FORCED RESPONSE ANALYSIS OF LARGE-SCALE MODELS OF STRUCTURES WITH CLEARANCES, INTERFERENCES AND FRICTION CONTACTS AT JOINTS

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An effective method has been developed for analysis of essentially nonlinear periodic vibrations of assembled structures with clearances, interferences and friction contacts at joints. The method allows fast and robust determination of multiharmonic forced response to be performed in frequency domain for finite element models with large numbers of degrees of freedom (DOFs).

Two major developments comprise the basis of the method:

(i) new nonlinear interface elements which provides exact expressions for multiharmonic components of forces and tangent stiffness matrices of the contact through the relative motion of the joined surfaces;
(ii) an effective reduction technique allowing size of the resolving equations to be decreased to the number of DOFs at the joints, where nonlinear interaction forces can occur, while preserving completeness and accuracy of the large-scale model.

The expressions for multiharmonic forces and tangent stiffness matrices for the interface elements accounting for clearances, interferences and friction contacts with the variable normal load are derived analytically and provide exact expressions for all characteristics of the dynamic contact. Accuracy of the analytical formulation allows the numerical difficulties in searching for solution of the nonlinear equations to be overcome. These difficulties have been inherent so far for the systems with the nonlinearities of considered types and have often caused the loss of the convergence and failure in searching for solutions. Another important advantage of the analytical formulation is extremely fast calculation of the characteristics of contact interface elements. The accuracy and speed of calculations provide possibility for a qualitatively new approach in analysis of large systems with joints. In accordance to this approach the interface elements can be disseminated over multitude of nodes of the finite element model over the surfaces where nonlinear forces can (but not necessarily) occur which are caused by friction upon slip-stick transitions or forces of unilateral interaction at the contacting surfaces. As a result of calculation not only multiharmonic contact forces but also contact areas and variation of the contact areas during period of vibration are determined.

A special reduction method has been developed to apply detailed large-scale finite element models in the analysis of the nonlinear vibrations. While accuracy of the initial model is preserved, the method keeps in the resolving nonlinear equations only DOFs where nonlinear forces are applied and excludes all the others. In practical applications number of DOFs where nonlinear contact forces act is usually much smaller than total number of DOFs. Because of that the size of the models that can be analysed by the method is restricted ultimately in these customary cases only by the size of the linear models of components of the assembled structure which can be analysed with available computers and software.

Numerical investigations demonstrate outstanding properties of the proposed method with respect to computational speed, accuracy and stability of computations and give a new insight into influence of nonlinear interfaces with clearances, interferences and friction on forced response characteristics.