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STRUCTURAL HYBRID MODELLING APPLIED TO INVESTIGATE CURRENT PROBLEMS OF ROTOR DYNAMICS

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ABSTRACT

The notion of rotor dynamics should be defined as a branch of dynamics of mechanical systems including dynamic investigations of machines and devices, the main working elements of which are under rotational motion. One of the main subjects of the rotor dynamics is a quantitative and qualitative examination of steady-state and transient bending/lateral, torsional and axial vibrations of these elements and the influence of these vibrations on the environment and cooperating objects, e.g. electric motors and generators. Because of design and technological reasons, these fundamental rotating operational elements are usually in the form of stepped rotor-shafts with segmentally constant or approximately constant cross sections. Such relatively simple geometric shape and realistic frequency ranges of practically tested vibration processes allow the use of one-dimensional structural dynamic models of the beam type ensuring an appropriate efficiency and reliability of results of theoretical analyzes carried out for this type of mechanical systems. According to the above, a one-dimensional discrete-continuous structural modeling seems to be a particularly useful modeling method for studying dynamic processes in rotating machinery. It consists in a hybrid combination of flexurally, torsionally and longitudinally deformable continuous beam finite macro-elements representing individual cylindrical or quasi-cylindrical segments of the real rotor-shaft with discrete oscillators corresponding to its bearing supports, rotor disks, coupling flanges, flywheels, etc., in accordance with a structure of the real object. Mutual connections of the successive macro-elements creating the stepped shaft as well as their interactions with the discrete oscillators and other objects, e.g. electric machines or magnetic supports, are described by equations of boundary conditions. These equations contain geometrical conditions of conformity for translational, rotational and axial displacements of extreme cross sections of the adjacent continuous elastic macro-elements. The second group of boundary conditions are dynamic ones, which contain linear, nonlinear and parametric equations of equilibrium for external forces and torques, static and dynamic unbalance forces and moments, inertial, elastic and external damping forces, support reactions and gyroscopic moments. For the local partial differential equations of motion of these macro-elements there are applied analytical solutions in the form of series in orthogonal eigenfunctions leading to the description of motion in modal coordinates. Such approach allows, on the one hand, to effectively obtain simulation results in the time domain of linear and non-linear forced vibrations and quickly-varying shock processes. On the other hand, they make it possible to conduct qualitative tests of the considered rotor-shaft systems in the form of natural vibration analyzes, generation of amplitude-frequency characteristics and determination of dynamic stability limits. Moreover, a relatively clear mathematical description of the adopted discrete-continuous (hybrid) models of the rotor-shaft systems enables us a convenient coupling of motion equations of the mechanical objects under study with circuit voltage equations being mathematical models of electric motors and generators cooperating with these objects, or with equations describing an interaction of magnetic supports.

Summing up, it should be stated that the degree of complexity of the mathematical description and numerical advancement necessary to obtain reliable solutions using this method of modeling of the above-mentioned objects can be classified as a kind of intermediate between the classical finite element modeling and traditional discrete modeling, now called "multi-body modeling". Owing to this, an application of the proposed structural discrete-continuous (hybrid) models for dynamic analyzes is associated with much smaller problems of physical parameters identification compared to a usually burdensome determination of such parameters of discrete models of respectively the same objects. As a result, this leads to an achievement of actual accuracy of calculations results comparable or identical to those obtained using analogous FEM models, while additionally there is obtained much greater numerical efficiency justified by the need to solve smaller numbers of mathematical relationships describing motion of discrete-continuous (hybrid) models.

The following examples will illustrate the calculation possibilities of the presented methodology:

1. Coupled lateral-torsional-axial vibrations of the steam turbogenerator shaft-line with a transverse crack. Here, as described in [1,2], the torsional and axial vibrations induced by the local cracked shaft anisotropy will serve as diagnostic symptoms for identification of this kind of fault.
2. Stability analysis of the automotive turbocharger rotor supported by the electrodynamic passive magnetic bearings. In order to stabilize such rotating system several ways of external damping introduction into the rotor-shaft suspension will be proposed, [3,4].
3. Dynamic investigations of the industrial fan with imperfections caused by static and dynamic unbalances of its heavy overhung rotor, parallel and angular misalignments of its drive shaft segments, inner anisotropy of couplings connecting its successive rotor-shaft segments and faulty stagger angles of its rotor-blades responsible for abnormal pressure pulsation exciting additional lateral vibration components. An influence of the above listed imperfections on sensitivity and stability of such rotor-shaft system will be tested, as demonstrated in [5].
4. Transient self-excited torsional vibrations of the electric locomotive drive system induced by a frictional interaction between the running wheels and the rails for various traction conditions.
5. A suppression of steady-state and transient torsional vibrations of the rotor machine driven by an asynchronous motor serving as a simultaneous source of drive and actuator. Here, severe resonances and rapid dynamic overloadings will be effectively attenuated by means of active motor control methods properly modified in comparison with standard ones described in [6].

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