Mechanism and Machine Theory 105 (2016) 260–271

Contents lists available at ScienceDirect

Mechanism and Machine Theory

journal homepage: www.elsevier.com/locate/mechmt

Integration of advanced stiffness-reduction techniques demonstrated in a 3D-printable joint

Ezekiel G Merriam, Kyler A Tolman, Larry L Howell*

Brigham Young University, Department of Mechanical Engineering 270 CB, Provo UT 84602, United States

ARTICLE INFO

Article history:
Received 7 April 2016
Received in revised form 9 June 2016
Accepted 11 July 2016
Available online xxxx

Keywords:
Static balancing
Lattice flexure
Cross-axis flexural pivot
Load-dependent stiffness

ABSTRACT

This work details the integration of three distinct methods for altering the stiffness of compliant joints: lattice flexures, compound joints, and static balancing. The methodology for applying these strategies is discussed in detail. Lattice flexures are a flexure modification that leads to low motion-direction bending stiffness. Compound joints improve a compliant joint's load-carrying ability and off-axis stiffness. Static balancing in this case is achieved through the addition of an auxiliary energy storage device. To statically balance a compound lattice-flexured cross-axis flexural pivot, the load-dependent stiffness behavior of a cross-axis flexural pivot (CAFP) with two lattice flexure types is determined. A balancer spring design is developed that is fully 3D-printable. The balancer is combined with a compound lattice-flexured CAFP. Physical hardware is 3D printed in titanium and its torque-displacement behavior is measured. The resulting device requires 1% of the actuation energy of a conventional CAFP of the same dimensions and material.

© 2016 Elsevier Ltd. All rights reserved.

1. Background

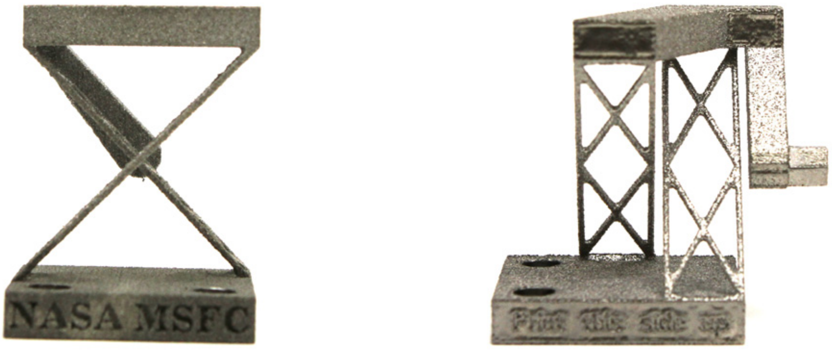
Static balancing is a method whereby the required actuation effort of a joint is decreased [1–7]. This is usually done through the addition of springs or auxiliary bodies that function to store and release energy in a manner opposite that of the target joint [2,3,8,9,10,11]. This results in a small net input of energy to the joint during actuation [4,5,7,11,12,13,14]. One challenge to balancer design is the pre-stressing required [11,15]. Creep and stress relaxation resulting from this pre-stressing negatively effect mechanism performance [16]. Joints of lower initial stiffness generally require less pre-stressing of the balancer, making the system easier to design.

The recently introduced lattice flexure [17] (see Fig. 1) has drastically reduced stiffness (60–80 % lower) compared to a blade flexure of the same material and outer dimensions. It will be shown here that using compound lattice flexures in concert with static balancing drastically reduces actuation effort.

The development of 3D printing technology has made many advances in recent years, but obtaining useful motion from 3D-printed mechanisms is difficult without incorporating flexures. The minimum feature size of most 3D printers puts a lower-bound constraint on flexure thickness that results in high mechanism stiffness. By applying stiffness reduction strategies to 3D printing, it is demonstrated that a 3D-printed titanium part can have low stiffness.

* Corresponding author.
E-mail address: lhowell@byu.edu (L. Howell).

http://dx.doi.org/10.1016/j.mechmachtheory.2016.07.009
0094-114X/© 2016 Elsevier Ltd. All rights reserved.



(a) Front view of cross-axis flexural pivot (CAFP) made with lattice flexures.

(b) Side view of lattice-flexured CAFP.

Fig. 1. An example lattice flexure printed in titanium.

To statically balance a flexure using the non-dimensional approach of Merriam et al., a balancer spring is required [18]. If this joint is to be 3D-printed, its balancer spring must be 3D-printable. Previous balancer designs have used coil springs or leaf springs [18,19]. However, coil springs do not lend themselves to 3D printing, and leaf springs lack the pre-load and stiffness behavior required by the balancing method used here. In this work a fully printable balancer will be presented.

The presence of the balancer spring introduces another challenge; it exerts a compressive load on the flexure to be balanced. Moreover, if this compressive load is not applied through the center of the joint it will result in an off-axis torque on the joint. To remedy this, a compound joint will be employed [20]. By arranging two flexures in parallel with the balancer spring between them, the stability of the joint is improved and the load from the balancer spring does not exert an unbalanced torque on the flexures.

Fig. 2 shows the statically balanced 3D-printed lattice-flexured cross-axis flexural pivot developed here. Each element of the mechanism is discussed herein. An overview of lattice flexures is presented first, along with an evaluation of their load-dependent stiffness that allow them to be statically balanced. Next static balancing is discussed, followed by a detailed discussion on the design of the nonlinear tension spring used as a balancer. Finally, integration of these elements is discussed and experimental results are presented for a titanium prototype.

The objectives of this work are:

1. Evaluate the load-dependent stiffness behavior of lattice-flexured CAFPS.
2. Design a printable balancing spring.
3. Design a statically balanced CAFP incorporating compound lattice flexures.
4. Validate the resulting design with measurements of a physical prototype.

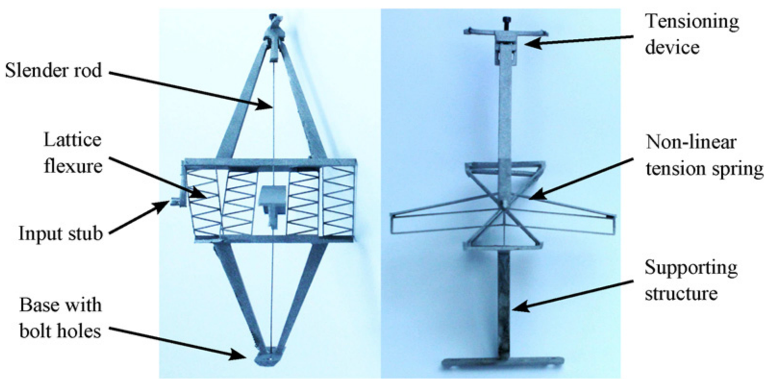


Fig. 2. Printed titanium flexure with its parts labeled.

Download English Version:

https://daneshyari.com/en/article/7179600

Download Persian Version:

https://daneshyari.com/article/7179600

Daneshyari.com