Project Proposal

Large-Deformation Simulation of a Screw Transmission Flexural Mechanism

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***Abstract*—Screw transmission flexural mechanisms are of interest for their precision engineering applications. To this end, we analyze an exactly constrained circular hyperboloid bent-blade flexure mechanism. We propose to use mid-edge normal based formulation to simulate this mechanism, and characterize its pitch as a function of translation position. We will then compare this result with other analytic methods. [complete this proposal]**

***Index Terms*—screw theory, compliant mechanism, bent blade flexures, discrete shells**

I. Introduction

On the basis of Screw Theory, any instantaneous single-degree-of-freedom (1-DOF) motion can be described as a translation in some direction, and a coupled rotation in a parallel axis. In everyday occurrences, it is easiest to imagine the special cases of no rotation or no translation: a linear bearing, for example, has translation and little-to-no rotation; whereas a circular ball bearing would have rotation and little-to-no translation.

Of interest are the third class of less-intuitive 1-DOF mechanisms that have concurrent translation *and* rotation. These mechanisms link a rotational input to a linear output, and vice versa. For example, ball screws convert between rotational and translational motion. In general, these "screw" type mechanisms are incredibly promising methods of constructing complex mechanisms and machinery; and that motivates our interest.

In particular, flexural screw mechanisms have no tribological surface interaction, and are instead comprised of compliant flexures that have specially designed directions of stiffness and compliance to create a screw motion between a stage and ground. They have the further benefit of maintaining zero friction loss, zero backlash, and high precision. Often these mechanisms are desirable in precision-engineered applications such as controlling micromirrors in micro-electromechanical (MEM) devices, controlling specimen stages in cleanrooms, or actuating galvo-lasers in precise marking applications. Naturally, to successfully develop these products, the screw behavior of each mechanism must be precisely characterized and understood. This forms the motivation for our work to characterize one particular screw mechanism, by way of discrete shell simulation or similar methods.

II. Screw Theory and Pitch in Screw Mechanisms

In representing the velocity of an object using screw theory, we formulate the instantaneous twist vector

$$T = \begin{bmatrix} \omega \\ v \end{bmatrix} \tag{1}$$

where ω represents the rotational velocity in an axis parallel to translational velocity v. We then define the instantaneous pitch for a screw mechanism:

$$p = \frac{v}{\omega} \tag{2}$$

Notably, flexures and compliant mechanisms are highly nonlinear beyond the neutral equilibrium state of the mechanism: the more a blade is flexed, the more nonlinear its behavior and response. Thus, the pitch p in a screw mechanism will change as a function of either its translation v or rotation ω. In this paper, we are interested to find p as a function of translated position.

III. Mechanism Design

Using the FACT approach to design a screw mechanism provides an accurate picture of the instantaneous motions that the mechanism can accommodate, but fails to account for nonlinear effects or changes in geometry as the mechanism is actuated [1]–[3]. Using these techniques, however, we can create a mechanism to put through further computational analysis with simulation methods. We first take the circular hyperboloid constraint space described in [4] and creating three bent-blade flexures, each providing one constraint line along the bends. We then attach these to a stationary base and floating stage through fixed contact areas. The resulting mechanism is depicted in Fig. 1.

As analyzed by [4], this mechanism provides a fixed-pitch screw around its instantaneous region of motion. However, as may be evident, the constraint line angle (and thus the screw pitch) changes as the mechanism undergoes deformation in either direction. We wish to characterize the effect that the

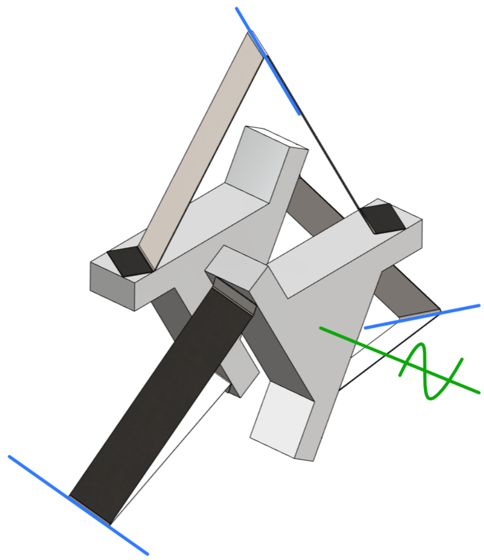

Fig. 1. An image of the proposed mechanism for study. The blue lines represent constraint lines, while the single green line with a wavy indicator represents the 1-DOF screw motion permitted by the constraint lines.

nonlinear deformations have on the pitch of the screw motion as the stage is actuated towards and away from the base.

IV. Proposed Approach to Simulation Project

We propose to model three bent blades as discrete shells with zero natural curvature other than at their bent corners. There, the radius of natural curvature will be extremely small or zero. One stage will be held fixed, and the other stage will be free to rotate along the central axis and translate along the same axis. The bent blades will be fixed in rotation and translation to their mounting points on the stages. We will actuate the moving stage with force or displacement inputs along the translational axis. We can then record the corresponding rotational movement.

We will then compare against other analytical methods, such as the theoretical models found in [3], [5]–[7]. We will also compare these results against finite element analysis models, which are computationally intensive but may provide more accurate results.

A. Simulation Method

The simulation method we intend to explore is midedge normal based formulation as described in [8], which is expected to be robust in convergence tests for different types of meshing and mesh refinement in our compliant mechanism. There must be great care taken around the modeling of the bent radius, since we anticipate the analysis having high sensitivity to the mesh characteristics in this region. We may also investigate the computational time and mesh sensitivity for a discrete shell method laid out in [9].

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