Design of a Force-Controlled Cartilage Bioreactor

Proof-of-Concept Prototype Presentation

Background

Mechanical **loading** → **metabolic dysfunction** → osteoarthritis-like **damage** and cartilage disease

To enable research on cartilage **metabolic dysfunction and its connection to** cartilage disease state, **Dr. Henak has requested** a device to **apply cyclic loading over long timescales** (1 hr to days & weeks) with **control over amount of force applied**

Design Requirements

Incubator-Compatible

1. Fits within 20 x 21 x 25 [in^3] space
2. Operates in 37 ^oC, humid environment
3. Aseptic Technique Friendly
    1. Capable of adequate sterilization to ensure proper tissue culture

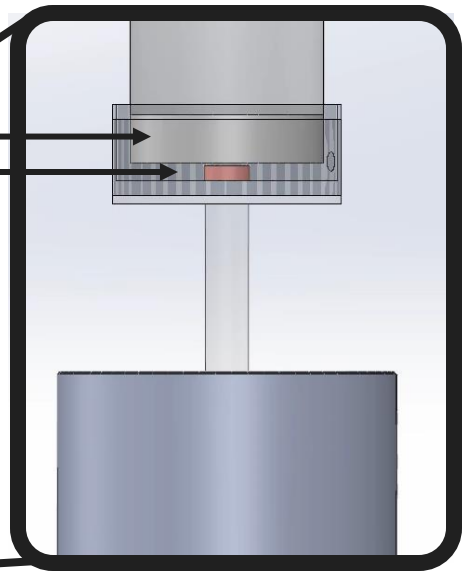
Relevant, Biocompatible Force Application

1. ~ 20% strain on cartilage samples
2. Applied strain must be force-controlled, not displacement-related, due to poroelastic behavior of cartilage
    1. Linear elastic approximation yields ~ 6 N minimum requirement; to ensure client needs are met, actuation needs to apply 12 N
3. Sinusoidal loading profile, ~ 0.1 – 10 [Hz]
4. Low-friction, biocompatible interface contacting sample in compression

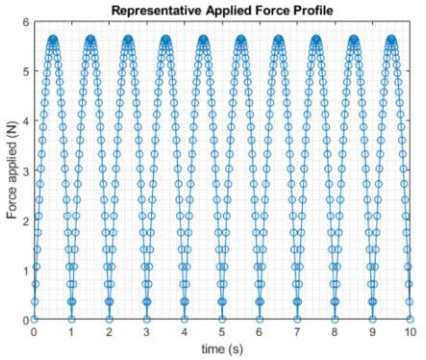
Budget

1. ≤ $5000

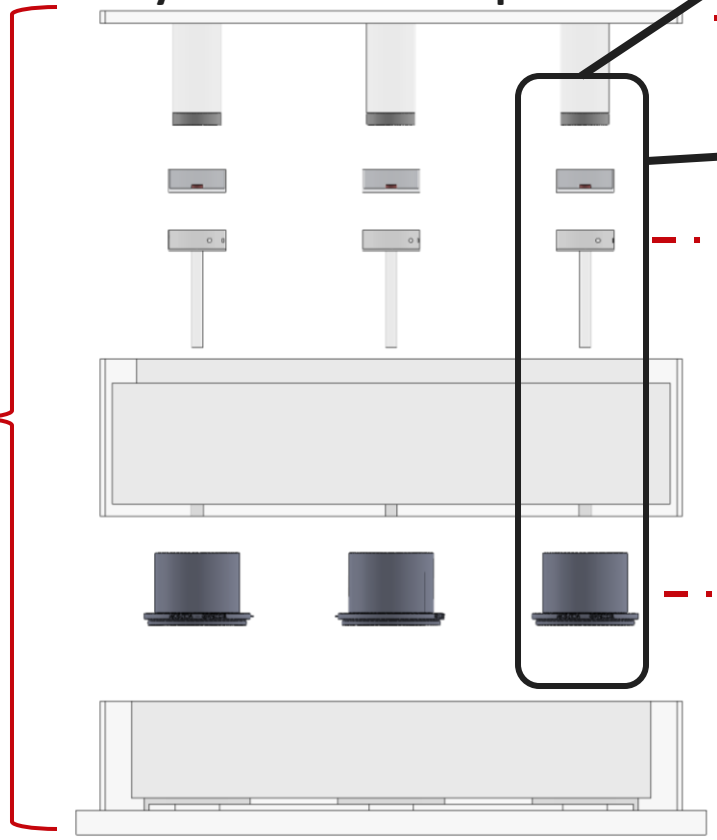
Proof-of-Concept Overview



Application of Compressive Load



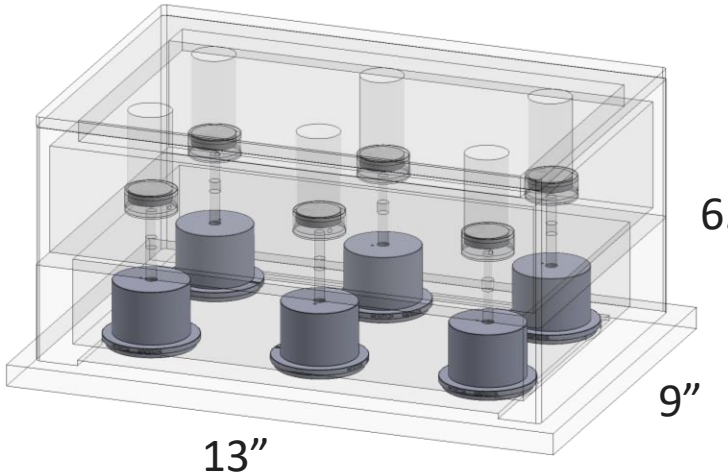
Key Bioreactor Components



- Teflon Compressive Interface / Cover
- Sample Dish
- Plunger / Interface w/ VCA
- Voice Coil Actuators (6)

Casing:
BioMed Clear V1
** Actual design will include anodized power screws in each corner for securing cover to the sample package & electronics package.*

Footprint



Design Requirements

Incubator-Compatible

1. Fits within 20 x 21 x 25 [in^3] space → **See provided dimensions.** ☑
2. Operates in 37 ^oC, humid environment → **All components can function in environmental conditions.** ☑
3. Aseptic Technique Friendly → **All non-electronic materials are autoclave-friendly.** ☑
    1. Capable of adequate sterilization to ensure proper tissue culture

Relevant, Biocompatible Force Application

1. ~ 20% strain on cartilage samples → **Selected VCA outputs sufficient force for ~40%.** ☑
2. Applied strain must be force-controlled, not displacement-related, due to poroelastic behavior of cartilage → **VCA translates electric current to force output.** ☑
    1. Linear elastic approximation yields ~ 6 N minimum requirement; to ensure client needs are met, actuation needs to apply 12 N
3. Sinusoidal loading profile, ~ 0.1 – 10 [Hz] → **Sinusoidal function input.** ☑
4. Low-friction, biocompatible interface contacting sample in compression → **Teflon allows for low-friction, biocompatible impact.** ☑

Budget

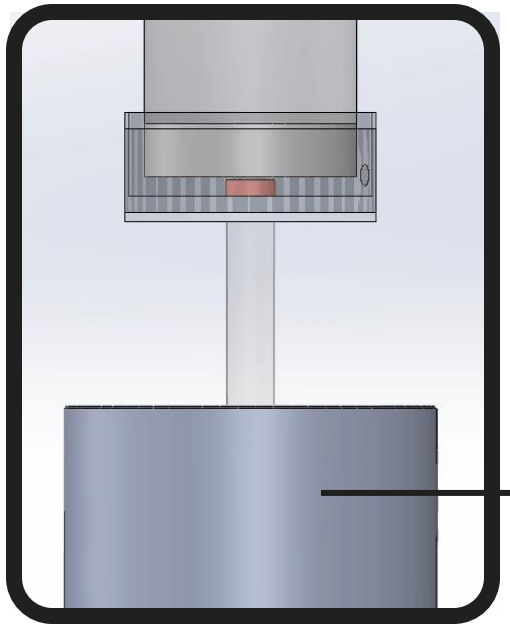
1. ≤ $5000 ☑

Questions?

Supplementary information available on actuation, actuation control, and Teflon interface.

Actuation

- Voice coil actuator operation
  - Apply current or voltage → Magnetic field in coil → **Displacement/Force**
- **Pros:**
  - Can **quickly modulate** current and **force** at 0.1-10 Hz
  - No significant losses due to friction



DC Current/Voltage Source → Circuitry to Output Sinusoidal Profile at 0.1-10 Hz

Circuitry to Output Sinusoidal Profile at 0.1-10 Hz → Voice Coils → Cartilage Samples

ThorLabs VC125C/M
$520 / unit
At standard operating conditions, can produce relevant forces

Relevant, Biocompatible Force Application

1. ~ 20% strain on cartilage samples
2. Applied strain must be force-controlled; actuation needs to apply 12 N to meet 20% strain
3. Sinusoidal loading profile, ~ 0.1 – 10 [Hz]
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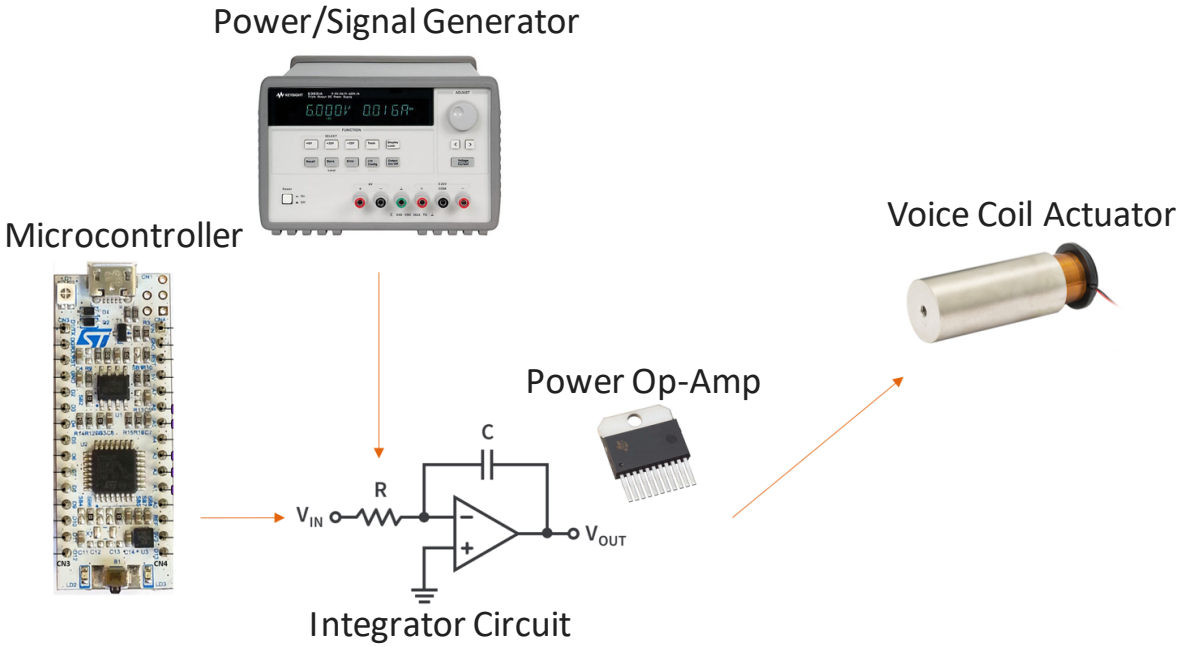
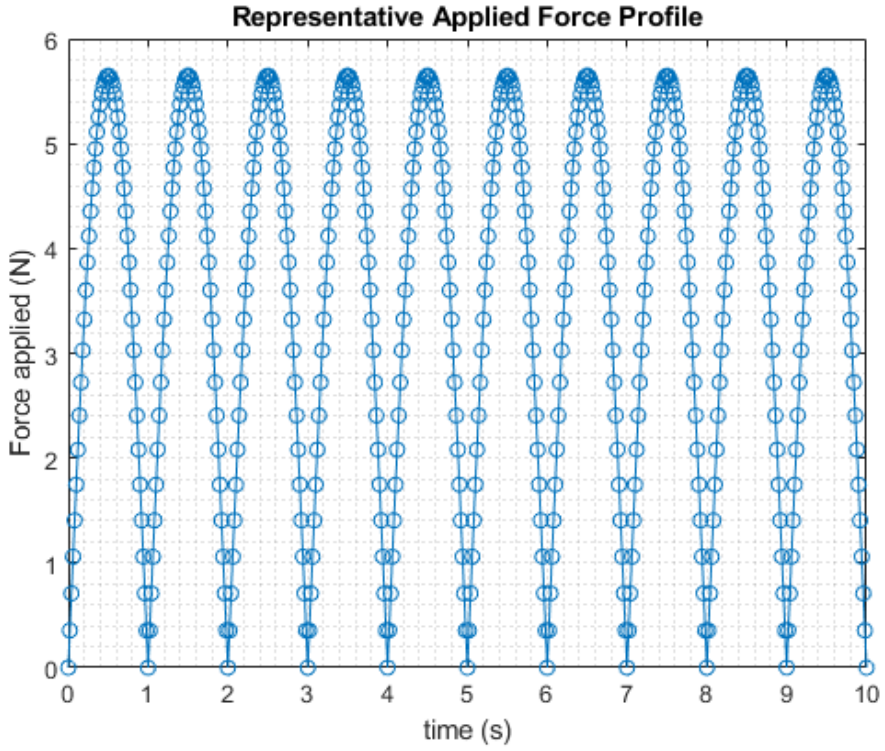
Actuation Control

- 0.1-10Hz of sinusoidal loading profile
  - Start with a triangle wave
- Different components to generate signal





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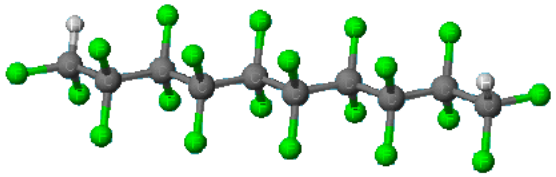
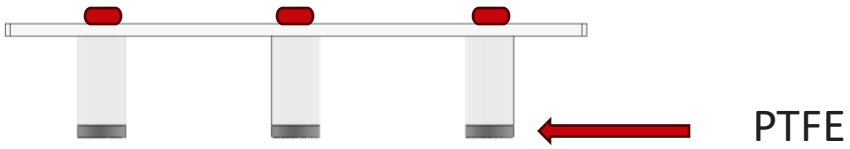
Proof-of-Concept

Interface Material - PTFE

- Chemically inert, nontoxic, and nonflammable substances
- Low coefficient of friction ➔ less shear stress on the tissue
- High-temperature resistance: M.T.: 635°F (335°C)
  - Sterilization method: Autoclave
- Fabrication
  - The plate and PTFE columns will be fastened using button head socket cap screws along with flat washers





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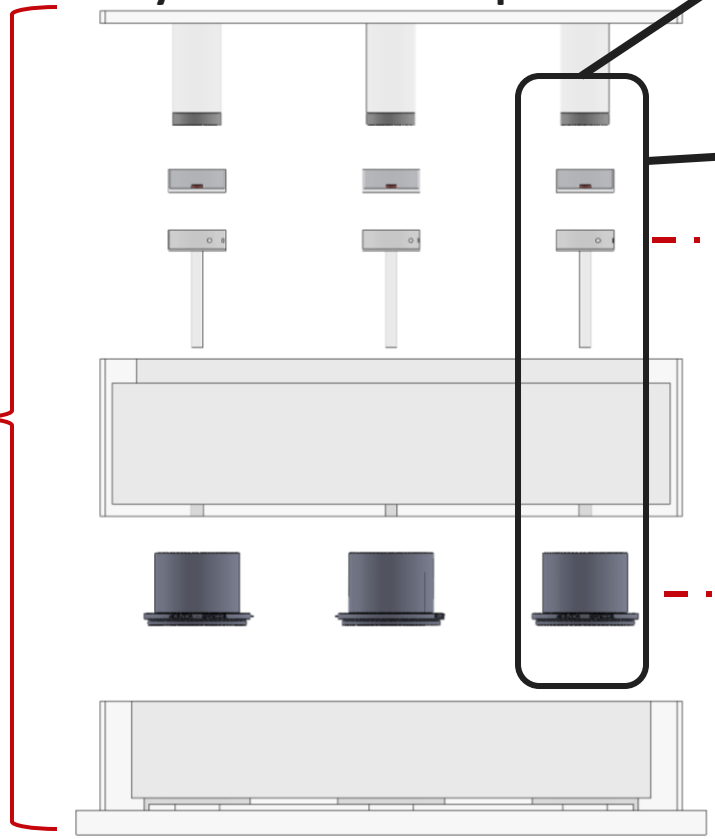
Proof-of-Concept

Proof-of-Concept Review

Key Bioreactor Components



Compressive Interface / Cover

Sample Dish Plunger / Interface w/ VCA

Voice Coil Actuators (6)

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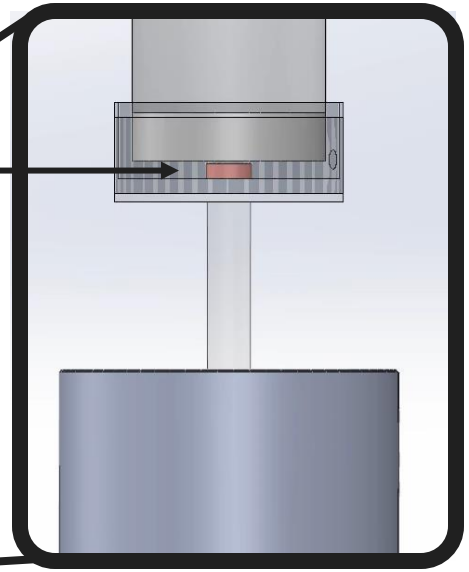
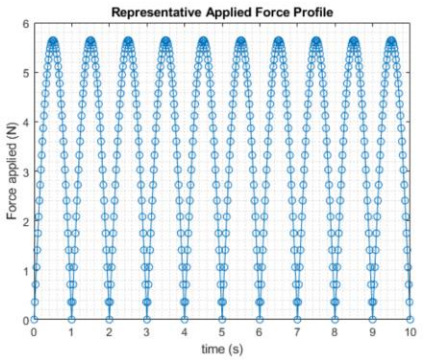
Cartilage Sample





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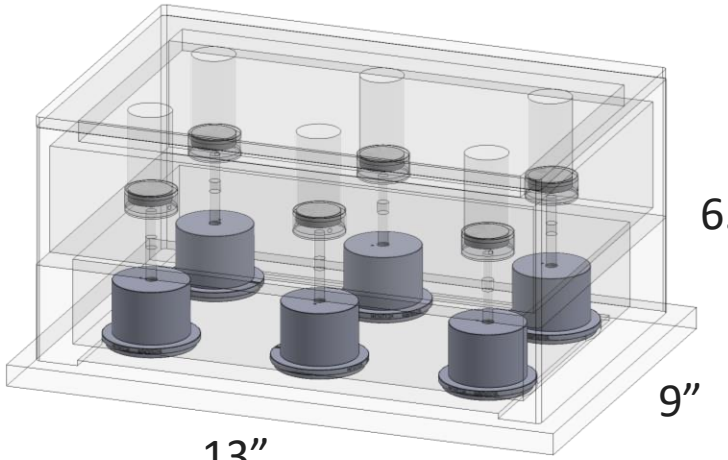

6.25”

9”

13”