Stiffening Cantilever-Disk Springs for the OSL

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I. Introduction

Series elastic springs for prosthetic legs (including the Open Source Leg or OSL [1]) confer several well known advantages, including torque sensing, shock absorption to protect the transmission, energy savings [3], and artificial backdrivability [5]. Series springs are typically linear, but computationally efficient design methods for nonlinear springs have recently highlighted the potential advantages of nonlinear spring profiles [2]. Such profiles are difficult to achieve mechanically, and often require a dedicated nonlinear transmission element [4]. Direct design of nonlinear flexible elements is a formidable challenge in the domain of iterative finite element analysis (FEA).

In this talk we introduce a novel spring design paradigm that uses simple design indexes to quickly arrive at complex spring designs. The paradigm focuses on the stiffening rotary spring sub-problem and employs stacks of disk-like springs in sliding contact with a central gear-like cam shaft, and our example spring is compatible with the OSL's in-pulley spring-disk system.

II. Methods

We decompose target piecewise stiffening spring profiles into a series of linear spring flexures engaging one at a time (Fig.1.b–c). As additional flexures are recruited, the effective stiffness increases. For each spring flexure, we use the peak torque to calculate the minimum beam width possible given a yield stress limit as a function of distance from the point of contact. Any spring with this width profile will store energy at a fixed ratio to its total area in the (constant-thickness) disk. We define two key design indexes that predict the feasibility of the design:

- a 'serpentine factor' representing the requisite amount of deviation from a straight flexure, and
- a 'density factor' representing the percentage of the disk that must be metal.

We then design a spring that closely approximates the width profile and the target area.

Using our preliminary design (Fig. 1.a) in electrical discharge machined stainless steel 410, we empirically measured the deflection torque curve. Due to limitations of the testbed configuration, our initial tests only sample a fraction of the full range.

III. Results & Discussion

The match between the target spring rate and the measurement is quite accurate in the 1, 2, and 3 engaged springs region (Fig.1.d).

IV. Conclusion

Our design process produces accurate spring rates, despite the relative simplicity of designing a spring geometry based only on area and width constraints.

References

[1] A. F. Azocar, *et al.*, *Nature BME*, vol. 4, no. 10, pp. 941-953, 2020.
[2] E. A. Bolívar-Nieto, *et al.*, *TMech*, vol. 24, no. 3, pp. 1334-1345, 2019.
[3] M. Grimmer, *et al.*, *Actuators*, vol. 3, no. 1, pp. 1-19, 2014.
[4] J. Realmuto, *et al.*, *J. Med. Devices*, vol. 9, no. 1, p. 011007, 2015.
[5] J. W. Sensinger & R. F. Ff Weir, *2006 Mechatronics Emb. Sys. App.*

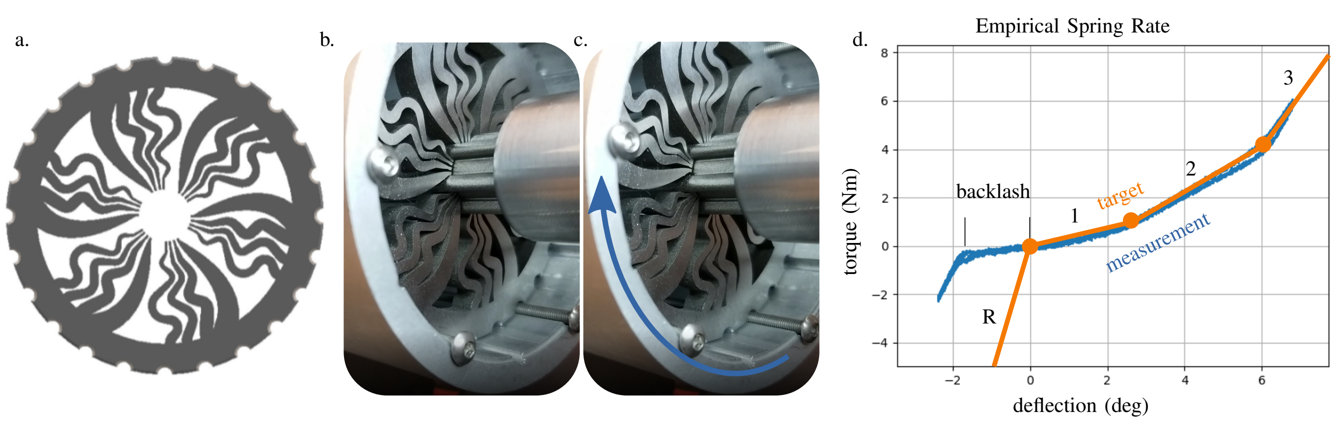

Fig. 1. Preliminary design of a stiffening-profile cantilever-disk spring for the OSL (a), demonstration of the spring recruitment process in the tested spring disk (b-c), empirical spring profile measurement (d).