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Dynamic analysis of the mechanical systems vibrating transversally in transportation

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Analysis and modelling

ABSTRACT

Purpose: Purpose of this paper is 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.
Design/methodology/approach: 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.
Findings: 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.
Research limitations/implications: 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.
Practical implications: Results of this 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.
Originality/value: 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.
Keywords: Applied mechanics; Transversally vibrating systems; Manipulator; Transportation effect

1. Introduction

There are considered objects in the kinematical and first of all in the dynamical sense in problems of controlling mechanical systems and generally in their analysis. Dynamical flexibility is the most appropriate tool for description of dynamic features of complex technical systems. So far solutions have done by consider main motion (in this thesis transportation) and local vibrations separately. That assumption has essential sense because vibrations from flexibility of elements of the mechanical composition are much smaller than main dislocation of this composition [12,13]. There was increased scope of velocities and accelerations after there were used more efficient drives. In order to constraint power output of drives needful for motion of mechanical systems began using materials with lower mass density (for example aluminums alloys), lower than mass density of materials using up to now (for example steel). All those things are a reason of creating new models of designing systems. Those new models should take into consideration the flexibility of mechanism's links. A new way of analysis put into use in many applications where high precision of positioning (medical robots and biomechanics) are required [2-5]. Theoretical derivation where local vibrations superimpose on motion of a rigid system are also well known [1,14]. An effect of that superimpose is the approximate solution in the global reference system. Realization of those solutions can make mathematical simplification and general-purpose applications [12,13]. This thesis considers dynamical characteristics and first of all dynamical flexibility. Dynamical flexibility as we understand is the amplitude of generalized displacement with a mathematical symbol in a direction of "i" generalized coordinate changed by generalized harmonic force with amplitude equal one in direction of "k" generalized coordinate.

$$s_i^1 = Y_{ik} s_{k2} \tag{1}$$

Derivations of suitable dynamical flexibilities apply to systems vibrating longitudinally and also systems vibrating transversally in transportation.

There is maintaining a tendency to optimization parameters of working machines and mechanisms in the technique, tied with permanently growing technical requirements. It concerns mainly to maximal precision of working mechanical systems and also positioning of manipulators and robots and increase of quality and reliability. There is discrepancy between main motion and the amplitude of vibrations in applied solutions. Apart from the method of superposition we use more accurate ways of modelling machines and mechanisms. One of those there is presented in this thesis.

Rods and beams systems were modeled with taking into consideration in mathematical model the effect of main motion on local vibrations. Main motion is considered as transportation and local vibrations as relative motion. There are applied basic systems such as systems vibrating longitudinally and systems vibrating transversally in plane motion and in spatial motion. The most interesting element of dynamical analysis are: derivation of flexibility of system and presenting mutual coupling between amplitude of vibrations and velocity of transportation. Analysis of systems working with little velocities or vibrating only in the local reference system is a well-known problem in literature [1,6-11,14-16] and has known forms of vibrations. An important thing is also derivation of dynamical flexibility of complex systems with an optional number of elements. In case of complex systems and simple systems moving large velocities can put forward a phenomena of flatter or a phenomena of resonance, so depending on a type of system growing amplitude of vibrations theoretically ad infinitum and practically to a moment of durable destroying mechanisms or growing amplitude to a level adequate to a velocity, so this is a reason of decreased durability of devices. More detailed formulation of vibration's problem is the reason of considering new aspects in the contemporary technique. All those things are the cause of more accurate ways of modelling and if so the analysis of systems as rigid systems is too much simplification.

2. Modelling of the mechanical system vibrating transversally in transportation

In this section the new way of modelling mechanical systems was presented. In the thesis there were considered the models of the free beam and the beam fixed in the origin of a global reference system and also the manipulator, the two-linked system.

2.1. The transversally vibrating beam fixed in the origin in transportation

The considered arrangement is the homogeneous flexible beam with a symmetrical section (fig. 1). The beam was loaded by the harmonic transversally acting force. The force is engaged into the end of the beam. The invariability of sections assumed in whole lengths of the beam and movement analysis bounded to two-dimensional reference systems, so it determines plane motion. The model of mechanism was described in the local reference frame concerns local vibrations and totally in the global inertial reference system, where local vibrations were transformed. The beam is fixed in the origin of the global reference frame.

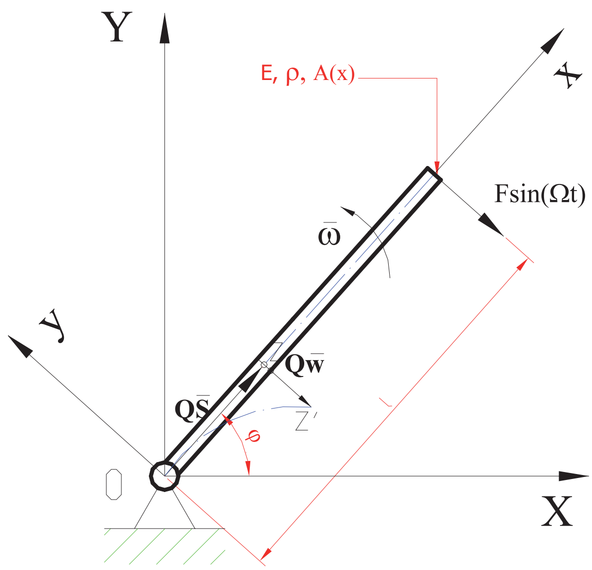

Fig. 1. The model of the rotating beam loaded by a transversal force

The beam is being rotated with respect to the origin of the global reference system in the analyzing system {0,0} with the constant angular velocity. The cross-section is not able to deformation and it is flat after straining of the beam up to the Bernoullie's hypothesis of planar sections and the stresses are in direct proportion to the strains up to the Hooke's law, also amplitudes of deflections equal values of static deflections. Hence it can be assumed that all points of the vibrating beam moves along the perpendicular line to the axis of the beam [11,14].

2.2. The model of the vibrating transversally free beam in transportation

There is considered the system vibrating in transportation. The system is consisted of the homogenous elastic beam with a full cross-section *A(x)*. The constancy of the cross-section into whole length of the beam *l* was assumed (fig. 2). The beam was made by the material with Young's modulus *E* and mass density *ρ*. There is acted the harmonic time-dependent bending force. Equations of motion were derived in the global reference system that is the independent from the beam planar system.

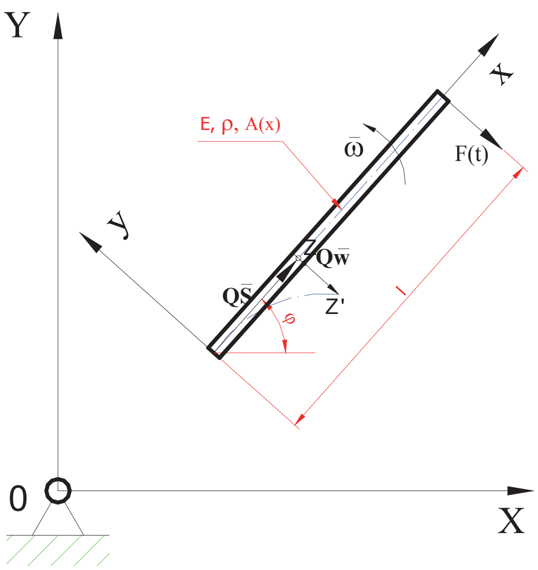

Fig. 2. The model of a vibrating beam in terms of plane motion and loaded by a harmonic bending force

2.3. The model of the transversally vibrating two-linked system

The two-link vibrating system is considered. Beams from this system have cross sections suitably $A(x)_1$ as the section of first link and $A(x)_2$ as the section of second link which are constant on the whole length of beams appropriately for first link l_{01} and in second link l_{12} (fig. 3). Beams were made from materials with Young's modulus E_1 and E_2 and mass densities ρ_1 and ρ_2. Beams were loaded by a harmonic transverse force. The mathematical model was determined in global independent reference system in terms of plane motion (XY).

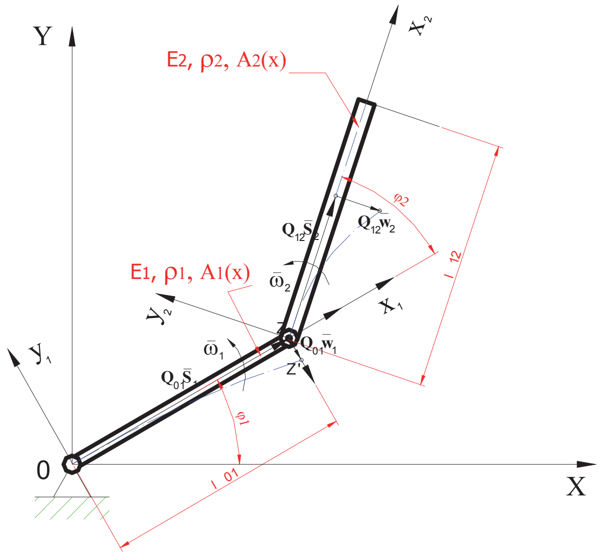

Fig. 3. The two-link model loaded by a transversal force in transportation

3. Mathematical model

In this section the mathematical models of the analyzed systems were presented. The difference between the free beam and the fixed beam in the origin of the global reference system is expressed by boundary conditions.

3.1. Equations of motion of the beam

In the previous works [2,3,5] there were derived the equations of motion of the beam by using the classical methods such as the Lagrange's equations and were presented as projections into axes of the global reference frame. The projection into the X axis of the global reference system:

$$\frac{\partial^2 w_X}{\partial t^2}+\frac{E\cdot I_Z}{\rho\cdot A}\cdot\frac{\partial^4 w_X}{\partial x^4}=-\omega^2\cdot\left(s_X-w_X\right)+2\cdot\omega\cdot\frac{\partial w_Y}{\partial t}. \quad (2)$$

The projection into the Y axis of the global reference system:

$$\frac{\partial^2 w_Y}{\partial t^2}+\frac{E\cdot I_Z}{\rho\cdot A}\cdot\frac{\partial^4 w_Y}{\partial x^4}=-\omega^2\cdot\left(s_Y-w_Y\right)-2\cdot\omega\cdot\frac{\partial w_X}{\partial t}. \quad (3)$$

3.2. Equations of motion of the two-linked system

The mathematical model of the manipulator in form of the equations of motion is presented as the system of equations, there are equations tied with first beam and second beam, projected into axes of the global reference system. The equations are not coupled each other. The main difference between equations for first and second beams is that we add to the angular velocity of the second beam the local velocity of second frame.

4. Conclusions

The dynamical analysis of the transversally vibrating systems were made in this thesis. There were took into consideration occurrences of unbalanced forces bound with transportation in the mathematical model. There was emphasized the interactions between local displacements and transportation. There was took into account acting of the Coriolis' force and the centrifugal force, that was analyzed after projection of the forces components into the appropriate axes of the global reference system. The thesis can be considered as the introduction to the analysis of complex systems in transportation. The numerical examples were derived assumed that the material of beams was the aluminum alloy and the length of the beam was assumed as equal one meter. Equations of motion were derived by classical methods. 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, in particular we can use those equations to derivation of the substitute dynamical flexibility of multibody systems. Derived mathematical model can be put to use into machines and mechanisms in transportation such as wind power plants, high speed turbines, rotors, manipulators and in aerodynamics issues, etc. Results of course ought to be modified and adopted to appropriate models. One of the new way of modelling and analyzing beam systems was presented in this thesis. There were considered mechanical systems vibrating transversally in terms of plane motion. Next problems of dynamical analysis are the analysis of systems in non-planar transportation and systems loaded by longitudinal forces.

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