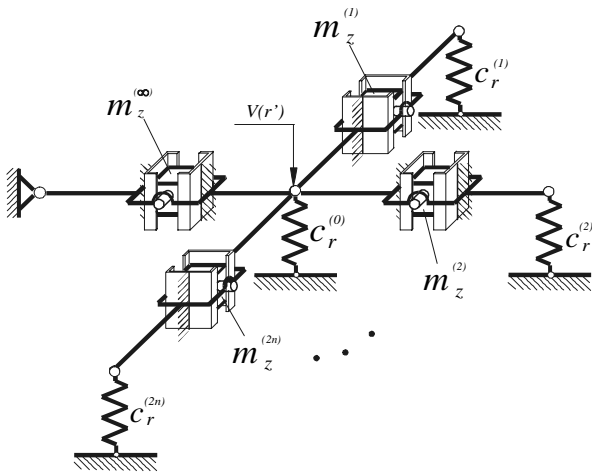


Fig. 14. The model of the mechanical system as an implementation of equation (10)

8. Vibration in transportation [16,17,18]

Main purpose of those papers [16,17,18] was analysis and modelling of mechanical systems in transportation. The contemporary technical problems are lashed with high work demands such as high speeds of mechanisms, using lower density materials, high precision of work, etc. The main objective of this thesis was the dynamical analysis with taking into consideration the interaction between main motion and local vibrations during the model is loaded by transverse forces. Equations of motion were derived by classical methods, the Lagrange equations with generalized coordinates and generalized velocities assumed as orthogonal projections of individual coordinates and velocities of

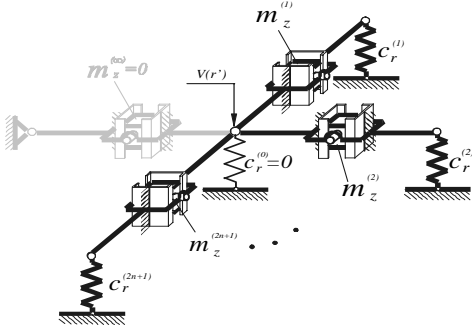
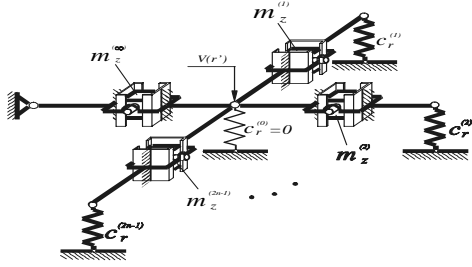
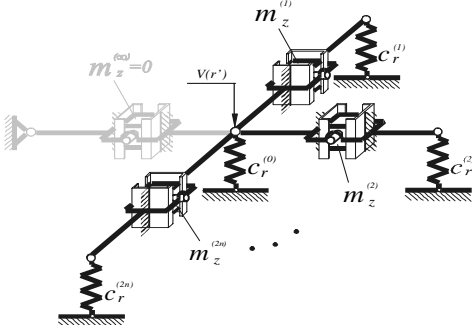
the beam and manipulators to axes of the global inertial frame. Presented mathematical model of the transversally vibrating systems in planar transportation can be put to use to derivation of the dynamical flexibility of these systems, moreover those equations are the starting point to the analysis of complex systems. In particular we can use those equations to derivation of the substitute dynamical flexibility of multibody systems. There were considered mechanical systems vibrating transversally in terms of plane motion. Next problem of dynamical analysis is the analysis of systems in non-planar transportation and systems loaded by longitudinal forces. Results of that thesis can be put to use into all machines and mechanisms running in transportation such as wind power plants, high speed turbines, rotors, manipulators and in aerodynamics issues, etc. Some results ought to be modified and adopted to appropriate models. High requirements applying to parameters of work of machines and mechanisms are caused the new research and new ways of modelling and analyzing those systems. One of these ways are presented in this thesis. There was defined the transportation effect for models vibrating transversally.

9. Mechatronics [11,12,15]

It is generally well know engineering applications of standard materials for example aluminum, gold, steel etc. In recent years, piezoelectric materials being used to construct new mechatronic systems. Equivalent circuit of piezoelectric was delivered and it was modeled by graph methods [15]. This kind of modeling by graph methods it is author's method. Piezoelectric layer was modeled by Mason's equivalent circuit. Graph method for complex system was delivered. This method is based on the matrix method and the application of the graph aggregation. After examination of piezoelectric layer, the matrix of impedance was delivered and complex system was analysis by graph methods. This matrix was author's idea for the impedance calculation of systems compound of many elements. Recurrent formula and the analysis of other kinds of smart materials are proposed in the future research. Piezoelectrics are widely applied as sensors and actuators. The advantages such as: little dimensions, simple structure, low noise factor at operating provide wide applications at vibration generating, damping, conversing of mechanical energy into electrical energy, elements of precise positioning and many others. Graph method for piezoelectric layer for modeling complex system.

Application of approximate method was main purpose of work to solution task of assignment of frequency-modal analysis and characteristics of mechatronic system [11, 12]. The problem in the form of set of differential equation of motion and state equation of considered mechatronic model of object has been formulated and solved. Galerkin's method to solving has been used. The considered torsionally vibrating mechanical system is a continuous bar of circular cross-section, clamped on one end. A ring transducer, which is the integral part of mechatronic system, extorted by harmonic voltage excitation is assumed to be perfectly bonded to the bar surface. Parameters of the transducer have important influence of values of natural frequencies and on form of characteristics of considered mechatronic system.

Table 1.
The set of characteristics and their implementations

Characteristics	Discrete mechanical system as an implementation of characteristic
$\frac{V(r)}{H} = \frac{r(r^2 + r_2^2)(r^2 + r_4^2) \dots (r^2 + r_{2n}^2)}{(r^2 + r_1^2)(r^2 + r_3^2) \dots (r^2 + r_{2n+1}^2)}$	
$\frac{V(r)}{H} = \frac{r(r^2 + r_2^2)(r^2 + r_4^2) \dots (r^2 + r_{2n-1}^2)}{(r^2 + r_1^2)(r^2 + r_3^2) \dots (r^2 + r_{2n}^2)}$	
$\frac{V(r)}{H} = \frac{(r^2 + r_1^2)(r^2 + r_3^2) \dots (r^2 + r_{2n-1}^2)}{r(r^2 + r_2^2)(r^2 + r_4^2) \dots (r^2 + r_{2n}^2)}$	

The poles of dynamical characteristic calculated by mathematical exact method and the Galerkin's method have approximately the same values. The results of the calculations were not only presented in mathematical form but also as a transients of examined dynamical characteristic which are function of frequency of assumed excitation. In the papers the linear mechatronic system has been considered, but for this kind of systems the approach is sufficient. In articles other approach was presented, that means in domain frequency spectrum the analysis has been considered. The mechatronic system created from mechanical and electrical subsystems with electromechanical bondage has been

considered. This approach is other from considered so far. Using methods and obtained results can be value for designers of mechatronics.

The mechatronic system, which has been clamped at one of its end (Fig. 15), has been considered in the paper [12]. The system was excited by the harmonic electrical voltage from the electric side which was applied to the converter clips.

The torsionally vibrating system clamped at of its ends was considered in [13] (see Fig. 16). An ideal piezotransducer ring is perfectly bonded at a certain position x_1 , to the surface of the shaft.

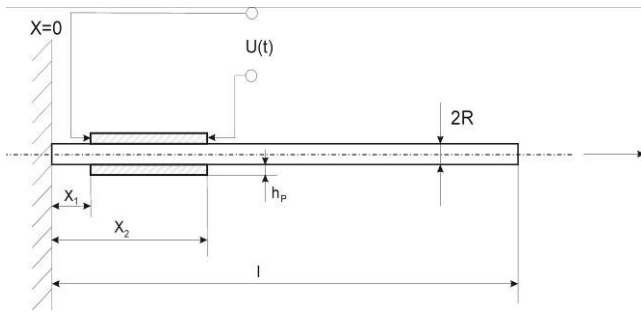


Fig. 15. The mechatronic system with electrical excitation

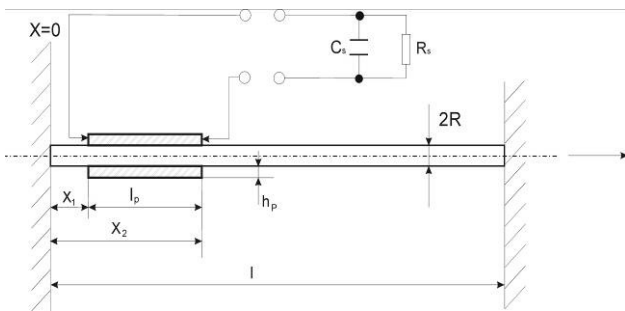


Fig. 16. Shaft with piezotransducer with mechanical excitation and shunting circuit

The mechanical part of considered mechatronic systems is the continuous elastic shaft with full section, constant along the whole length l . The shaft is made of a material with mass density ρ and Kirchoff's modulus G .

Transient of sum of $n=1, 2, 3$ mode vibration is shown in Fig. 17. For example the influence of thickness of piezoelectric on characteristics of mechatronic system are shown in Fig. 18

10. Last remark

Presented problematic is not more than the small part of the eighth year authors works and his co-authors and their cooperation with the AMME and CAM³S conferences.

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I would like to present my deep respect and gratitude to Prof. L.A. Dobrzański, the Chairman of the Scientific Committee of the AMME and CAM³S Conferences.

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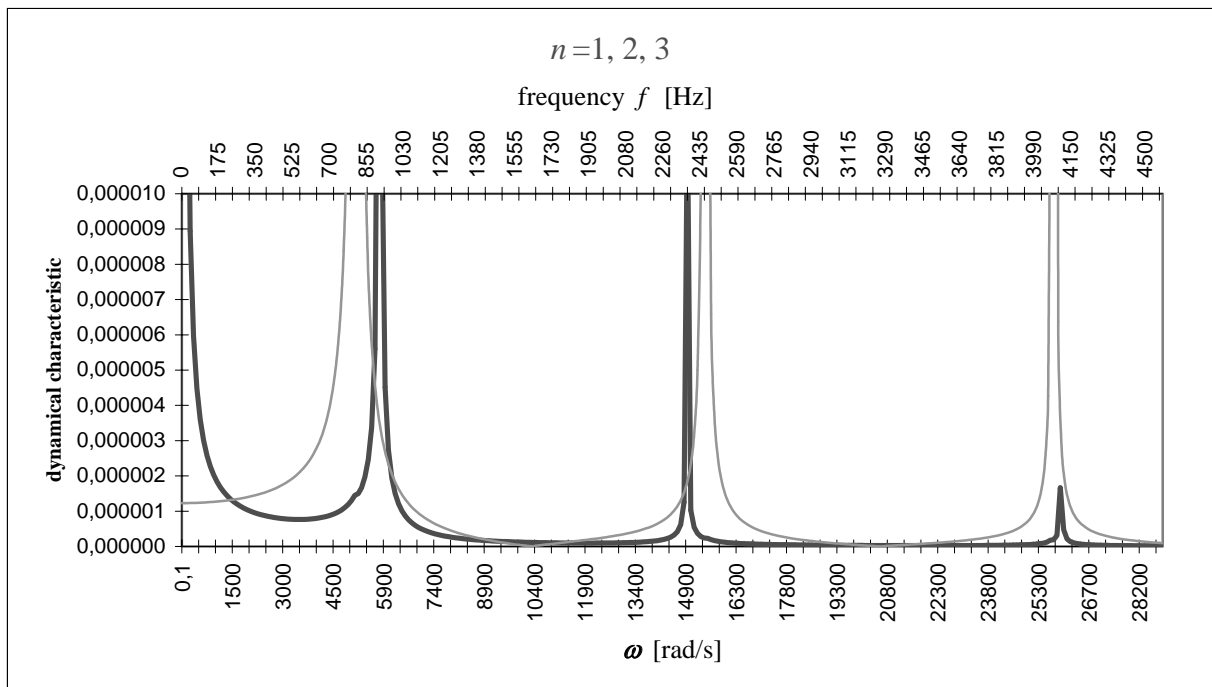


Fig. 17. Transient of the sum for $n=1, 2, 3$ mode vibration

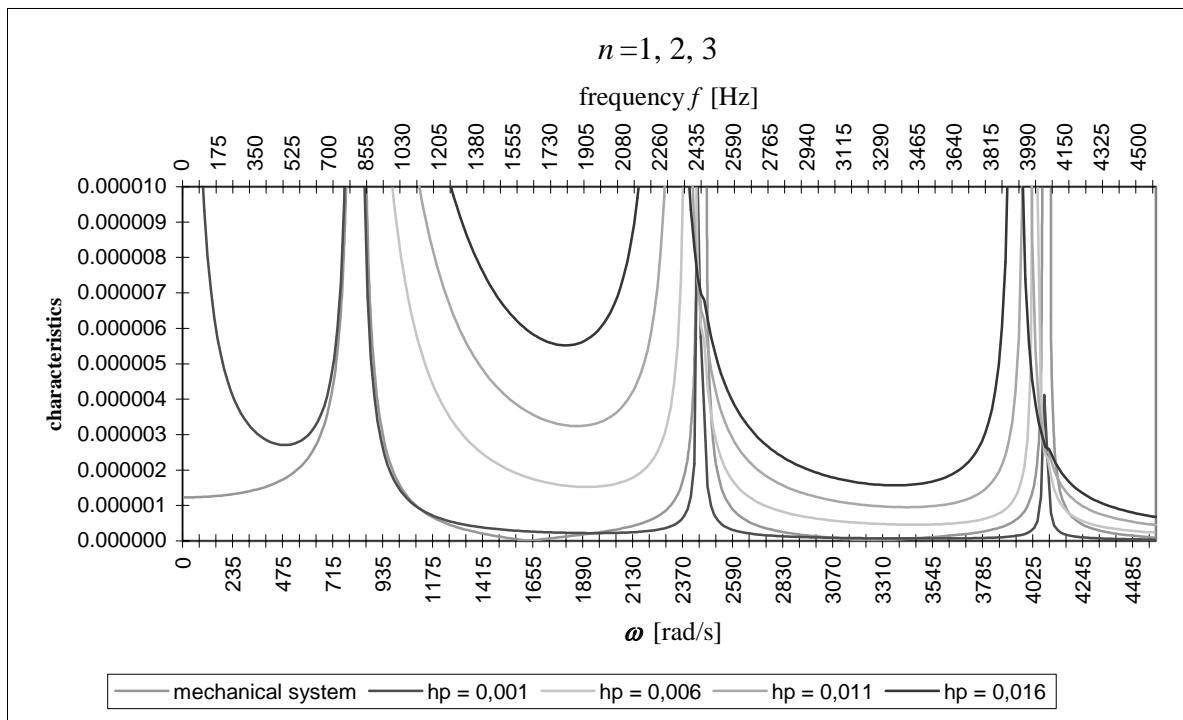


Fig. 18. Influence of thickness of piezoelectric h_p in [m] on characteristics of mechatronic system

References

- [1] A. Buchacz, Modelling of robots by means the hypergraphs method, Proceedings of 9th International Scientific Conference "Achievements in Mechanical and Materials Engineering" AMME'2000, Gliwice-Gdańsk-Sopot, 2000, 63-66.
- [2] A. Buchacz, Hypergraphs and structural numbers as the method of modification of mechanical bar-systems with cascade structure, Proceedings of the 10th International Scientific Conference "Achievements in Mechanical and Materials Engineering" AMME'2001, Gliwice-Kraków-Zakopane, 2001, 57-60.
- [3] A. Buchacz, Continued fraction expansion method represented by polar graphs as the tool of modification of discrete and continuous mechanical systems, Proceedings of the 11th International Scientific Conference "Achievements in Mechanical and Materials Engineering" AMME'2002, Gliwice-Kraków-Zakopane, 2002, 27-30.
- [4] A. Buchacz, Investigation of sensitivity of continuous vibrating systems by means the polar graphs as models of discrete systems and structural numbers method, Proceedings of the 12th International Scientific Conference "Achievements in Mechanical and Materials Engineering" AMME'2003, Gliwice-Zakopane, 2003, 127-130.
- [5] A. Buchacz, Hypergraphs and their subgraphs in modelling and investigation of robots, Journal of Materials Processing Technology 157-158 (2004) 37-44.
- [6] 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 (2004) 45-54.
- [7] A. Buchacz, The expansion of the synthesized structures of mechanical discrete systems represented by polar graphs, Journal of Materials Processing Technology 164-165 C, (2005) 1277-1280.
- [8] A. Buchacz, New structures of mechanical systems as an effect of synthesis of selected class of dynamical characteristics, Mechanical Review 5 (2005) 45-48 (in Polish).
- [9] A. Buchacz, Formulation of obtaining problem of "new" mechanical systems with branched structures as result of synthesis of selected class of dynamical characteristics, Proceedings of the 11th International Scientific Conference on "Contemporary Achievements in Mechanics, Manufacturing and Material Science" CAM3S'2005, Gliwice-Zakopane, 2005 (CD-ROM).
- [10] A. Buchacz, Sensitivity of mechatronic 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, Influence of a piezoelectric on characteristics of vibrating mechatronic system, Journal of Achievements in Materials and Manufacturing Engineering 17 (2006) 229-232.
- [12] A. Buchacz, Calculation of characteristics of torsionally vibrating mechatronic system, Journal of Achievements in Materials and Manufacturing Engineering 20 (2007) 327-330.
- [13] A. Buchacz, A. Dymarek, The sensitivity of mechanical system as criterion of solution of reverse task of dynamics by means the polar graphs method and structural numbers,

- Proceedings of the 9th International Scientific Conference “Achievements in Mechanical and Materials Engineering” AMME’2000, Gliwice-Gdańsk-Sopot, 2000, 67-70.
- [14] A. Buchacz, T. Dzitkowski, Computer aided design of discrete-continuous subsystems of machines with the assumed frequency spectrum represented by graphs, Proceedings of the 9th International Scientific Conference “Achievements in Mechanical and Materials Engineering” AMME’2000, Gliwice-Gdańsk-Sopot, 2000, 71-74.
- [15] A. Buchacz, A. Wróbel, Piezoelectric layer modelling by equivalent circuit and graph method, Journal of Achievements in Materials and Manufacturing Engineering 20 (2007) 299-202.
- [16] A. Buchacz, S. Żółkiewski, Longitudinal vibrations of the flexible-bar manipulator in terms of plane motion and taking into consideration the transportation effect, computer integrated manufacturing-intelligent manufacturing systems, Proceedings of the 13th International Scientific Conference “Achievements in Mechanical and Materials Engineering” AMME’2005, Gliwice-Wisła, 2005, 26-29.
- [17] 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.
- [18] 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.
- [19] A. Buchacz, K. Żurek, Design of active mechanical systems, Proceedings of the 12th International Scientific Conference “Achievements in Mechanical and Materials Engineering” AMME’2005, Gliwice-Zakopane, 2003, 131-134.
- [20] A. Buchacz, K. Żurek, Modelling, analysis and synthesis of active mechanical systems, Proceedings of the 3rd Scientific Conference on Materials, Mechanical and Manufacturing Engineering, M³E Gliwice, 2005, 689-694 (in Polish).