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Efficient isogeometric formulation for vibration analysis of complex spatial beam structures

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Abstract

Efficient isogeometric curved beam element is formulated to investigate the free vibration behavior of spatial beam structures with arbitrary curvature and torsion. Beam structures are described by multi-patch non-uniform rational B-splines. Isogeometric formulation with Timoshenko beam theory is applied with global formulation. Compared with prior formulations that use local formulation within a single patch, the present global formulation of stiffness and mass matrices for multi patch structures is effective in dealing with complex structures. Numerical tests are carried out on a series of models including a conceptual framework of an automobile to show the effectiveness of the present method.

Keywords: Free vibration; Spatial beam; Isogeometric analysis; Multi-patch; Curvature and torsion;

1. Introduction

Spatial structures with straight and curved beams are widely used in engineering. Complex steel framework structures are popular in the design of high-rise buildings and stadiums [1, 2]. In automotive engineering, buses and racing cars apply steel tubes to form load-bearing structure and provide strength against gravity loads of passenger, engine, and outer collision forces. In bio-mechanics, deoxyribonucleic acid is deemed as a spatially curved double helix structure and can be simulated with beam theory. The wide application of beam structure makes it a very important topic in engineering and mechanics.

The natural frequency is vital to the mechanical response of structures. For civil buildings, the natural frequency, especially lower-order frequencies, determines their performance under wind and earthquakes. Dynamic analysis is vital to the vehicles' performance on noise, vibration and harshness. Buckling analysis of structures also relies on the frequency and dynamic mode shapes [3]. Therefore, the dynamic analysis of beam structures has attracted much attention.

Since it has been proposed in 2005, isogeometric analysis (IGA) has been rapidly developed [4]. Dynamic simulation of beam structures has been an important topic in IGA. Cottrell investigated the free vibration of straight beams with Euler-Bernoulli theory with IGA, in which he considered only bending deformations [5]. Lee and Park carried out a study on thick beam element with Timoshenko beam theory and considered the transverse shear and rotary inertia effect of straight beams [6]. Weeger et al. conducted an isogeometric dynamic analysis for simple straight beams under nonlinear loads [7]. These works focus on the simple straight beam problem. In 2010, Nagy et al. extended the isogeometric framework to elastic arches to obtain maximum fundamental frequency [8]. Luu et al. studied free vibration of planar curved beams with variable curvature [9–11]. Maurin, Ge et al. considered the static and dynamic isogeometric analysis of rotation-free planar beams [12, 13].

In engineering applications, free vibration analysis of spatial framework structures with arbitrary curvature and torsion is needed. The differential geometry must be used to define a curvilinear coordinate

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