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A Global Interpolating EFG Method for the Axially Moving Hub-Beam System

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Abstract. Based on the global interpolating generalized moving least square (IGMLS), an element-free Galerkin (EFG) method for rigid-flexible coupling dynamics of axially moving hub-beam systems is implemented. With the consideration of the geometry nonlinear terms and the longitudinal shrinking induced by the transverse deformation, the firs-order approximate coupling (FOAC) model which both the dynamic stiffening and softening effects can be reflected is built. The global interpolating and element-free properties makes some advantages of the EFG: the convenient imposition for both displacement and derivative boundary conditions and the direct obtaining of actual nodal values compared with the standard EFG method; convenience in dealing with the rigid-flexible coupling terms, constructing highly continuous shape functions and assembling the whole spatial discretized equations by comparing to FEM. Numerical comparisons between the EFG and analytical solutions on the vibration of a cantilever beam show the good accuracy and efficiency of the EFG based on the proper option of related numerical parameters. Numerical results of the axially moving hub-beam system demonstrate the reasonability of FOAC model and the feasibility of the global IGMLS applied for rigid-flexible coupling dynamics.

AMS subject classifications: 74S30, 74F99

Key words: Rigid-flexible coupling dynamics, dynamic stiffening effect, axially moving hub-beam system, element-free Galerkin (EFG) method, numerical analysis.

1 Introduction

A beam with moving support constitutes the classical rigid-flexible coupling system which is always applied in practical engineering such as turbine machine rotor blades, aircrafts with flexible appendages and robot arms. Estimating the dynamic characteristics of these structures accurately and efficiently are essential for reliable and economic design.

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Researches on rigid-flexible coupling dynamic systems in which the large overall motion of rigid bodies and elastic deformation of flexible bodies coexist have emerged for more than 40 years. In 1987, Kane et al. [1] dealt with the hub-beam system which was subjected to a prescribed rotation motion and reported that the traditional hybrid coordinate formulation may lead to erroneous results and the dynamic stiffening was firstly put forward. Since then, extensive valuable researches [2–7] on flexible beams had been conducted to find novel modeling methods and reveal the nature of the rigid-flexible coupling effect in this system.

Based on the geometric nonlinear elastic theory, Hong et al. [8] put forward the first-order approximate coupling (FOAC) model for the rotating hub-beam system. With the consideration of the second-order coupling term that represents longitudinal shrinking induced by the transverse deformation of the beam, the geometric stiffness term is included in dynamic equations of FOAC model which have been verified by both numerical methods and experiment [9, 10]. Therefore, the traditional hybrid coordinate formulation which assumes that the longitudinal and transverse deformation variables are independent for each other is called zero-order approximate coupling (ZOAC) model. The large overall motion in practical applications may be rotating with a fixed axis, translating or other composite motion. However, most studies on the rigid-flexible coupling dynamics are focused on the rotating beams or plates. There is relatively less work on the axially moving hub-beam systems than rotating structures; and in most researches, influences of the deformation on the rigid motion are usually neglected by giving a described overall motion. Therefore, the actual rigid-flexible dynamics with the flexible deformation and the rigid motion interacting of an axially moving hub-beam system are studied in this paper.

Numerical methods provide a favorable and an important approach for solving the rigid-flexible coupling problems. So far, the assumed mode method (AMM) and the finite element method (FEM) are mainly used for the discretization of the deformation field of the flexible body [8–11]. For AMM, the modes are obtained easily according to the theory of traditional structure dynamics but they are limited to flexible bodies with regular shape; meanwhile the number of mode truncation is an undermined factor and has evident influence on computational efficiency. The inherent shortcoming of the EFM comes mainly from the elements which are necessary for finite element interpolates and the numerical integration. In recent decades, the element-free method [12, 13], where the approximate solution is obtained based on a set of scattered nodes in the whole domain, such as element free Galerkin (EFG) method [14], reproducing kernel particle method (RKPM) [15] and point interpolation method (PIM) [16,17] becomes an attractive alternative in computational mechanics.

The EFG method is one of the most popular element-free methods due to its high accuracy and simple implementation [18–20]. Belytschko [14] proposed the EFG method firstly by combining the Galerkin weak forms of partial differential equations (PDEs) and the moving least squares (MLS) approximation for elasticity problems. The generalized moving least squares (GMLS) proposed by Atluri et al. [21] can be used when deriva-