



Research paper

5R pseudo-rigid-body model for inflection beams in compliant mechanisms



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ABSTRACT

A 5R pseudo-rigid-body model (PRBM) is proposed for inflection beams in compliant mechanisms. This new model consists of six rigid links connected by five joints. Four joints with torsional spring are added at the joints to simulate the deflection and a free hinge without spring is used to present the inflection point of the flexural beam. An objective function is established according to relative angular displacement between the two rigid links jointed by the free hinge for finding the optimal characteristic parameters of the 5R PRBM. The spring stiffness coefficients of the 5R PRBM are obtained using a linear regression technique. Numerical examples are presented and the results are shown by comparing with elliptical integral solutions. This new pseudo-rigid-body model behaves as load independent and can be used to predict both the tip locus and inflection position of flexural beams.

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1. Introduction

Compliant mechanisms, obtaining part or all their motion from the relative deflection of their flexibility, have been of interest in the field of mechanisms [1]. In designing and analyzing compliant mechanisms, however, it is difficult to investigate the nonlinearity of flexible beams with large deflection. A set of tools are available for working out this problem, such as finite element models, non-linear shooting method, Adomian decomposition method, pseudo-rigid-body model method, and elliptic integral solutions [2].

Compared with other methods, the pseudo-rigid-body model which requires less computation is essential to the design and synthesis of compliant mechanisms in early stages. Howell et al. [3,4] proposed a 1R PRBM with two rigid segments connected by a revolute joint. A torsional spring was placed at the joint to represent the ability of resistance to the deflection of flexible beams. However, the precision was guaranteed only in a limited range of the slope angle. Su [5] proposed a 3R pseudo-rigid-body model whose parameters were independent to the load. The accuracy of the model was relatively high when there was no inflection point on the flexible beam. In Ref. [6], a 2R pseudo-rigid-body model was proposed to improve the simulation accuracy of 1R PRBM and simplify the iterative process of the 3R PRBM. Moreover, a PR pseudo-rigid-body model was proposed to deal with the axial deflection of the flexible beam and the simulating precision was improved [7]. Based on the 3R and PR PRBM, a PRR pseudo-rigid-body model was presented further to simulate both lateral and axial deflections of flexural beams [8].

The PRBM method was one of the methods for the dynamic analysis approach of compliant mechanisms. Boyle et al. [9] developed a dynamic PRBM for the constant-force compression mechanisms. Based on the theory of dynamic equiv-

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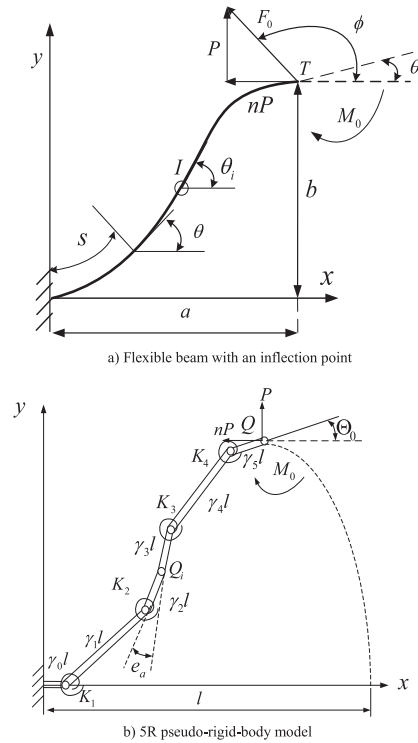


Fig. 1. Inflection beam and 5R PRBM.

alence, Yu et al. [10] derived a dynamic equation of general planar compliant mechanisms using the pseudo-rigid-body model.

The PRBM method can also be used to design compliant mechanisms. Midha [11] developed a loop-closure method for the analysis and synthesis of compliant mechanisms using the PRBM method. Jensen et al. [12] used pseudo-rigid-body model to design bistable compliant mechanisms. Aten et al. [13] proposed a numerical method for finding the equilibrium position of a given PRBM of compliant mechanisms based on the principle of minimum potential energy. According to the same theory, Jin et al. [14] proposed a more efficient approach to analyze compliant mechanisms. A node coordinate of PRBM was selected as the variables to express the elastic deformation, which simplified the formulation for the analysis of compliant mechanisms.

The study of pseudo-rigid-body model for a cantilever flexible beam with no inflection point is comparatively mature. Actually, the inflection normally exists on the flexural beams of compliant mechanisms, e.g., fixed-guided compliant mechanisms and compliant bistable mechanisms. There were only a few pseudo-rigid-body models can be applied to inflection beams. Kimball and Tsai [15] used the PRBM method to simulate the large deflection of a cantilever beam subjected to an arbitrary end load. Nevertheless, this model was oversimplified and the accuracy cannot be ensured. The 3R PRBM developed in Ref. [5] was also hard to improve the simulating precision of such flexible beam. Neither of the PRBM in Ref. [5] nor Ref. [15] were able to predict the inflection position of flexible beams. Midha et al. [16] used the concept of PRBM to generate the beam tip deflection domains where an inflection occurred in a flexible beam. The result obtained from this method was compared with those from FEM and elliptic integral solutions. However, this model was established by combining two 1R models into one model. In Ref. [17], two types of 4R PRBM were proposed to simulate the flexural beam with an inflection point. However, these two models were load dependent due to their asymmetric structures. In this paper, a new symmetric 5R PRBM is further developed to predict precisely both the location of end tip and inflection position of large deflection beams with inflection points in compliant mechanisms.

The rest of the paper is organized as follows. In Section 2, a 5R pseudo-rigid-body model is proposed for inflection beams. In Section 3, the characteristic parameters of the 5R PRBM are determined through optimization and linear regression. In Section 4, a numerical example is presented to show the effectiveness and superiority of the new model. Finally, some conclusions are made in Section 5.

2. A 5R pseudo-rigid-body model

The flexible beam is one of the major components in compliant mechanisms. When a force and a torque load are applied to the beam tip, an inflection may occur on the beam, as shown in Fig. 1(a). T is the free end of the flexible beam. l is the

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