Controllable, High Ratio Force Amplification Using Constrained Elastic Cable Capstans

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Existing capstan configurations using ropes, cords, or other media with relatively low bending stiffness exhibit binding as the force amplification ratio increases [5,6,7]. This binding leads to loss of predictability and controllability.

Our solution is a cable with a significant bending stiffness and a constraining housing, providing capstan configuration less likely to bind.

Advantages of Capstan-Based Actuation

- Favored for their low backlash and high stiffness nature [1,2]
- Have the potential to increase the dynamic performance of a robotic system by reducing the overall inertia of moving parts [4]

Applications

- Converts rotary motion from an actuator into translational motion in an end mover [1]
- Can act as friction drives or mechanical amplifiers [3]

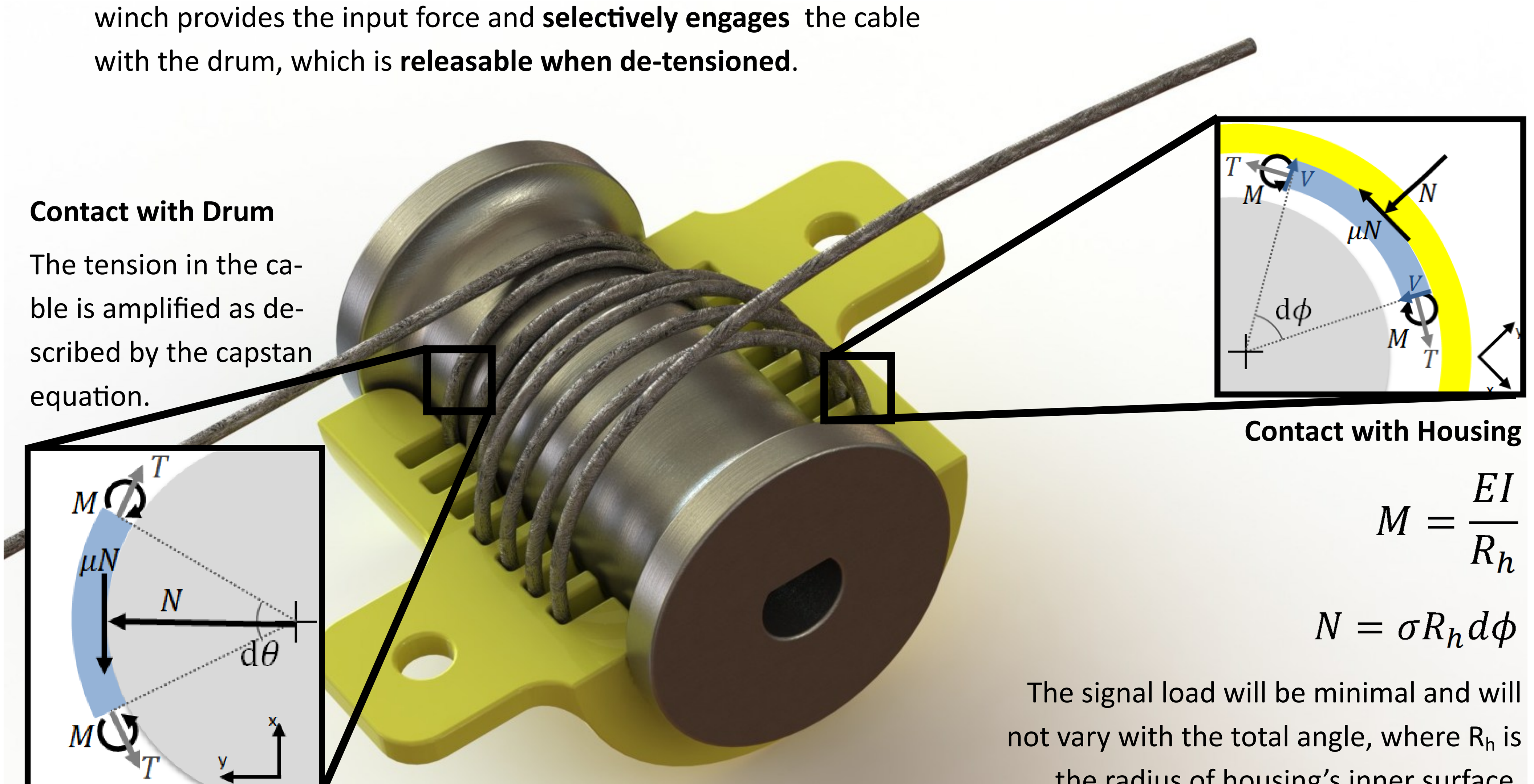
Principles of Operation

θ*: contact angle between cable and drum*
μ*: coefficient of friction*
φ*: contact angle between cable and housing*

The capstan relies on friction between a cord and a drum to amplify the tension force between the ends of the cord:

$$T_{load} = T_{signal} e^{\mu\theta}$$

Our design allows for an disengageable capstan by constraining a cable with non-negligible bending stiffness with a housing. This cable is **normally disengaged** from the capstan drum due to the cable's bending stiffness, which also discourages binding. A signal winch provides the input force and **selectively engages** the cable with the drum, which is **releasable when de-tensioned**.



Contact with Drum

The tension in the cable is amplified as described by the capstan equation.

Contact with Housing

$$M = \frac{EI}{R_h}$$

$$N = \sigma R_h d\phi$$

The signal load will be minimal and will not vary with the total angle, where R_h is the radius of housing's inner surface.

FIGURE 1. Diagram of cable capstan system.

Results

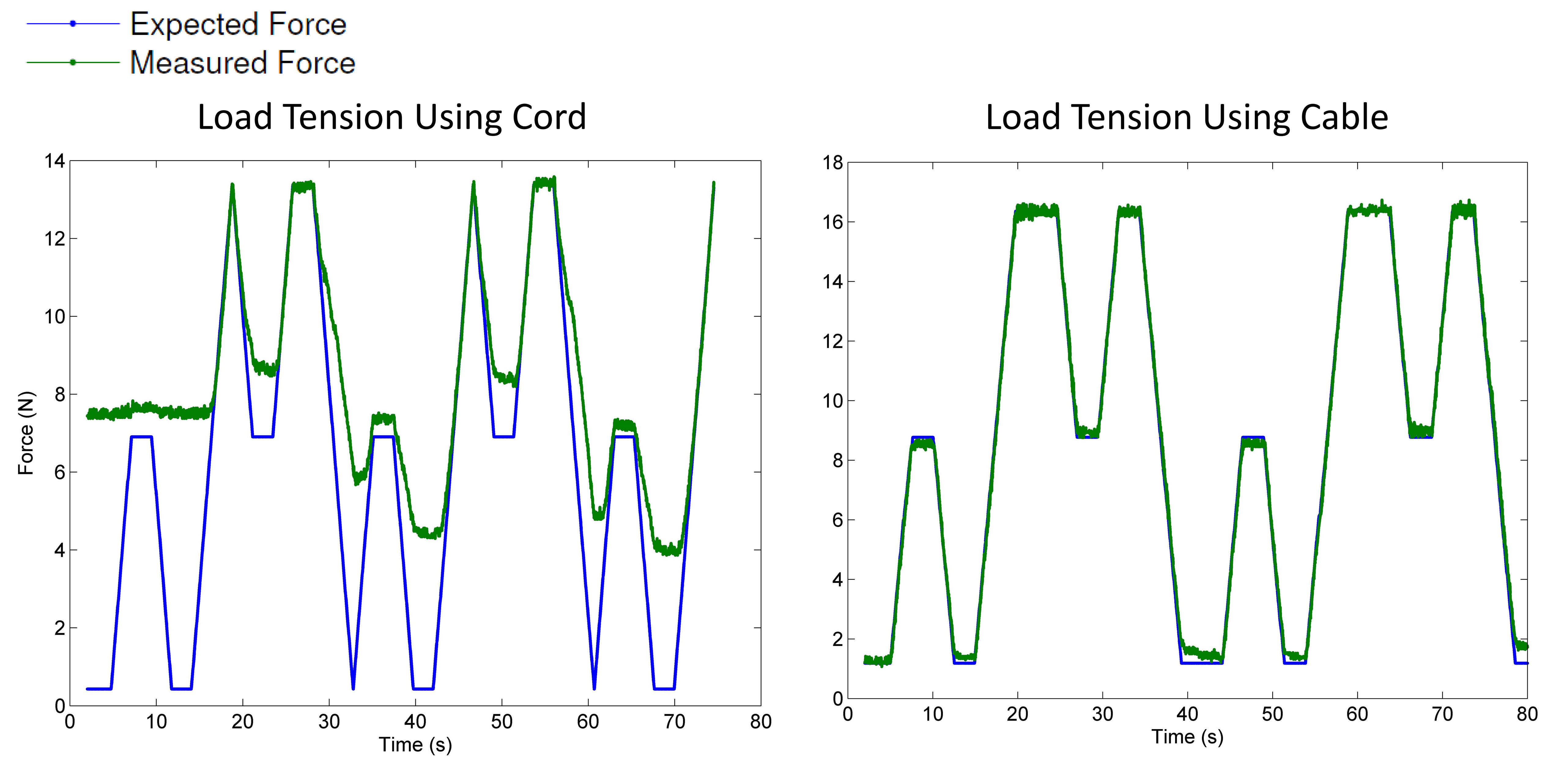


FIGURE 2. The figure depicts the relationship of expected to observed load force over a series of sample signals, assuming ideal release of the cable/cord from the capstan drum. Notice that the cable capstan (right) exhibits significantly more ideal behavior than the cord capstan (left).

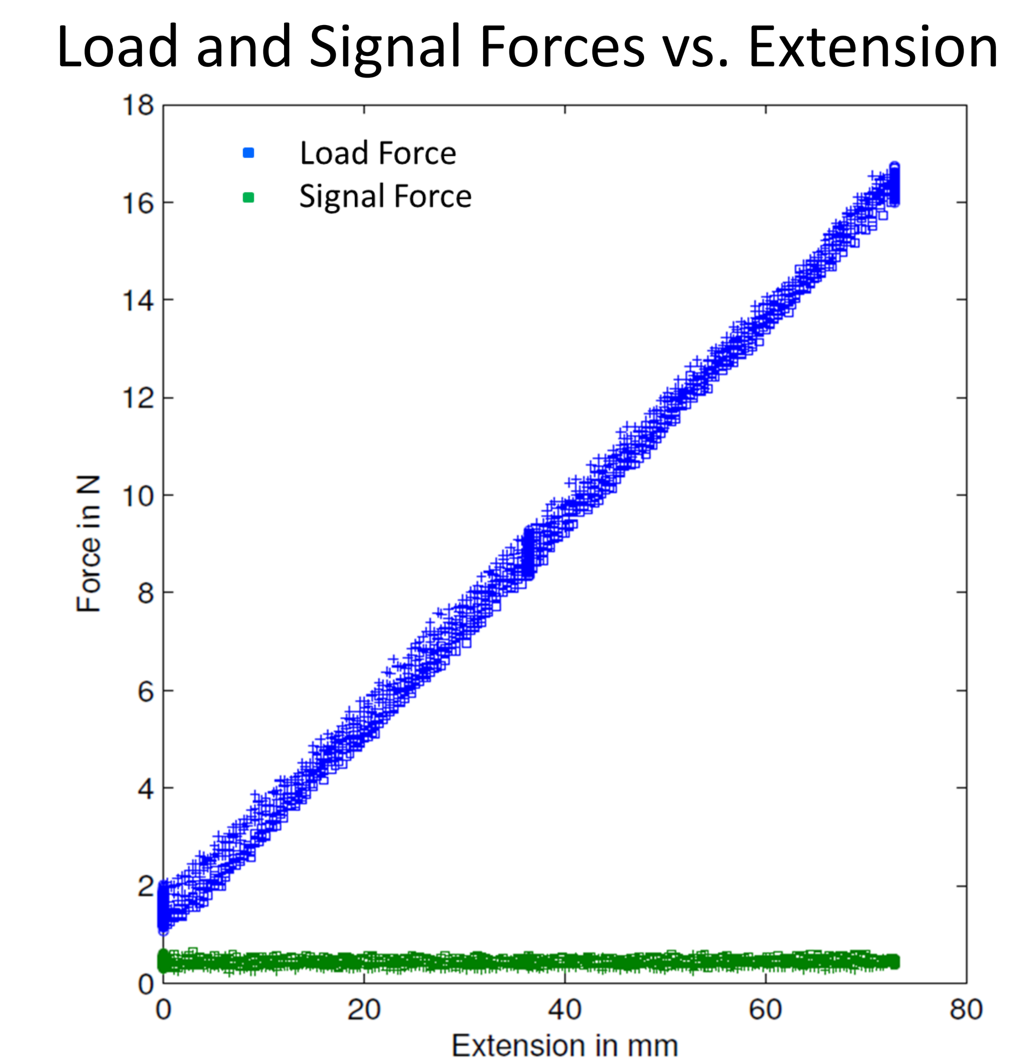


FIGURE 3. To date, the **highest observed amplification ratio without binding is 21:1.** This is not the maximum non-binding ratio, which is yet undetermined.

Methods

The capstan actuator is driven by a small PWM motor. The input tension is provided and controlled by a signal winch driven by a PWM servo. A National Instruments DAQ-6211 and LabView software control the motors

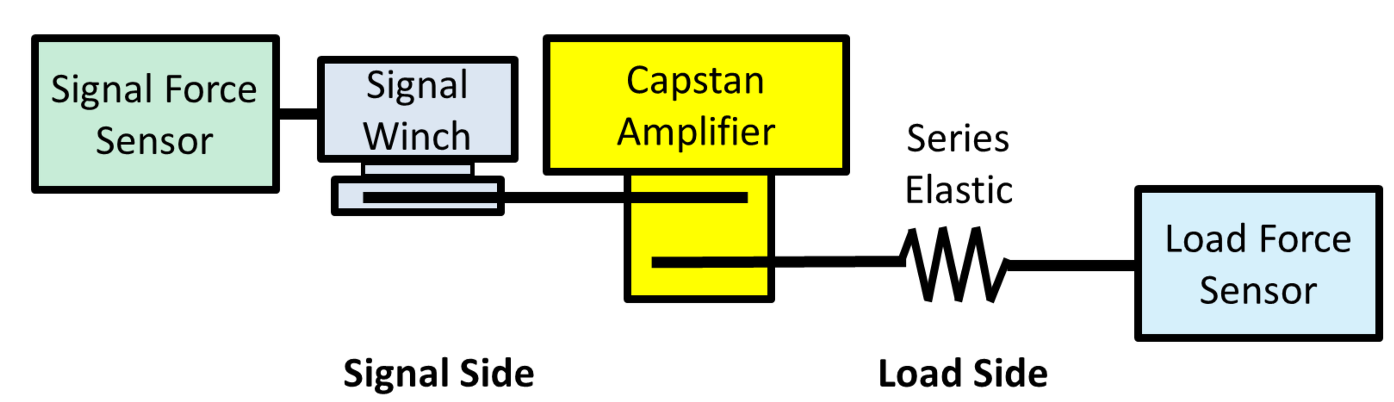


FIGURE 4: Test apparatus schematic

Future Work

Areas of future work include investigation of:

- The maximum non-binding force amplification ratio of the system.
- The behavior of the system as a function of system characteristics, such as drum diameter, cable properties, and constraint housing design.
- The dynamic behavior of the system.
- The characterization and modeling of the system.

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