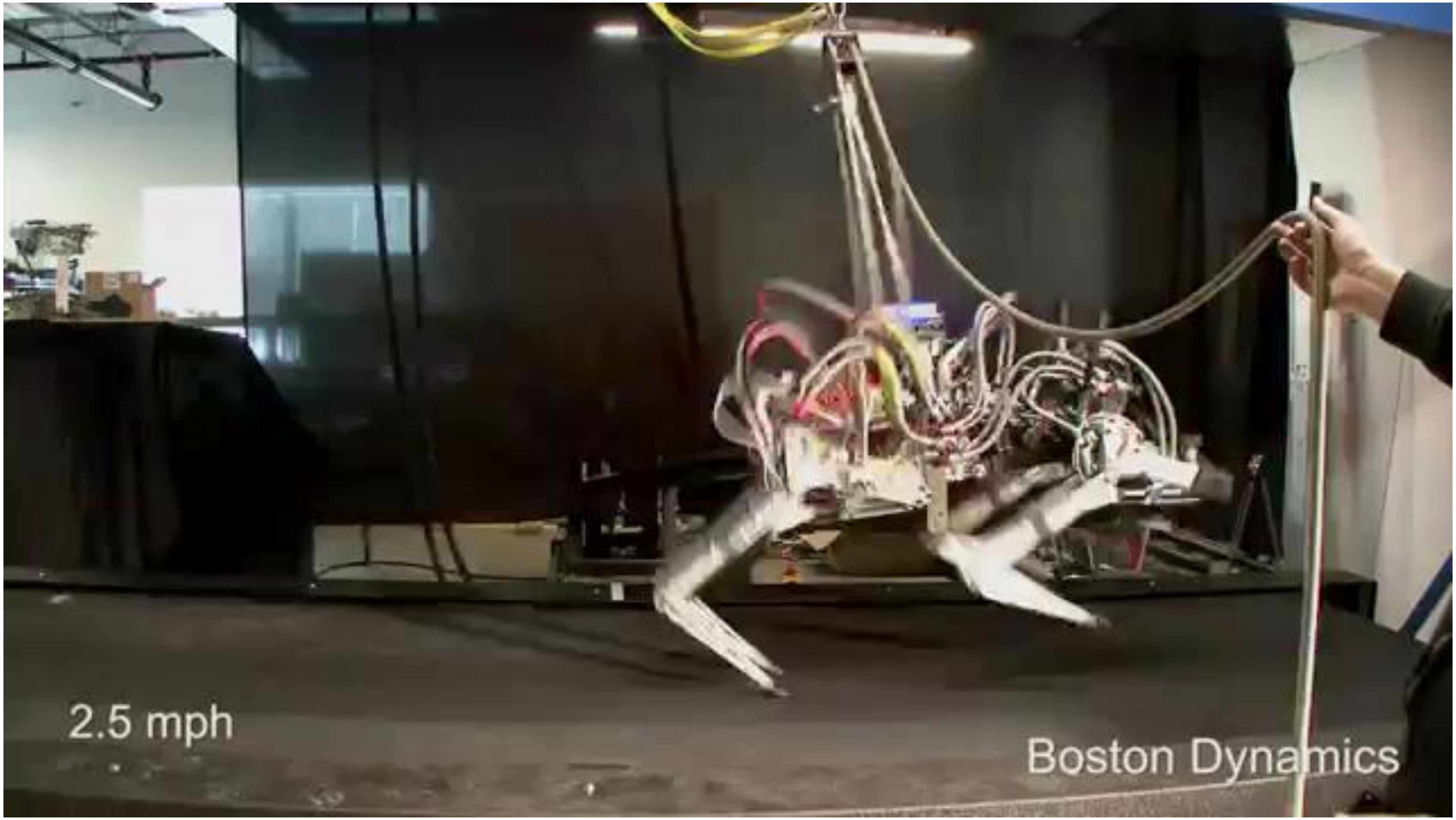
Development of an Actuator for Dynamic Legged Locomotion

Nicholas Paine

4/4/12

Problem Definition



What makes this possible?

1. Good actuators
2. Clever mechanical design
3. Good embedded systems
4. Good control
5. Tight system integration

We'll focus on this today

What makes a good actuator?

1. Good actuators
   a) High mechanical power output
   b) Light weight
   c) Force controllable (up to high bandwidth)
   d) Compact size
   e) Efficient
   f) Low cost
   g) Low maintenance

What options are there?

- Actuation Technologies
  - Hydraulic
  - ~~Pneumatic~~ ← Compressible air makes control difficult, low bandwidth
  - Electric
  - ~~Other? (SMA, Piezo, …)~~ ← Low output force, low displacement, low bandwidth

Hydraulic Actuator Drawbacks

- Very high overhead
- Expensive
- Combustion engine when untethered (noisy)
- Potential for leaks (messy)
- Has been done

Electric Actuator Drawbacks

- Lower power than hydraulic
- No proven modular design
  - Complicates robot design
- Requires geartrain
  - Fragile
  - Losses, backlash

General Approach

1. Design a "good" actuator
2. Addresses problems associated with conventional designs
    a) Maximize power
    b) Modular if possible
    c) Deal with geartrain issues

Similar Approaches

General Approach

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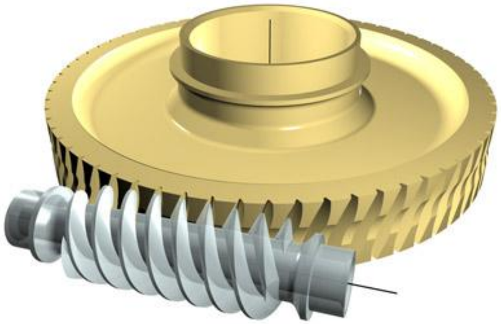
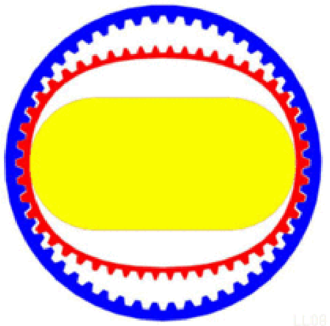
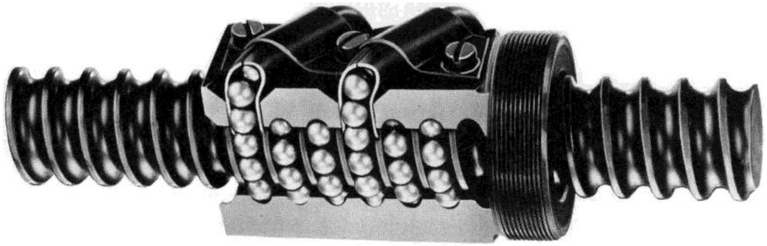
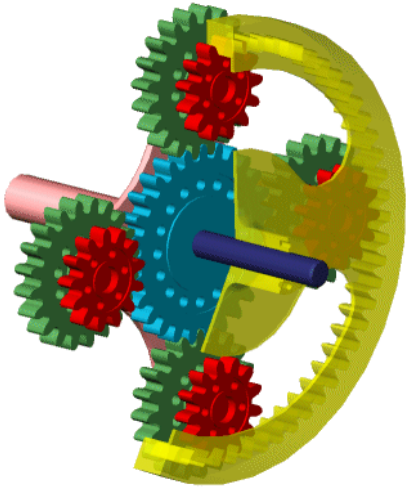
Large Speed Reduction Mechanisms

- Multi-stage planetary gearbox
- Worm Gear
- Harmonic drive
- Ball screw









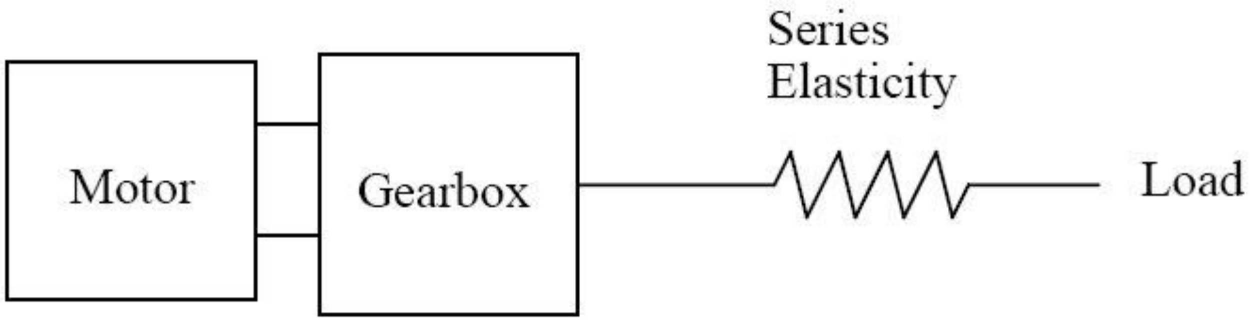
Large Speed Reduction Mechanisms

	Planetary	Worm	Harmonic	Ballscrew
Efficiency	~70%	~50%	~80%	90+%
Backlash	Yes	Yes	No	No
Impact Tolerance	Low	Low	Med	High

Dealing with drivetrain issues

- Series Elastic Actuation (SEA)
  - Force sensing
  - Protects drivetrain
  - Stores energy

Meets force control requirement



Dealing with drivetrain issues - Summary

- Use Series Elastic Actuation (SEA)
  - Protects drivetrain
- Use a ballscrew as main reduction
  - No backlash
  - High efficiency
  - Impact tolerant

General Approach

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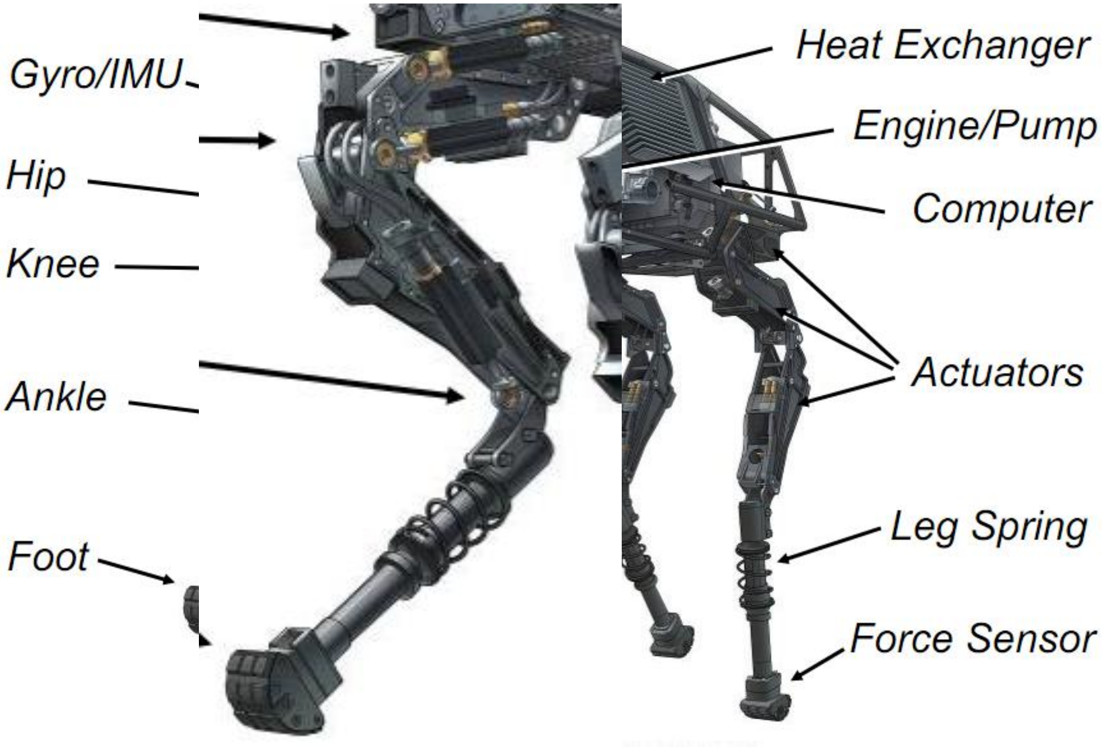
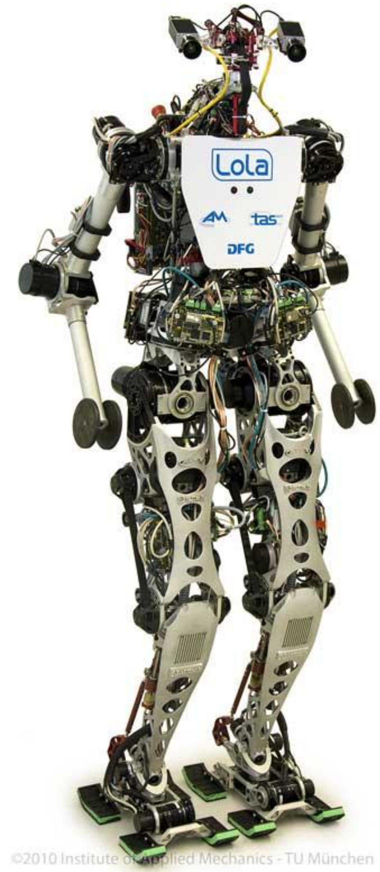
Actuator modularity

Modular

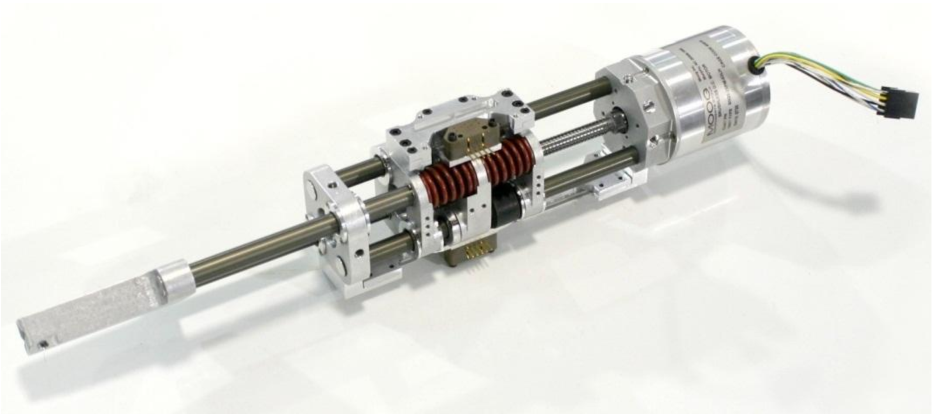


Not Modular

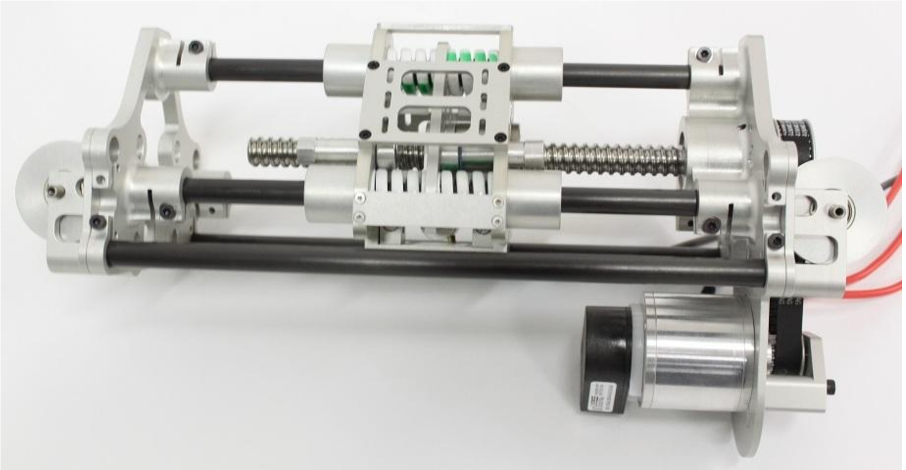


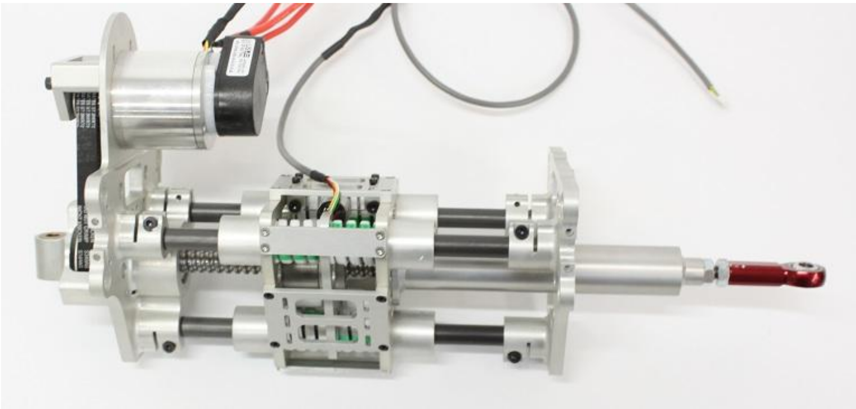
Actuator modularity greatly simplifies system level mechanical design

Existing Ballscrew SEA Designs



Each of these drive the ball screw, which moves an output carriage back and forth

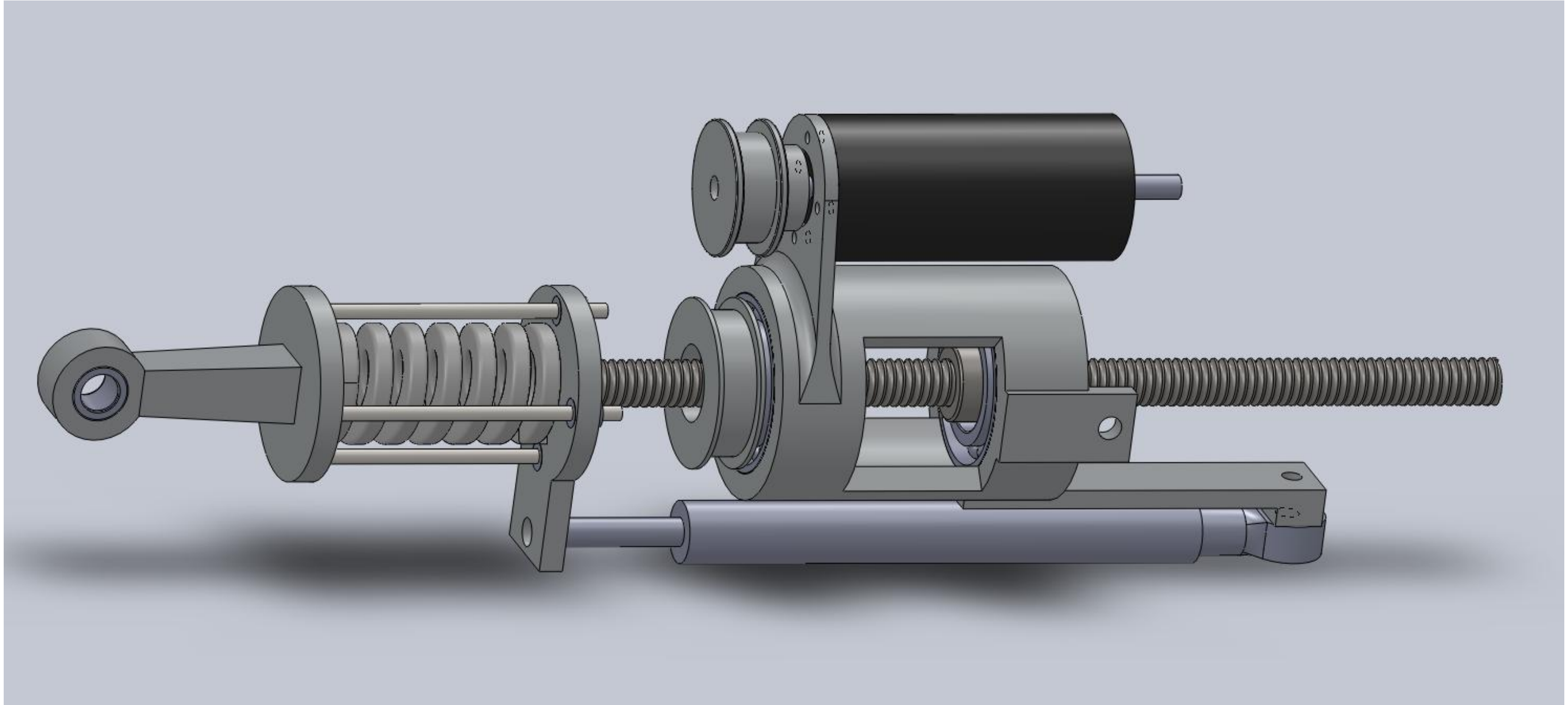




Our Design

- What if we drive the ball nut instead?
  - Obtain prismatic motion without the need for a carriage and guide rails
- Where do we put the springs?

Design Iteration



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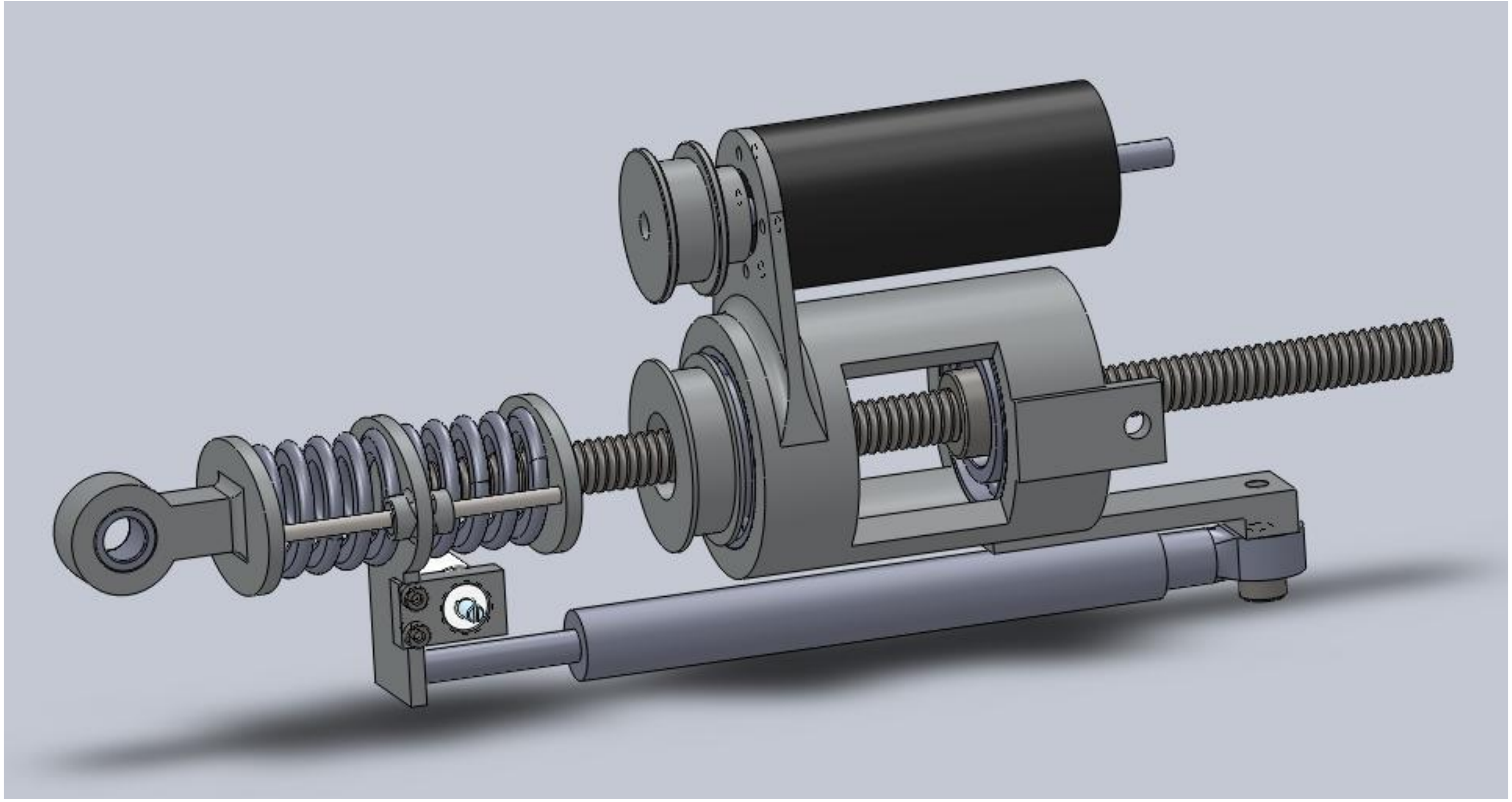

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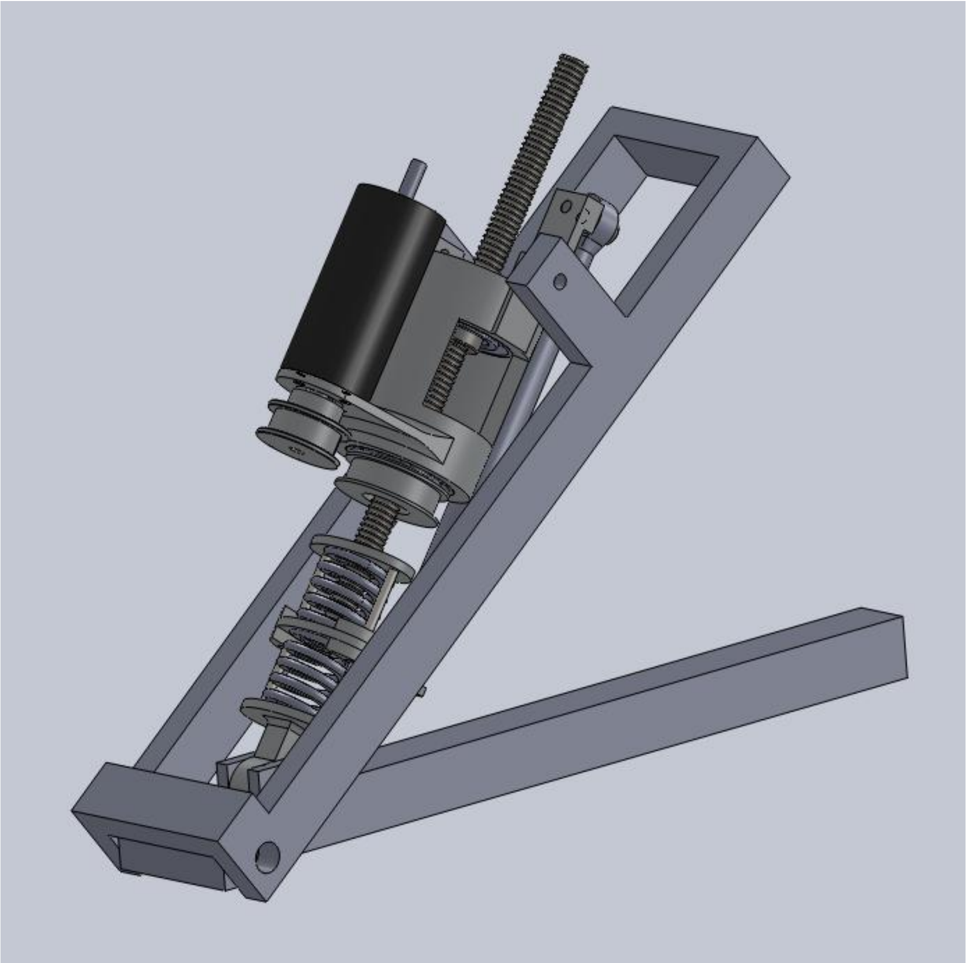

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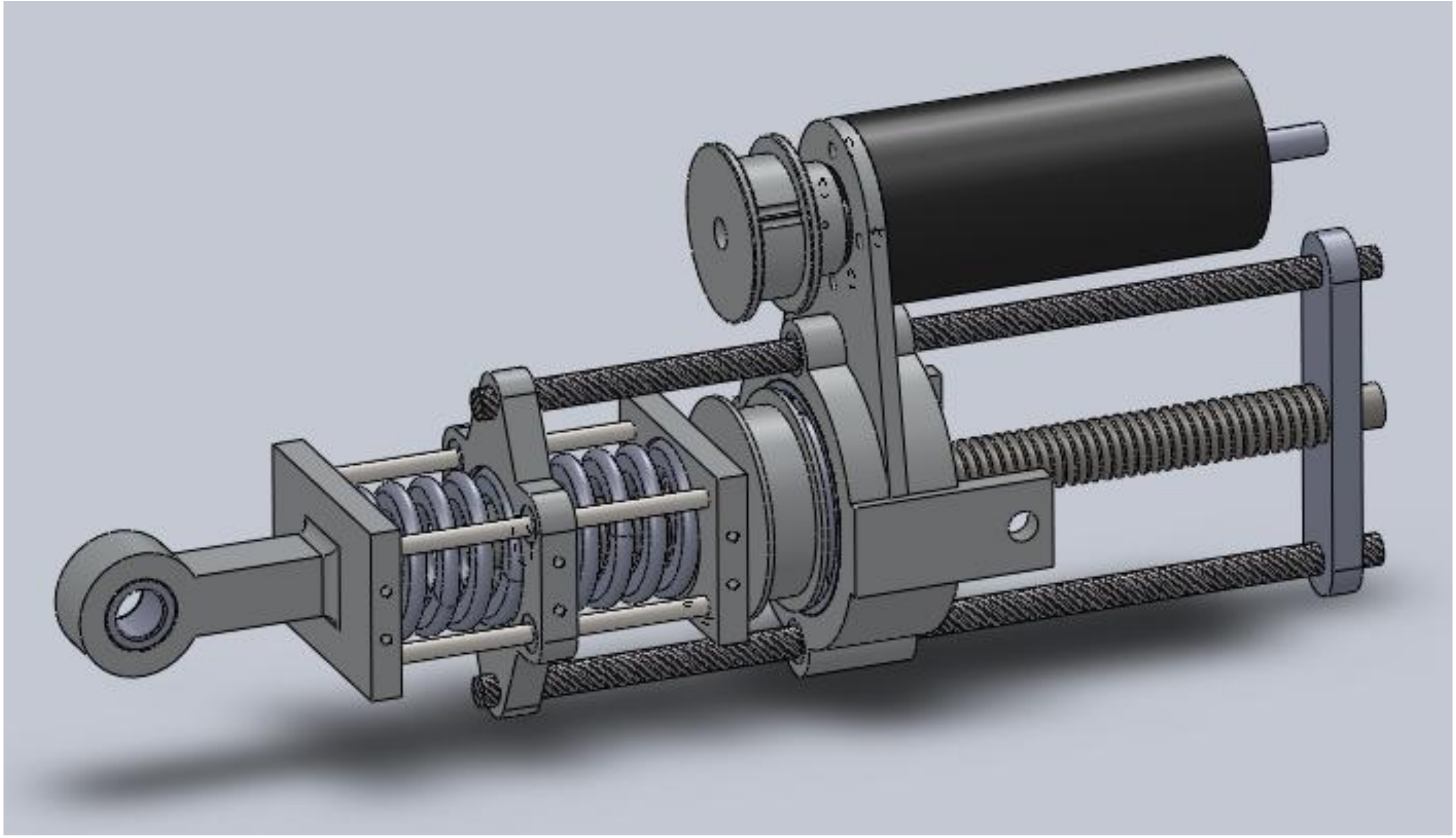

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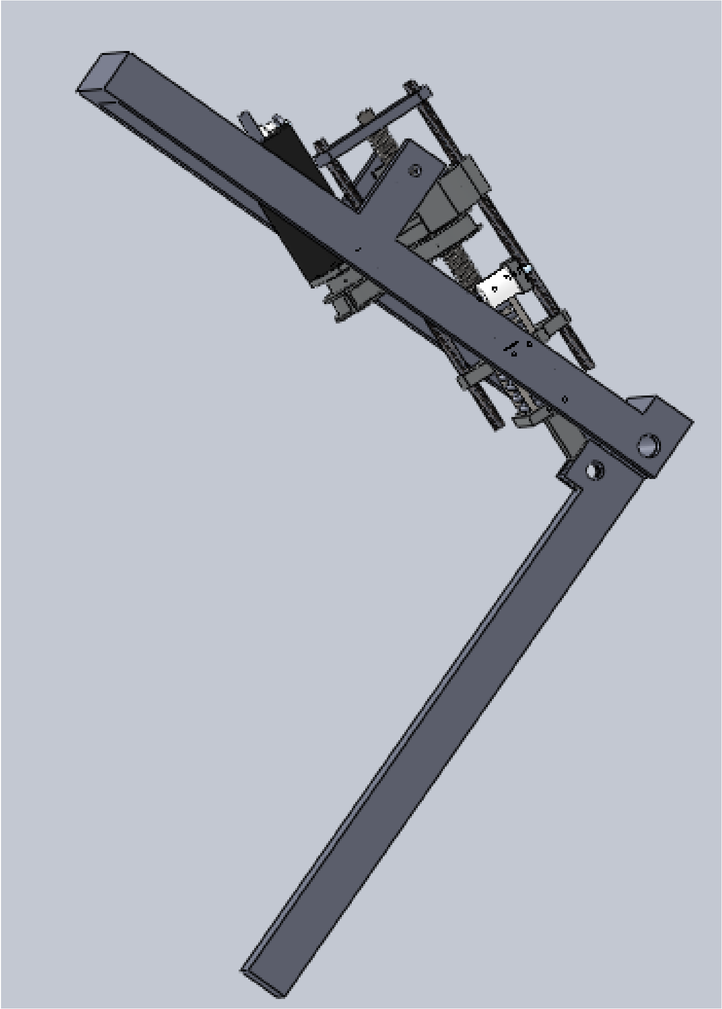

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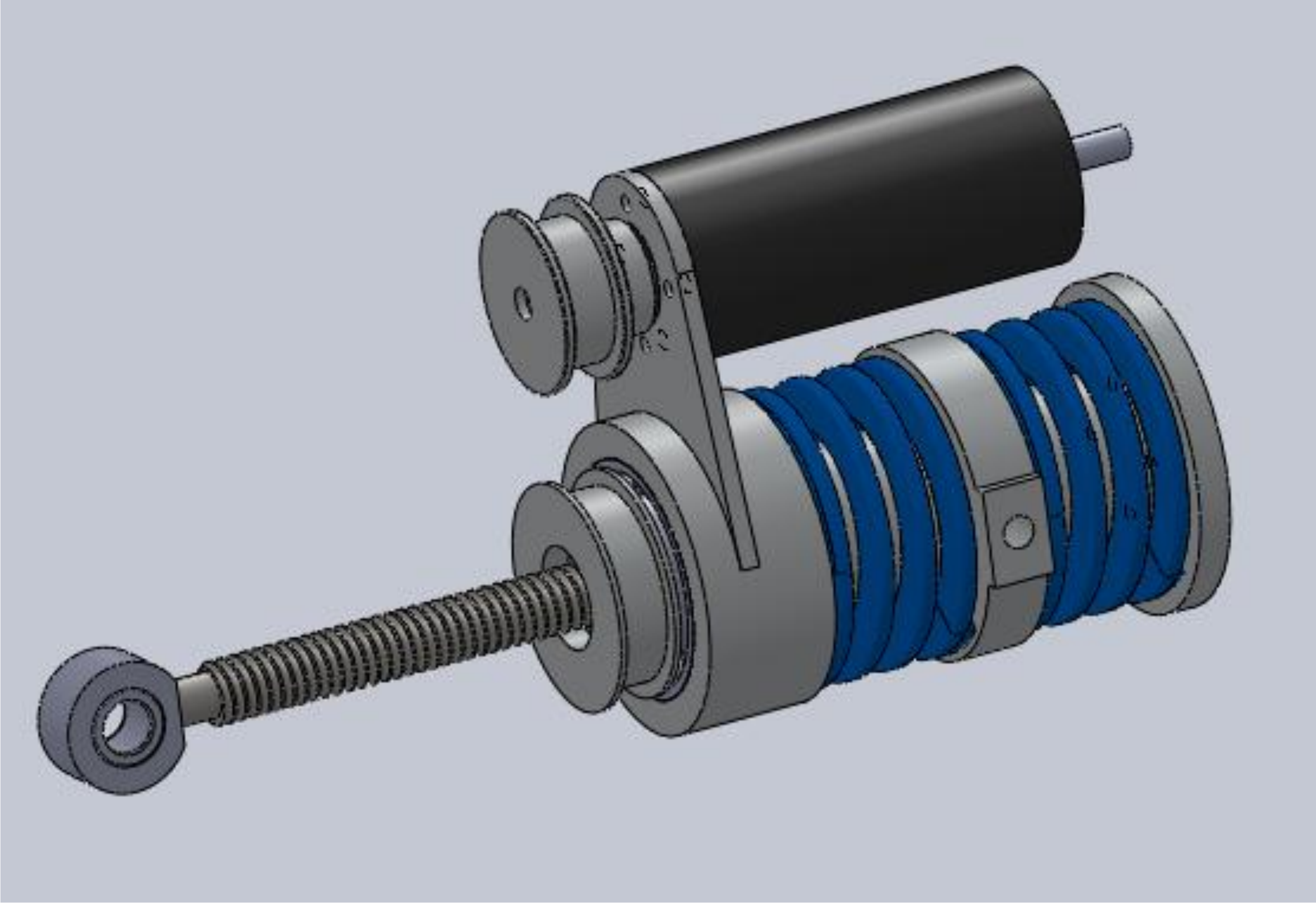

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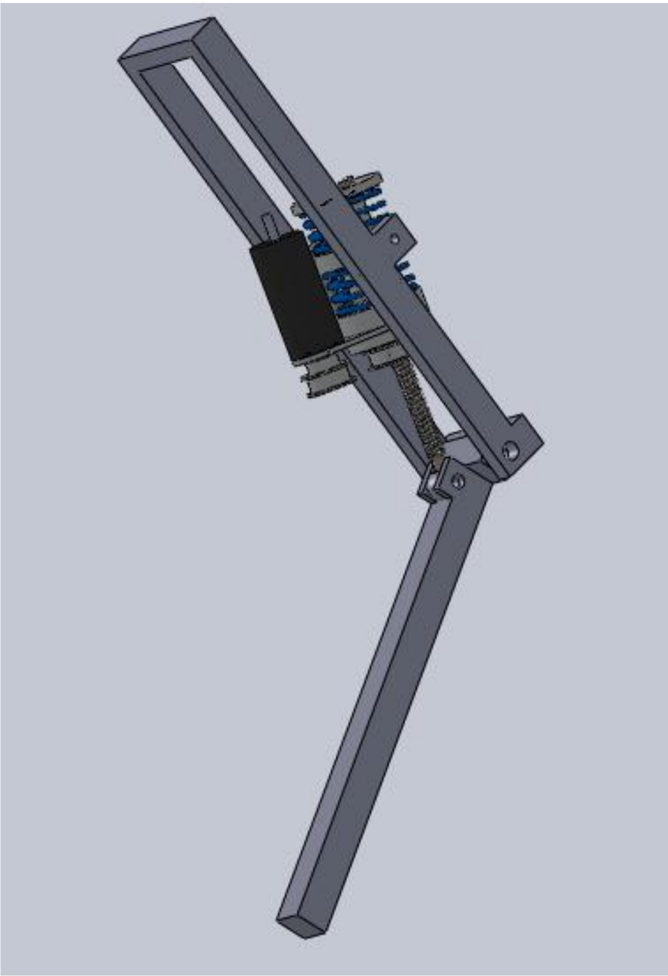

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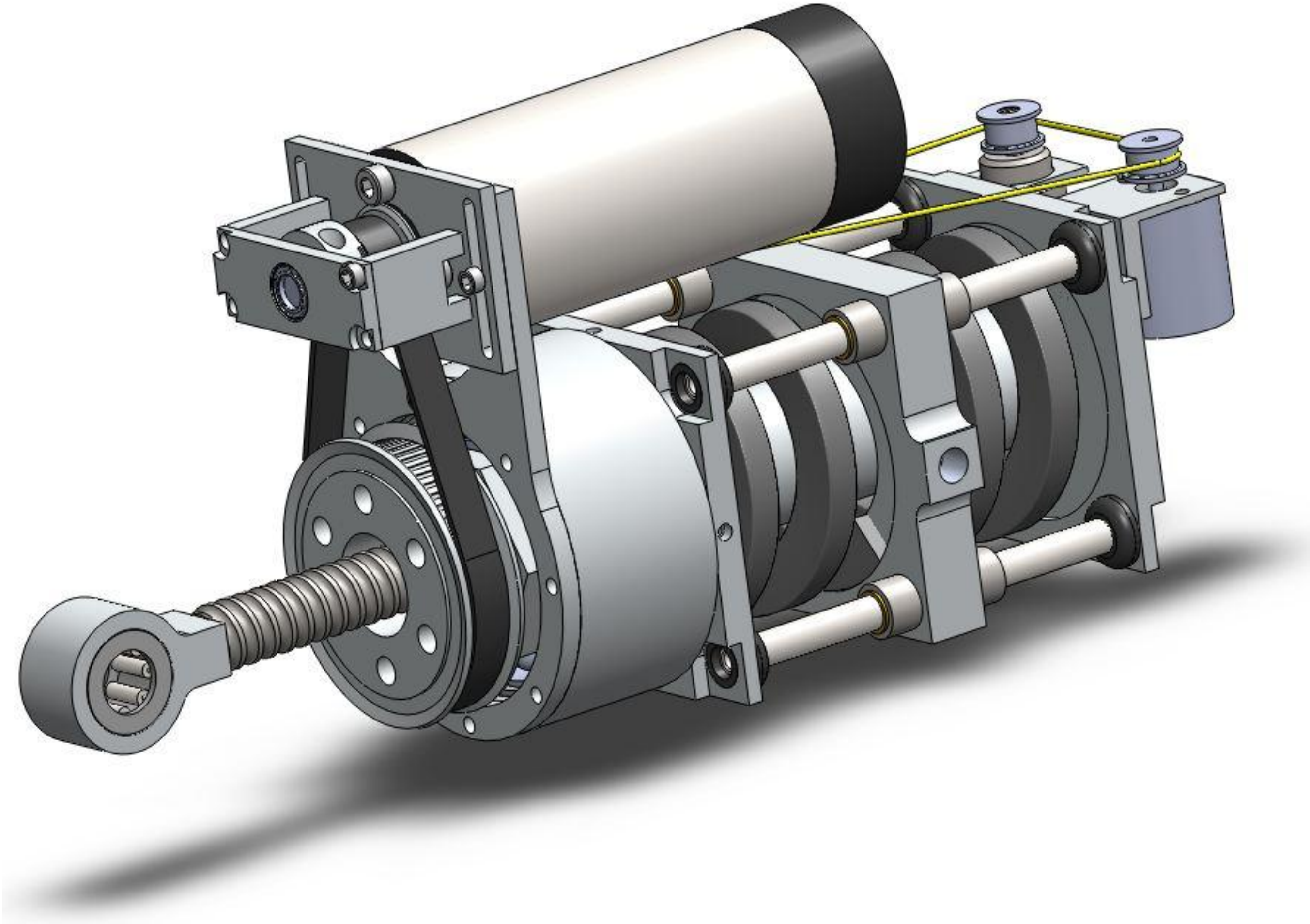

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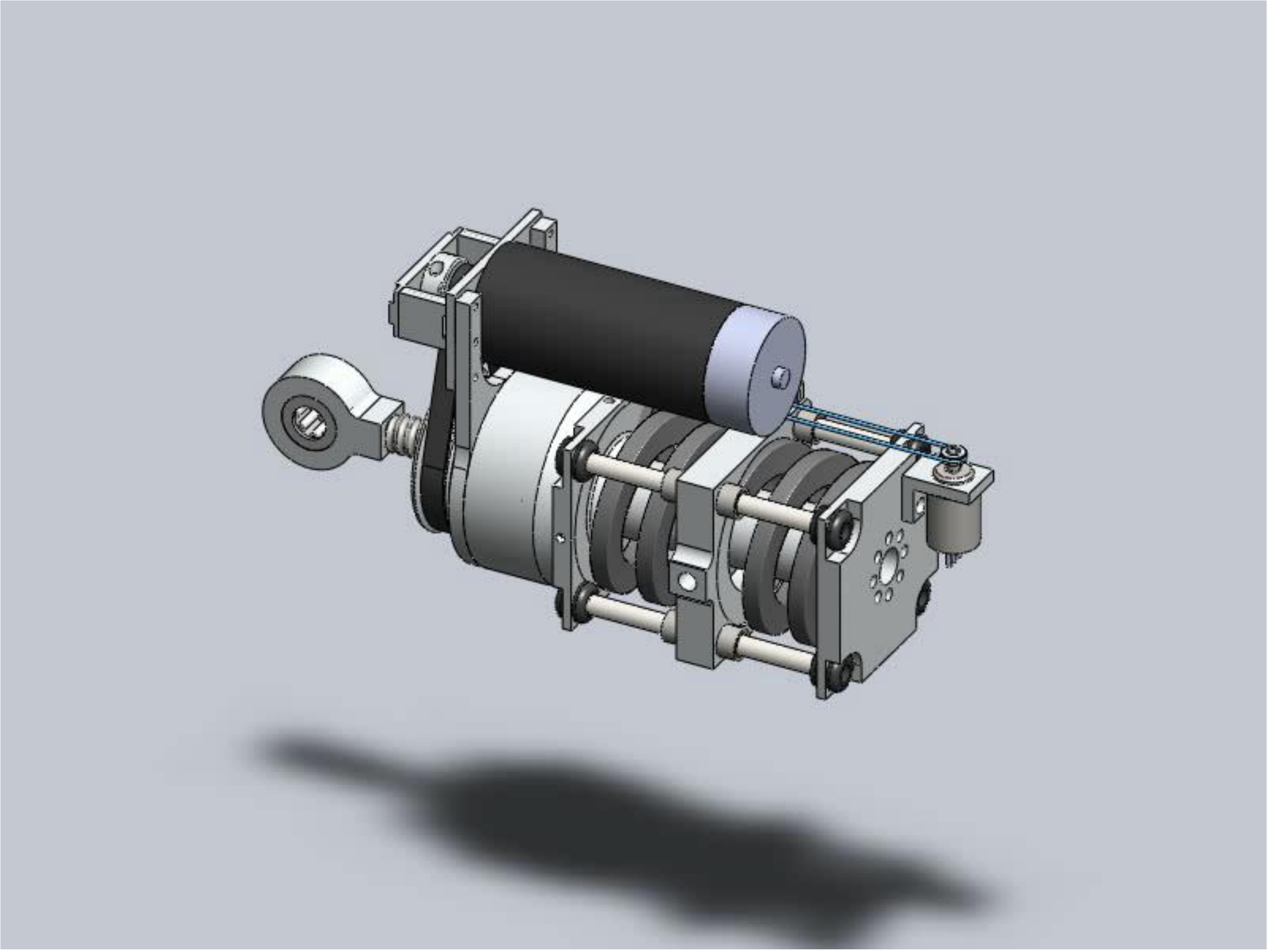

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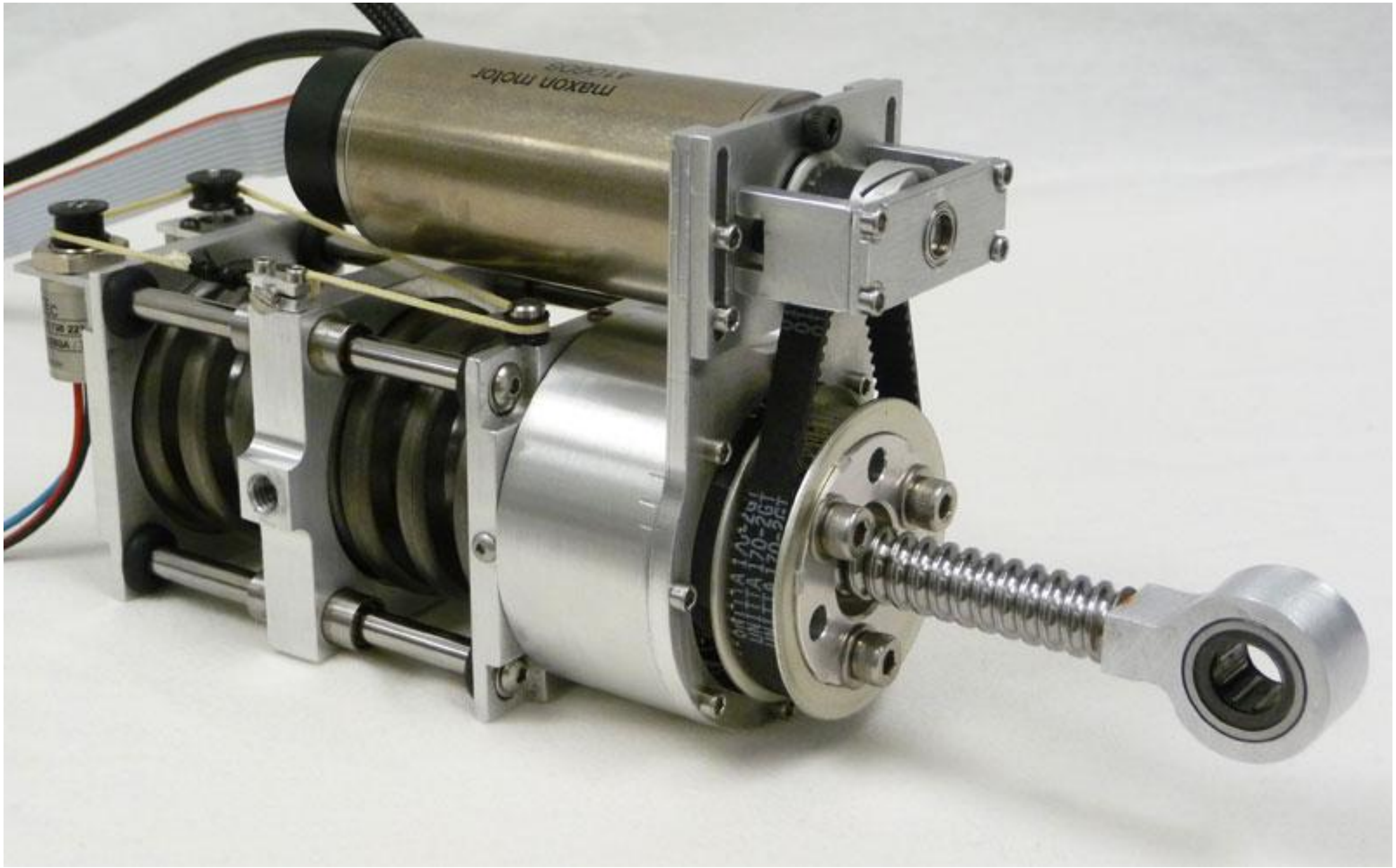

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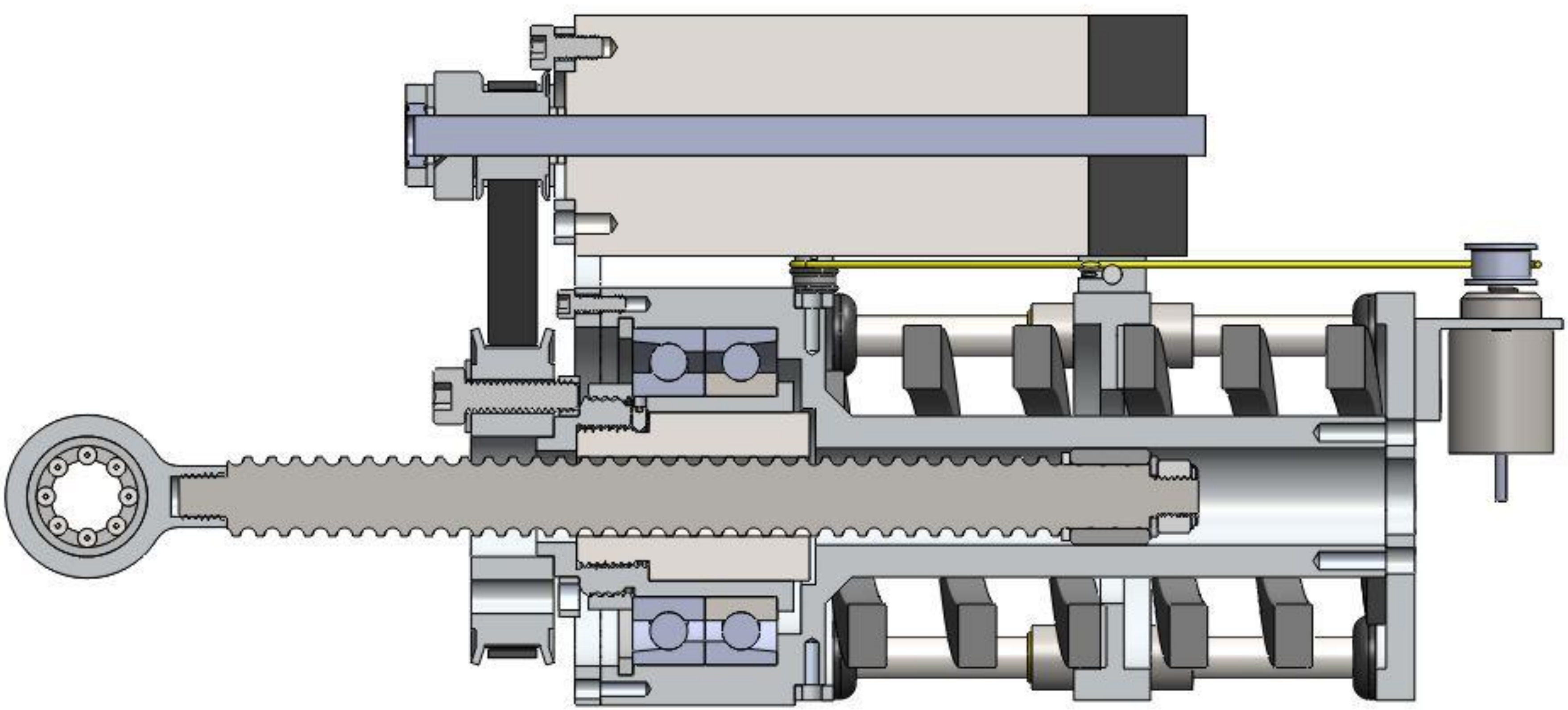
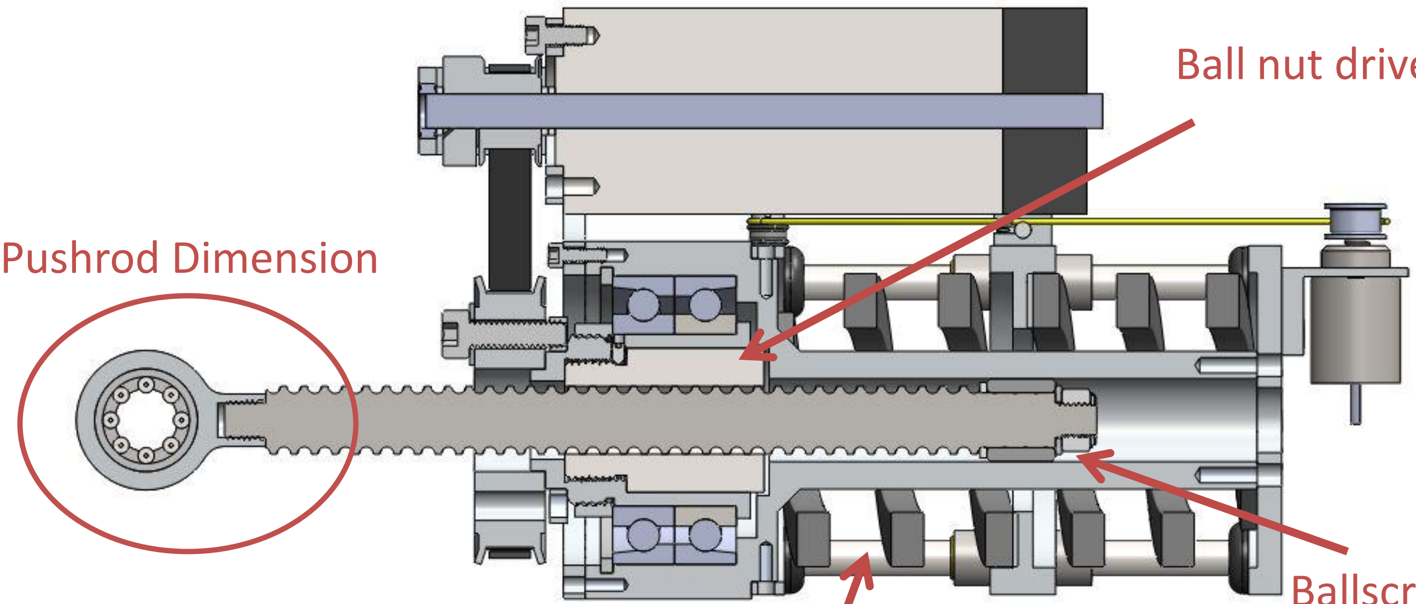
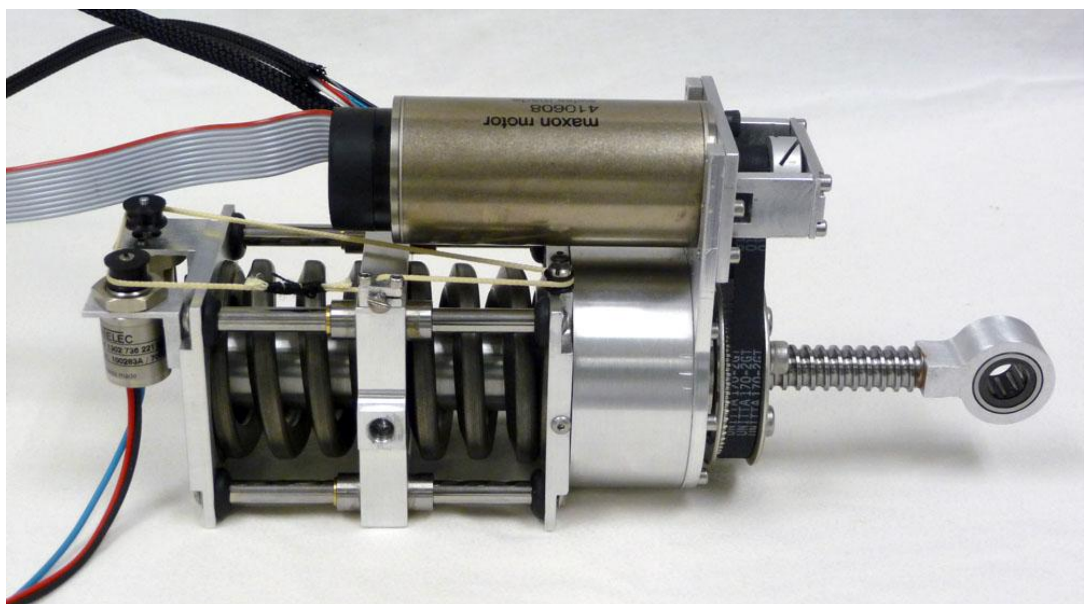


Design Features

Overall compact size



Modular Design



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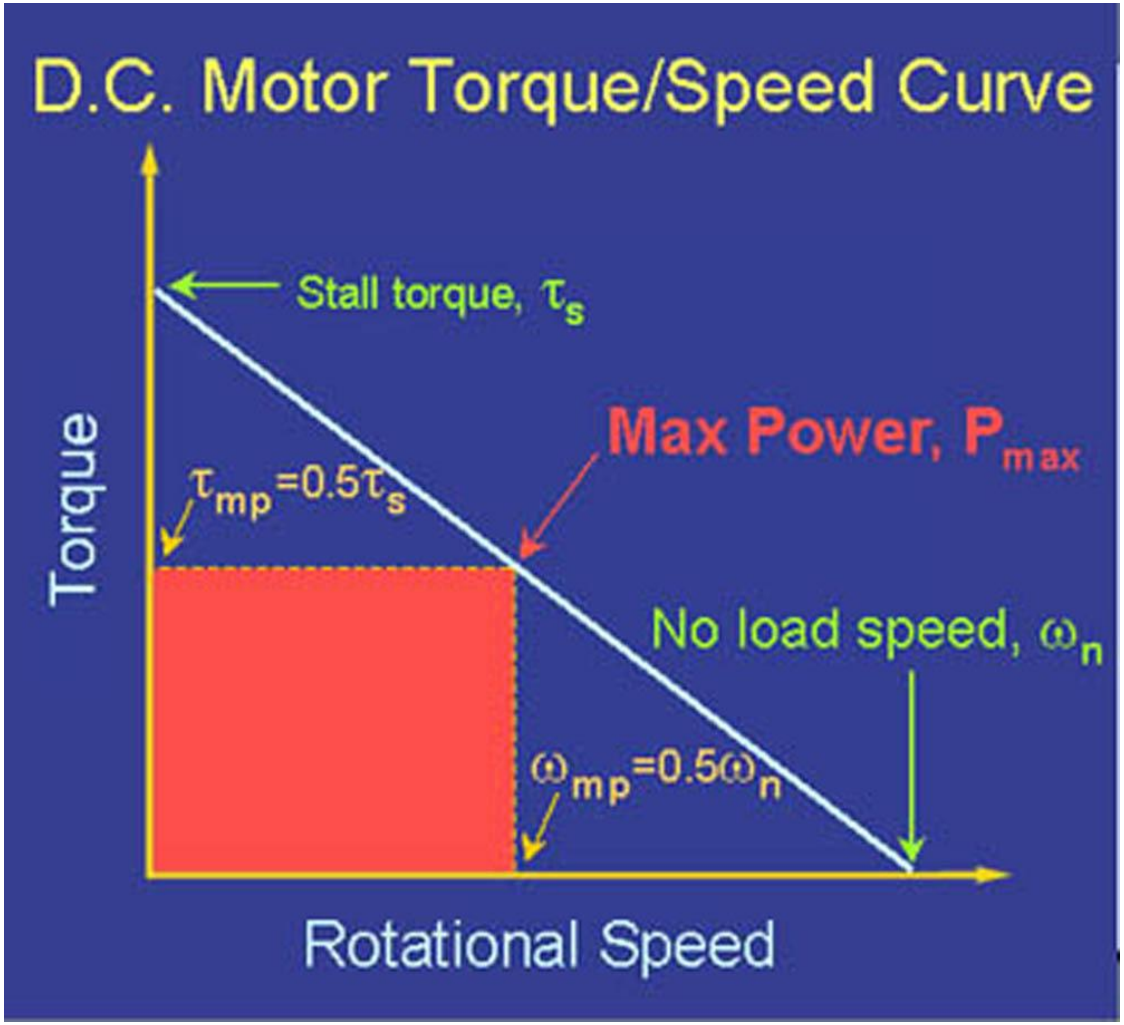
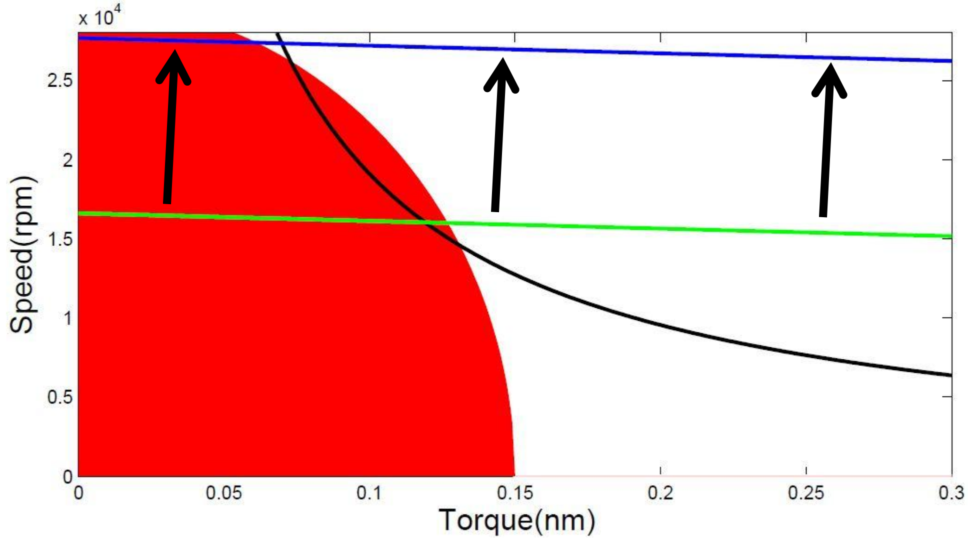
Motor Characteristics



Motor Overvolting

- Higher motor voltage increases operating area
- Increases continuous speed, intermittent torque and power

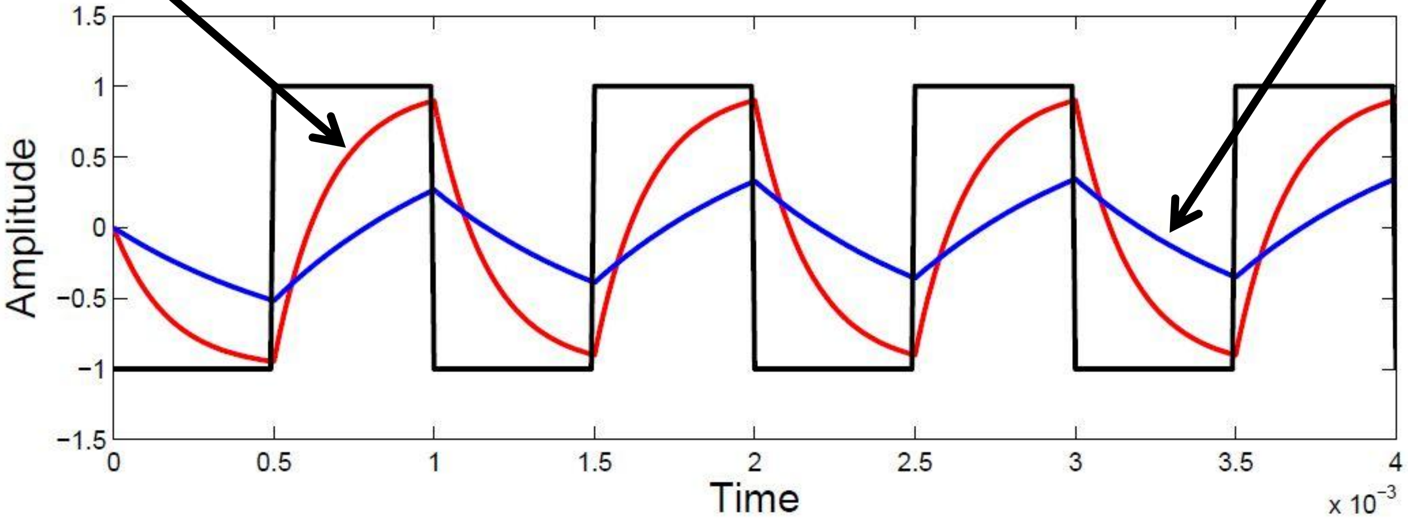


Motor Overvolting

- Increased voltage causes current peaks to increase
- Use series inductance to reduce peaks

High current peaks

Lower current peaks



Actuator Summary

- Series Elastic Actuator
  - Force control
  - Mechanical low pass filter
  - Energy storage
- Ballscrew reduction
  - Efficient
  - Impact tolerant
  - Prismatic

Actuator Summary

- Novel mechanical design
  - Small size
  - Low weight
- Motor Overvolting
  - Increased motor performance

Actuator Summary