Relative and absolute finite element nodal coordinates in the dynamics of large flexible structures subject to seismic excitations

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Abstract

In the paper general approach to dynamics simulation of rigid and flexible multibody systems based on relative and absolute coordinates of modified finite elements is proposed. The method enables the dynamic equations of rigid and flexible structures to be effectively derived and nonlinear deflections to be simulated and analyzed.

The general procedure for definition of the element nodes as moving coordinate systems makes possible their motion coordinates to be compared to the coordinates of rigid bodies, respectively, relative and absolute node coordinate formulation to be applied. Relative coordinates are successfully used for open branch multibody system simulation as single beam structures or systems compiled of many consequently connected adjacent elements as, robots and manipulators, large cantilever beam and corresponding structures, and etc. Finite elements in absolute coordinates are to be applied for complex structures with many adjacent flexible elements that form closed chains and possess many dependent coordinates.

The classical finite element approach cannot be used for dynamic simulation of large flexible deflections and for taking into account some nonlinear effects caused because of system global motion in space. An Absolute Nodal Coordinate Formulation (ANCF) approach was proposed [1] and recently developed for dynamics simulation of large rotations and deformations. The method applies specific coordinates and proposes some advantages, mainly in mass matrices formulation.

An approach called Floating Frame of Reference (FFoR) was developed [2] and has being successfully applied for dynamics simulation of large spatial motion and rotation of flexible multibody systems. Both methods, ANCF and FFoR, are the major methods developed and used at the Department of Mechanical Engineering, University of Illinois at Chicago. Similar approaches, Finite Elements in Relative and Absolute Coordinates but based on the classical Finite Element Theory [3] (FET), as well as, their further development, are presented in the paper.

Finite Elements in Relative Coordinates were successfully applied for dynamics simulation of large flexible structures and nonlinear deflections. But using this approach for complex structures with many mutually connected adjacent flexible bodies one could experience a lot of difficulties that mainly consists in its program system realization and complex pre-processor procedures.

In the paper a novel method of finite elements in absolute coordinates is discussed. The flexible elements and their node coordinate systems are considered free objects in space which motion is restricted by the elastic forces of the adjacent flexible elements. So, no kinematic restrictions, respectively algebraic equations, are imposed to the dynamic equations and the dynamic model is presented as Ordinary Differential Equations. Incremental approach for definition of system configuration during its global motion is applied, which avoids singularity of the large rotations. In Figures 1 (a, b), respectively, the relative and absolute nodal finite element coordinate formulation are presented. In Figure 1 (a) several adjacent flexible links are depicted, their motions being described by the coordinate systems of the flexible elements. The small flexible deflections are with respect to the moving reference frames. In Figure 1 (b) the absolute nodal finite elements are described. The nodes (the indices *ij* means node *j* of the element *i*) are described eider by the motion with respect to the absolute reference frame ($\rho_{0,ij}$, $\theta_{0,ik}$) or by the relative reference frame ($\rho_{i,ij}$, $\theta_{i,ij}$).

Using finite element discretization one needs precise definition of the inertia forces. In the paper generalized Newton – Euler dynamic equations for rigid and flexible bodies [4] are applied.

External excitations like wave propagations and seismic excitation are presented as reonomic constraints. A numerical method for solution of the dynamic equations subject to reonomic constraints is applied.

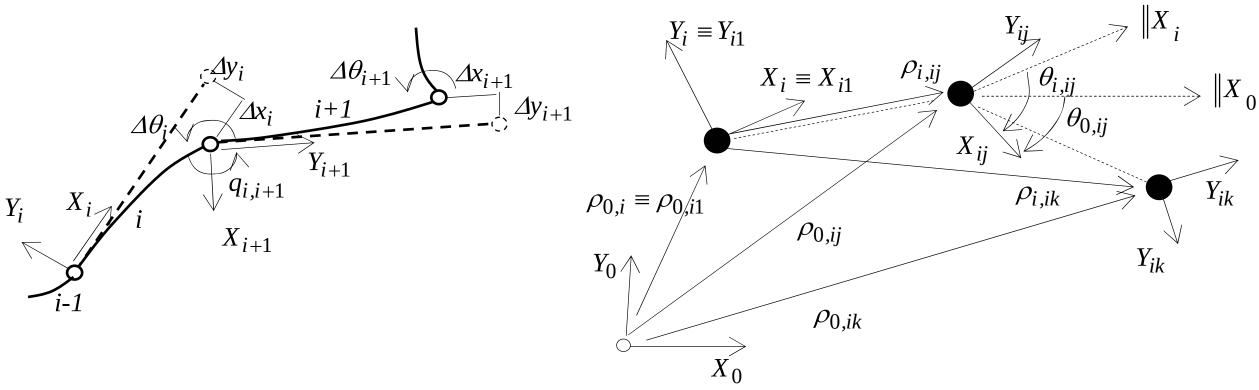

Figure 1: Relative and absolute finite element nodal coordinates.

Examples of large spatial and flexible deflections of complex rigid and flexible body structure, a wind power generator, show the effectiveness of the approach. The generator is presented in Figure 2. With black point the rigid bodies of the machine and with arrows the nodes of the finite elements discretization are shown schematically. The system of the generator, reducer, the hub and the wings are considered free objects that are fixed to the pillar and basement by damping and spring elements. The system is imposed on seismic excitations presented by two dimensional ground motions q_1 and q_2. Eccentricity of the large scale rotating electric generator is taken into account and the transient phenomena during the resonance are investigated.

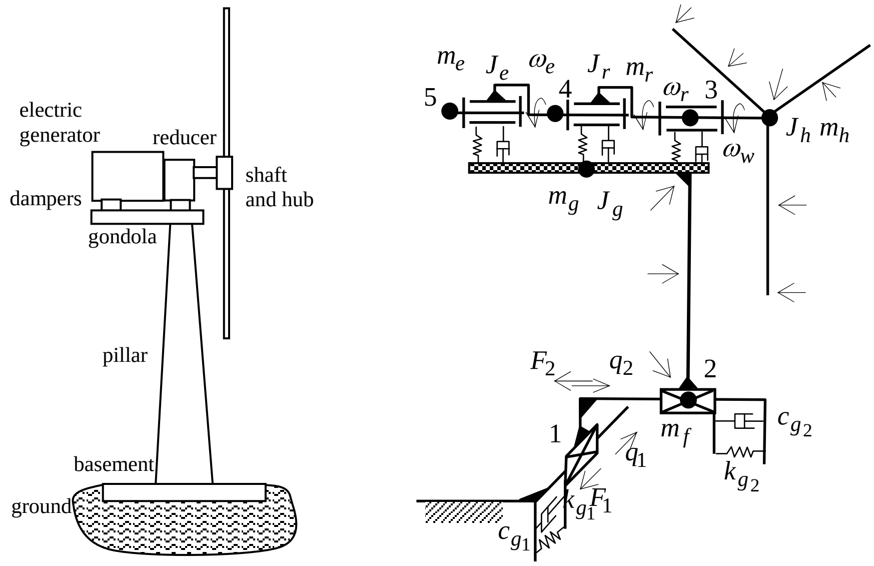

Figure 2: Virtual design scheme and dynamic model of large flexible structure (wind power generator) subject to seismic excitation.

References

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