Design, Model, and Application of Variable Stiffness Spring

Mason Mitchell, Shivangi Misra, Rongqian Chen, Cynthia Sung

Why do we want Tunable Stiffness Springs in Soft Robotics?

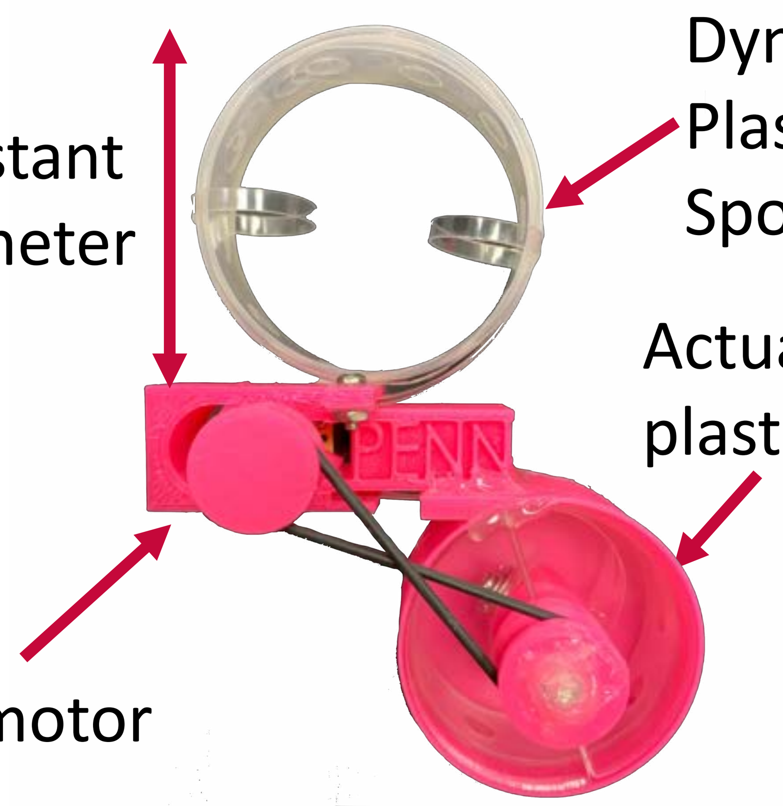
- Soft robotics has major implications in medical robotics, biological mimicry, and dexterous manipulation.
- Classical springs don't always give researchers enough flexibility in design.
- Tunable stiffness springs allow you to alter the stiffness of your spring dynamically.
- This flexibility allows for more **adaptive** and **manipulatable** structures.

Our Design

These springs come in many forms such as

- Smart materials
- McKibben actuators
- Origami
- Electromechanical actuators & more

We chose an electromechanical solution

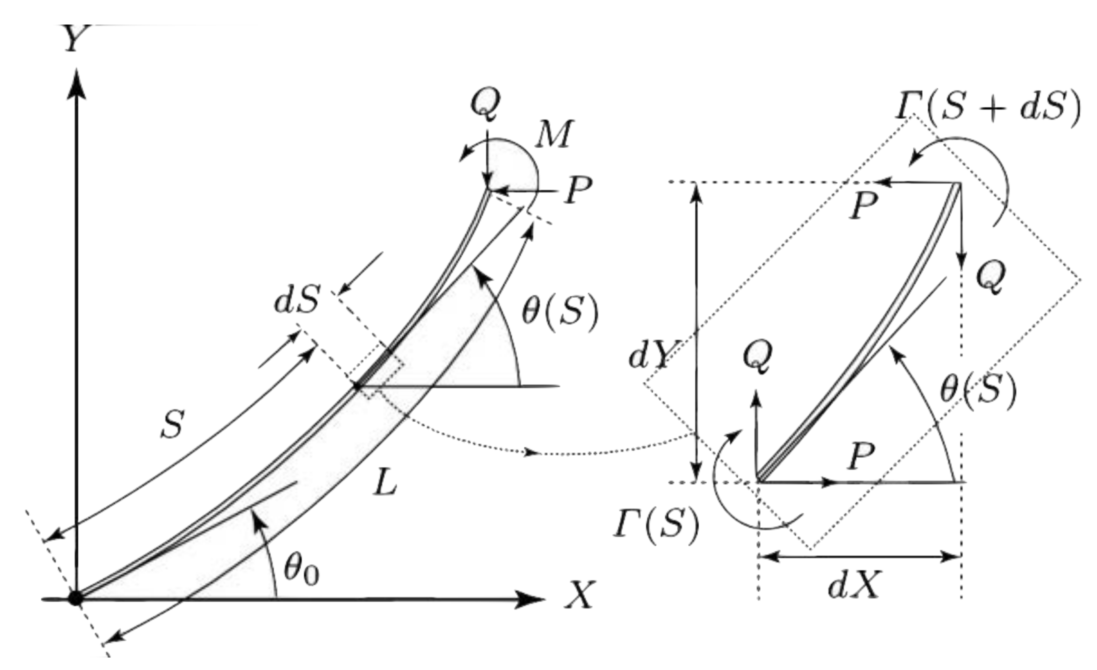


Design Advantages

- No dimension change
- Stiffness Doubling in <1s
- 10x Stiffness Range
- Low Cost, Fast Construction, Lightweight

Utilizing Non-Dimensional Differential Equations to Solve Ring Compression

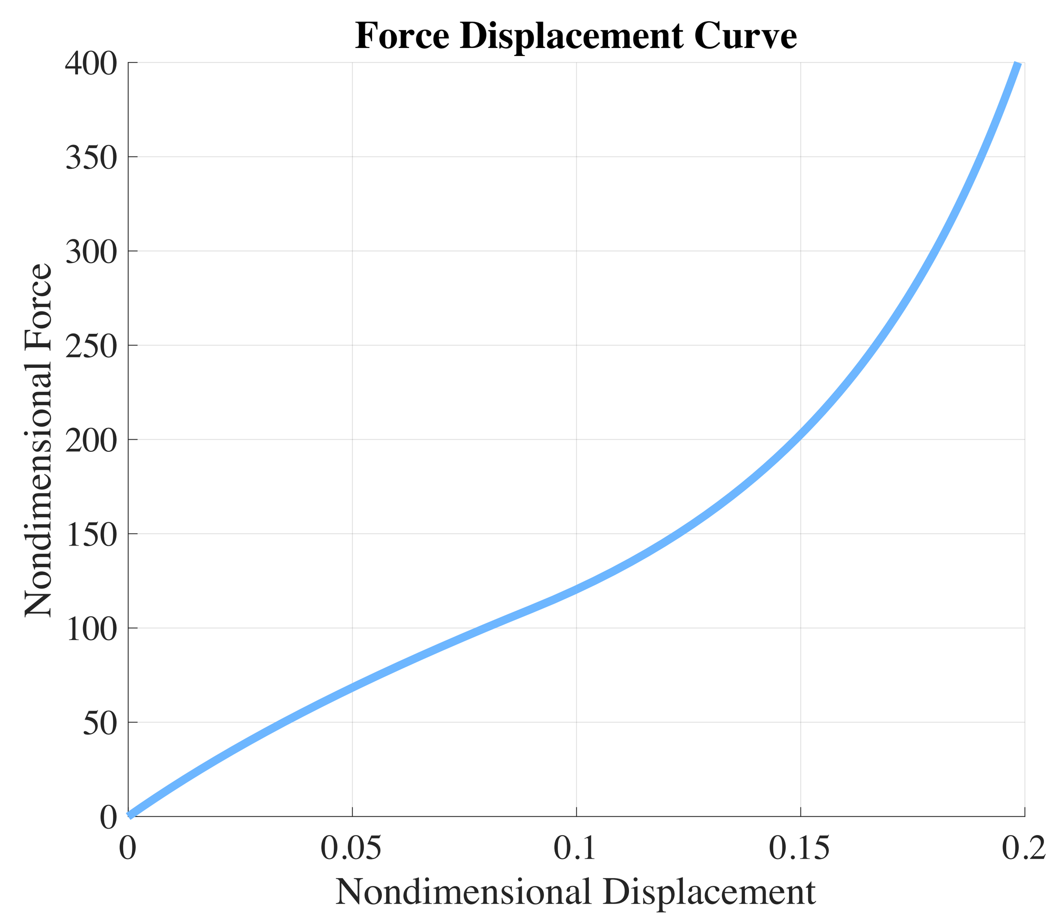
By modeling our coil as a set of nested rings, we can look at each circle individually, as a bent elastica.



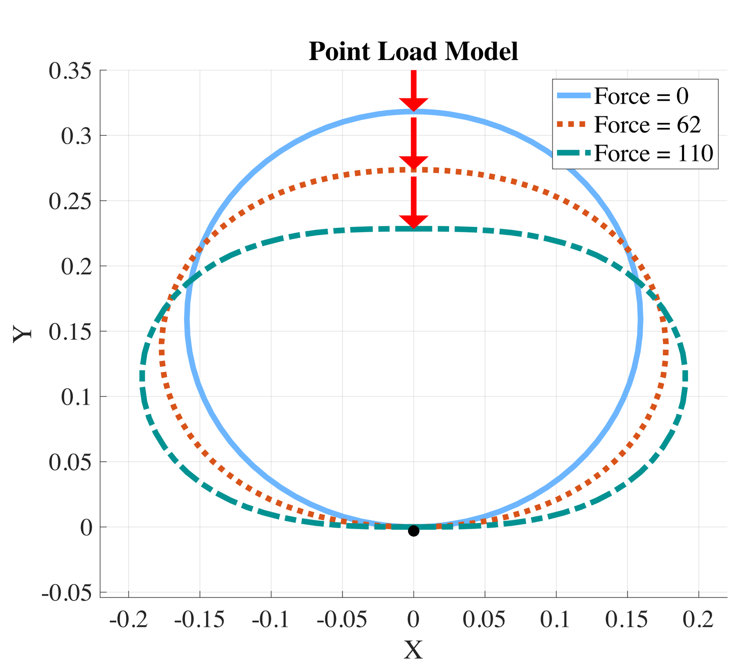
$$\frac{\partial x}{\partial s} = \cos\theta, \quad \frac{\partial y}{\partial s} = \sin\theta,$$

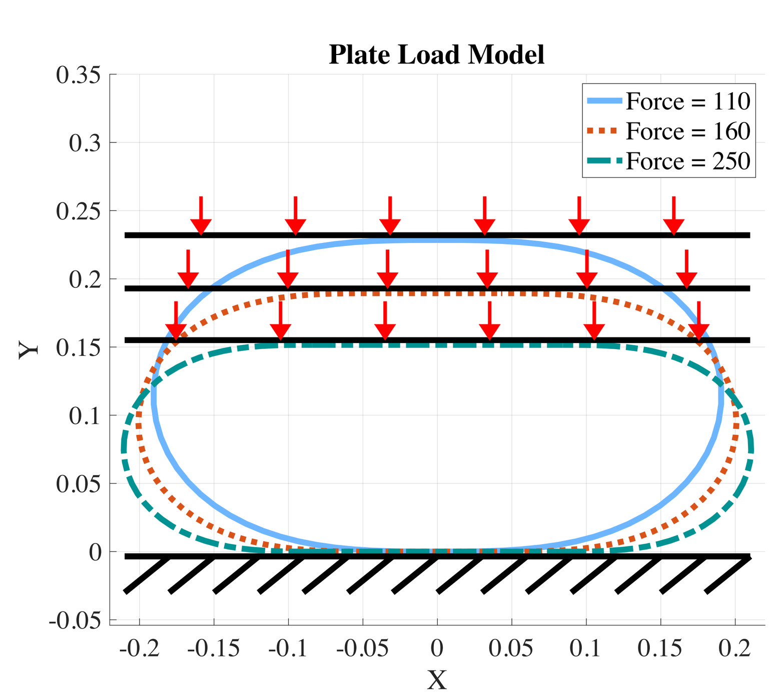
$$\frac{\partial \theta}{\partial s} = m + 2\pi, \quad \frac{\partial m}{\partial s} = \frac{f}{2}\cos\theta - p\sin\theta$$

By using MATLAB **ode45** & **Levenberg Marquadt** optimization to solve the ODE to build this curve.

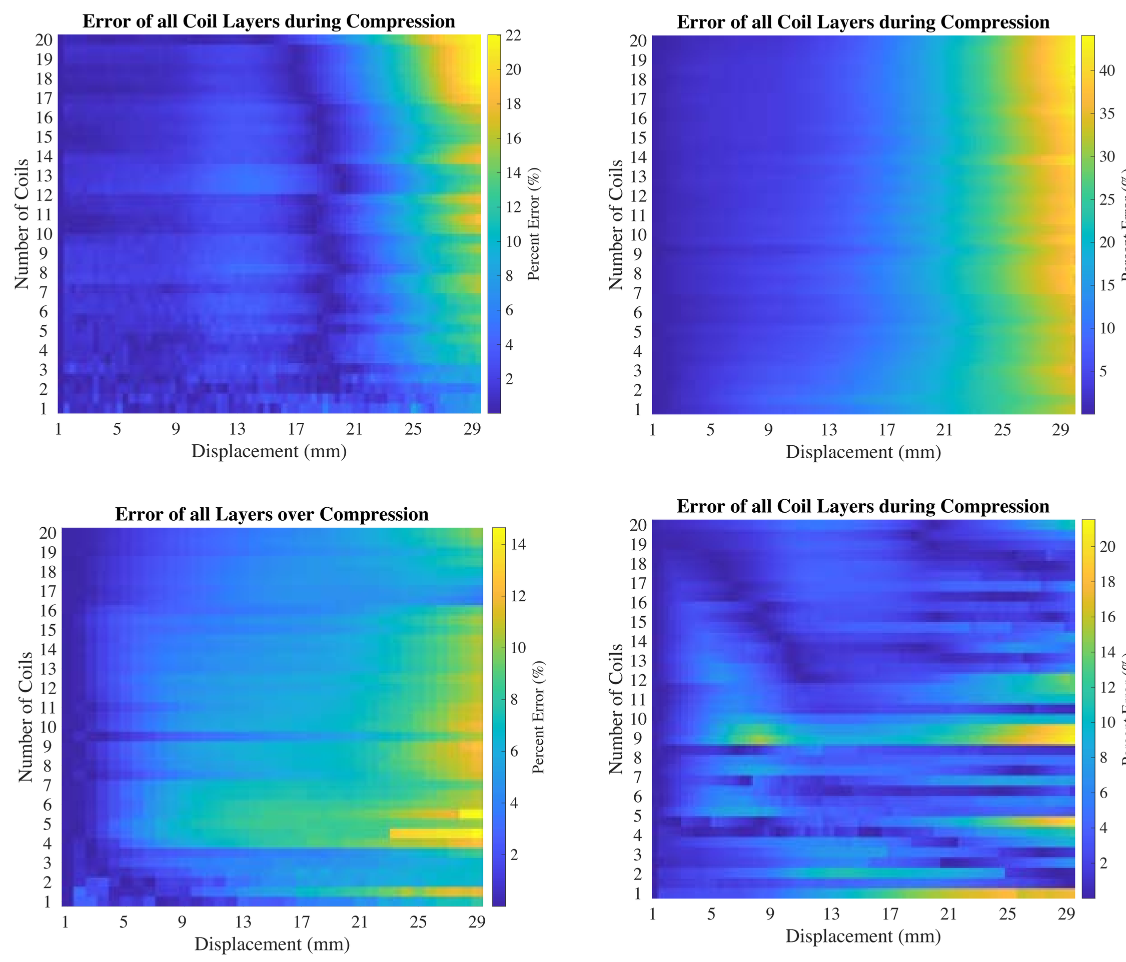


Simulated Ring Compressions

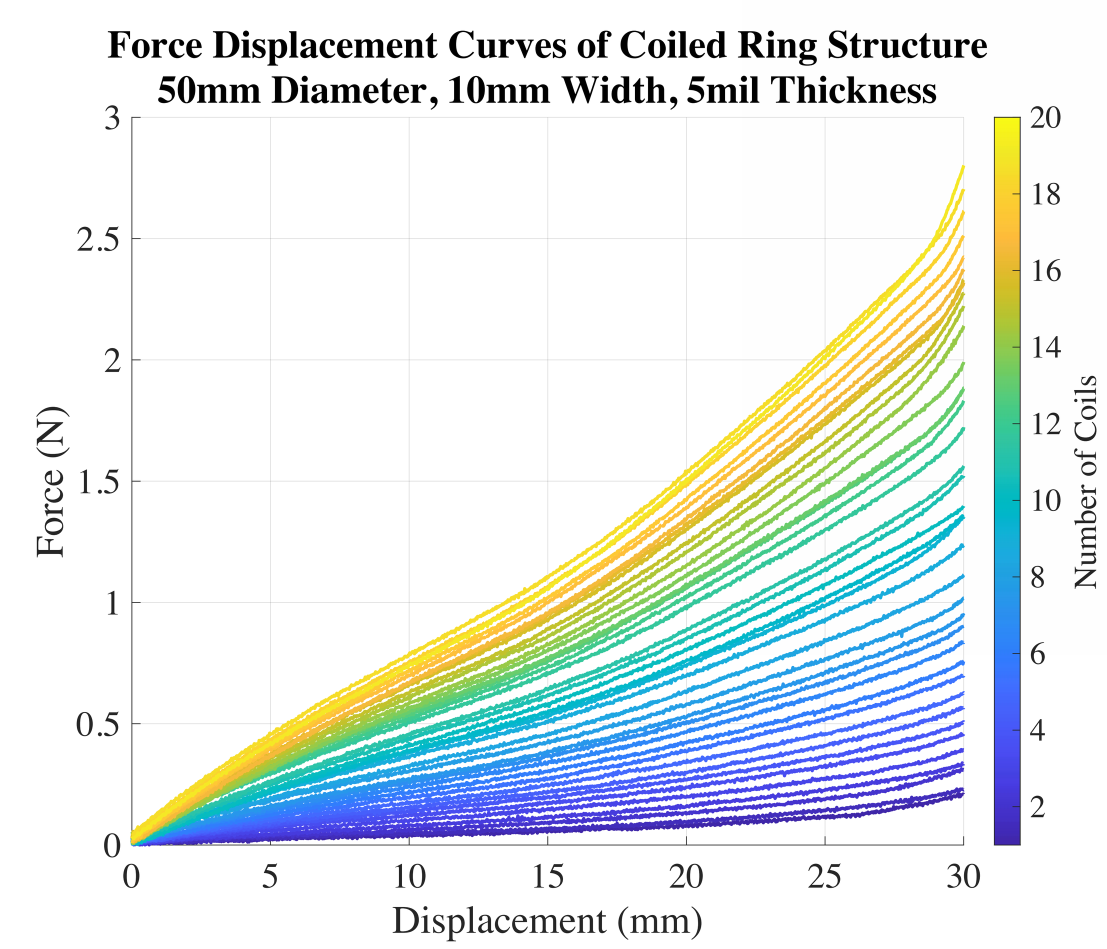




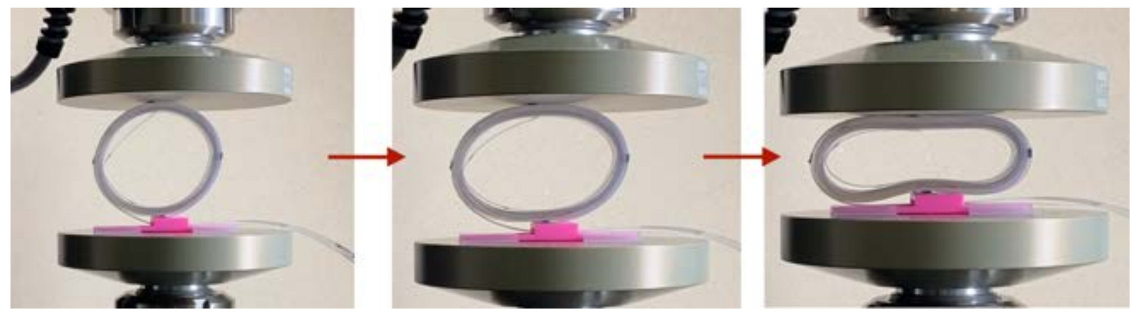
Model Verification & Testing



Model error using 4 separate coil structures



Experimental Force-Displacement curves from 0–20 coils

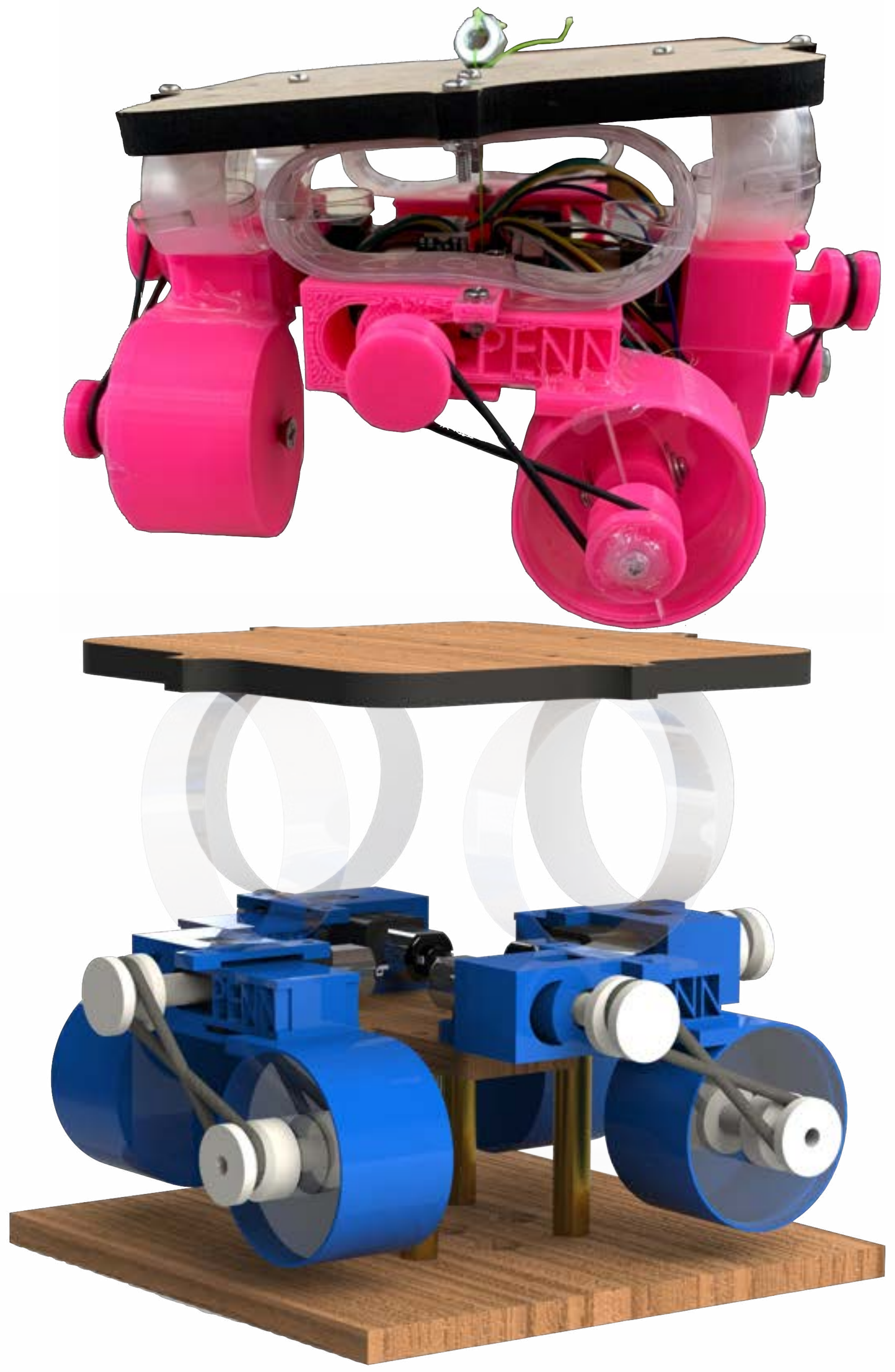


Material Test System Ring Compression Captures

Use Cases

A tunable stiffness manipulator

- Uses multiple tunable stiffness springs
- Can bend in any direction
- Alter stiffness for safe human robot interaction



Conclusion

This work has produced:

- A spring with high stiffness range at fast speeds.
- A mathematical model that fits experimental testing
- A 3-DOF tunable stiffness manipulator capable of stiffness change at multiple positions

References:

L. N. Virgin, J. V. Giliberto, and R. H. Plaut, "Deformation and vibration of compressed, nested, elastic rings on rigid base," Thin-Walled Structures, vol. 132, pp. 167–175, 2018.

Chau, S., Mukherjee, R. Force–displacement characteristics of circular-shaped massless elastica. *Acta Mech* **231,** 4585–4602 (2020).

S. Misra and C. Sung, "Forward Kinematics and Control of a Segmented Tunable-Stiffness 3-D Continuum Manipulator," *2022 International Conference on Robotics and Automation (ICRA)*, 2022, pp. 3238-3244

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