# BMVSS Knee

## a low-cost passive prosthesis to replicate able-bodied motion

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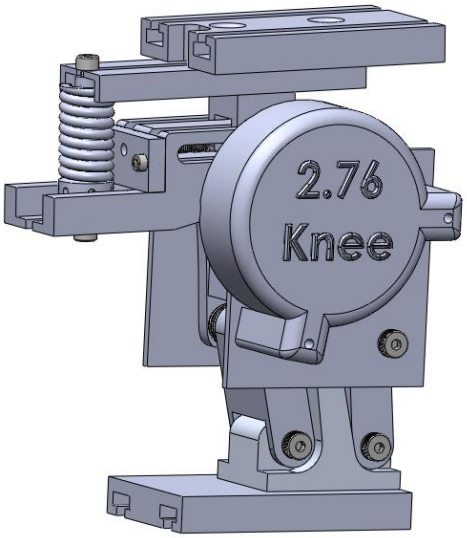
# Final Prototype




# Need for knee prostheses in India

200,000 above-knee amputees in India

Can cause unemployment and social stigmatization

# Current Products

**Jaipur Exoskeleton knee**
**$10**

**Jaipur-Stanford 4 bar knee**
**$25**

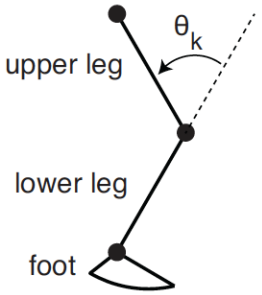
BMVSS Knee
**$150**

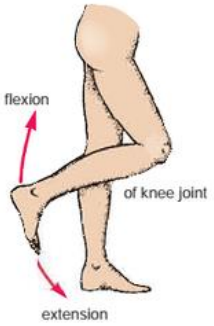
**Active knees**
**~ $10,000-60,000**

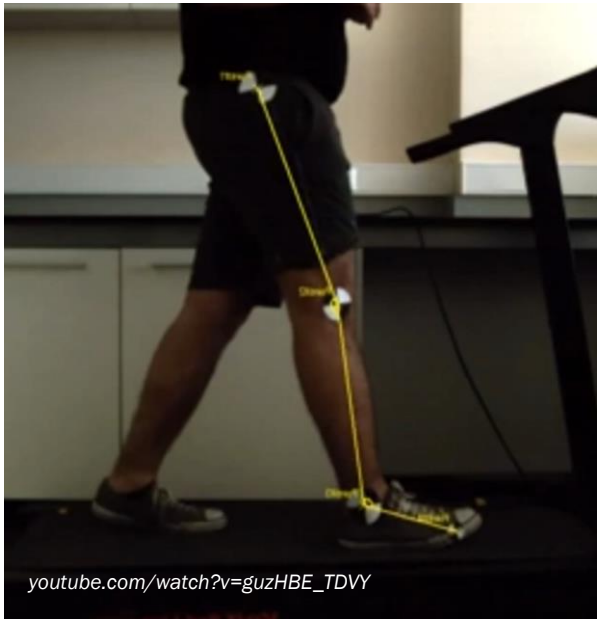
**$10** **$25** **$60,000**

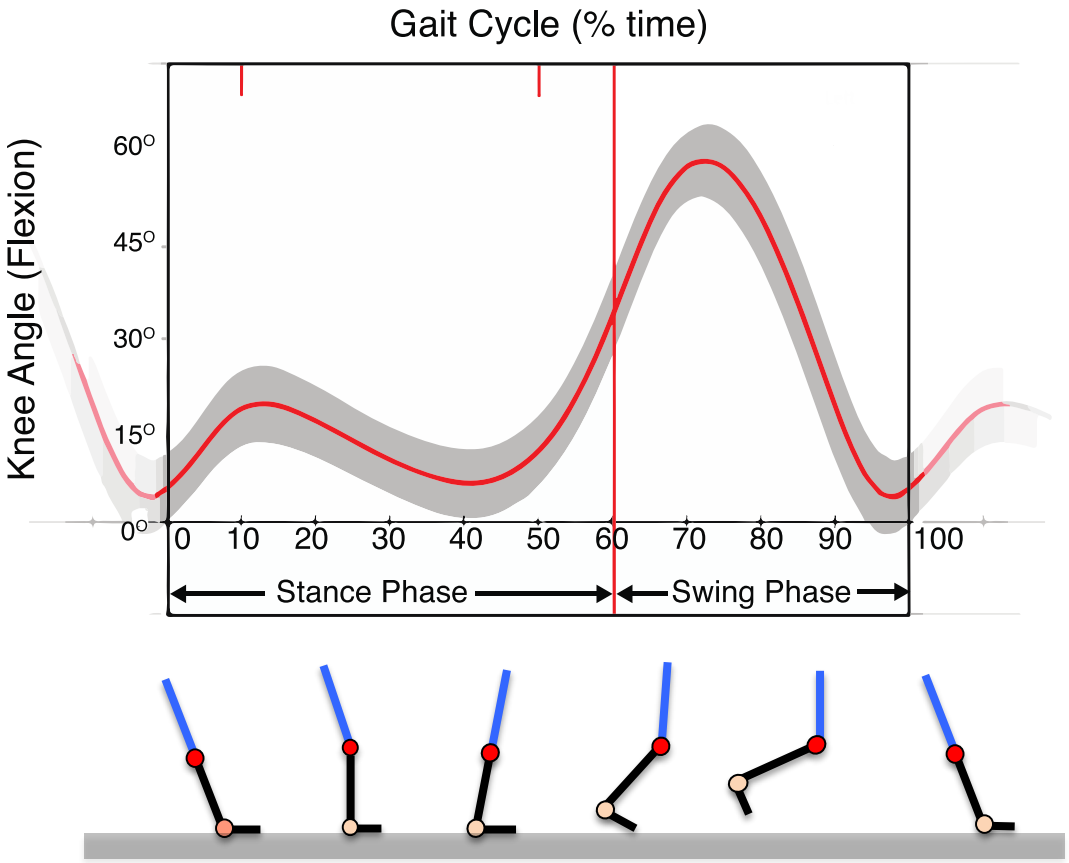
**cost vs. performance gap for prostheses**

# Goal: Able-Bodied Walking Kinematics



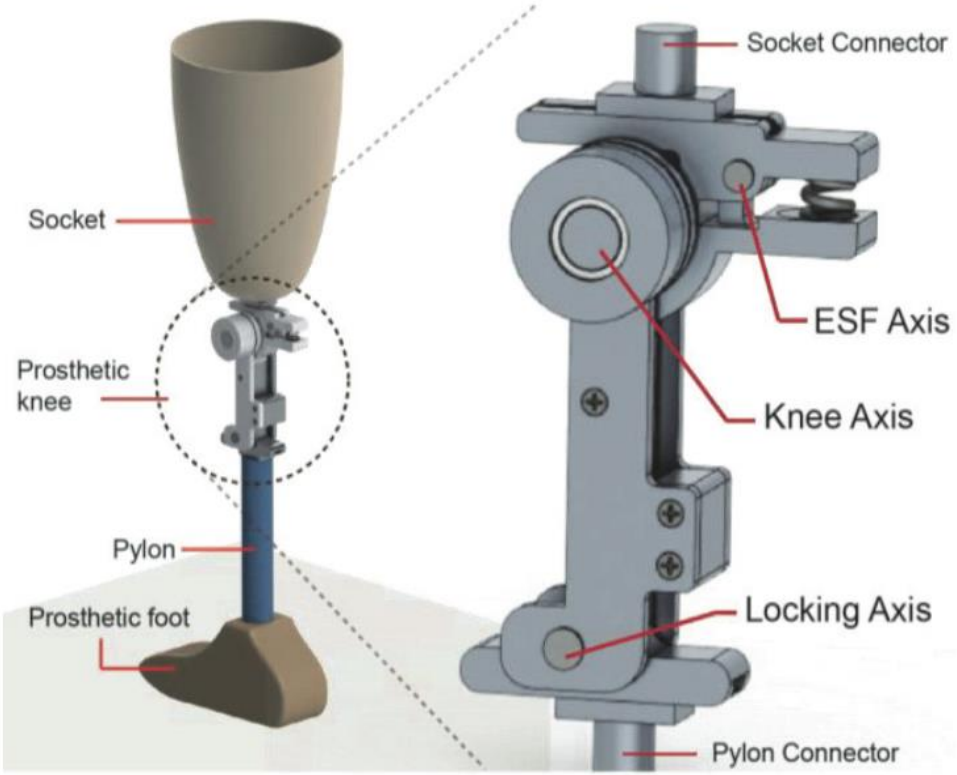



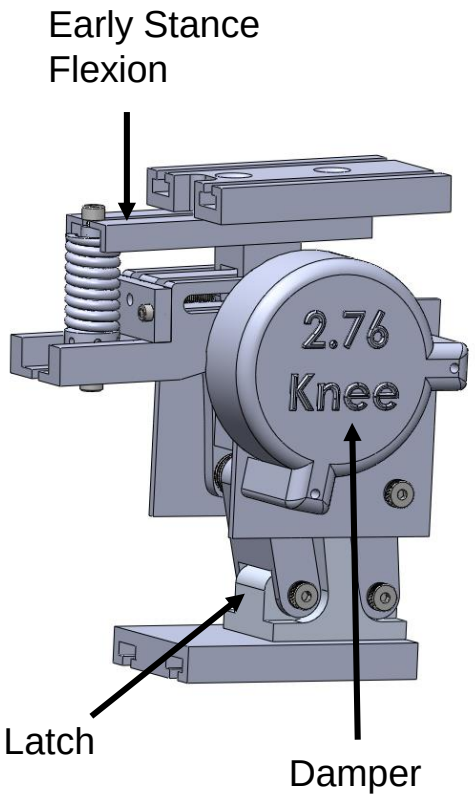



# Design Requirements

| | |
|---|---|
| **Consistent performance across environmental conditions** | • Range of temperatures (5-118 Fahrenheit in India)<br>• Dirt, sand, mud, water |
| **Low maintenance** | • 3 years before maintenance/replacement<br>• Fatigue life through 3 million cycle |
| **Close to able-bodied gait** | • 20 degrees early-stance flexion<br>• 60 degrees swing phase flexion<br>• Accommodates different walking velocities<br>• Damping of ~20-30Nm damping during flexion<br>• Damping of ~2.7-5.5Nm damping during extension<br>• Smooth motions in knee and prevent jerky/jolting stops<br>• Mechanism fixed before heel strike, regardless of knee extension<br>• Less than 3 degrees of backlash<br>• Energy conserving through early stance flexion (10.5 J) |
| **Low cost** | • Cost: <$150 |
| **Discreet** | • Quieter than current design<br>• Must be worn discreetly under pants (size consideration) |
| **Structural integrity** | • Accommodate body weight (70kg)<br>• Stability to withstand flexion moment of 40 Nm without buckling |

# Building on Prior Work

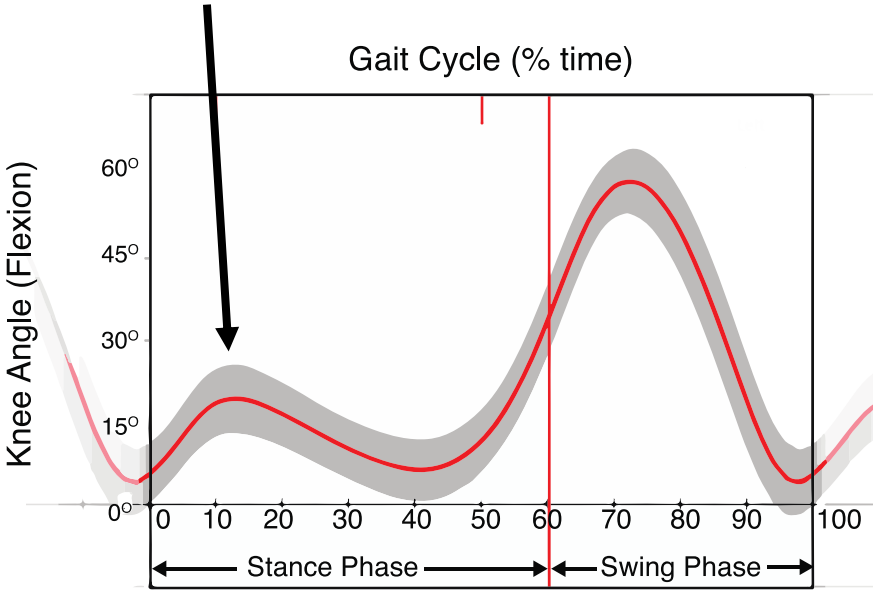


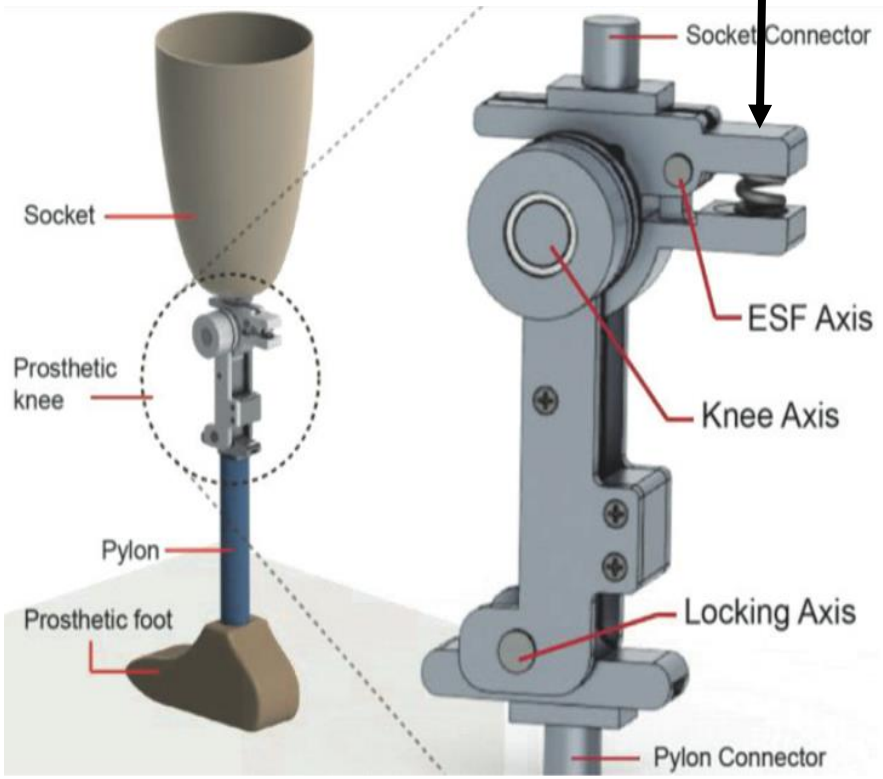

V.N.M. Arelekatti and A.G. Winter. (2015) *Design of a Fully Passive Prosthetic Knee Mechanism for Transfemoral Amputees in India.* IEEEE ICORR.

# Issues with Previous Design: Early Stance Flexion (ESF)

ESF of gait cycle

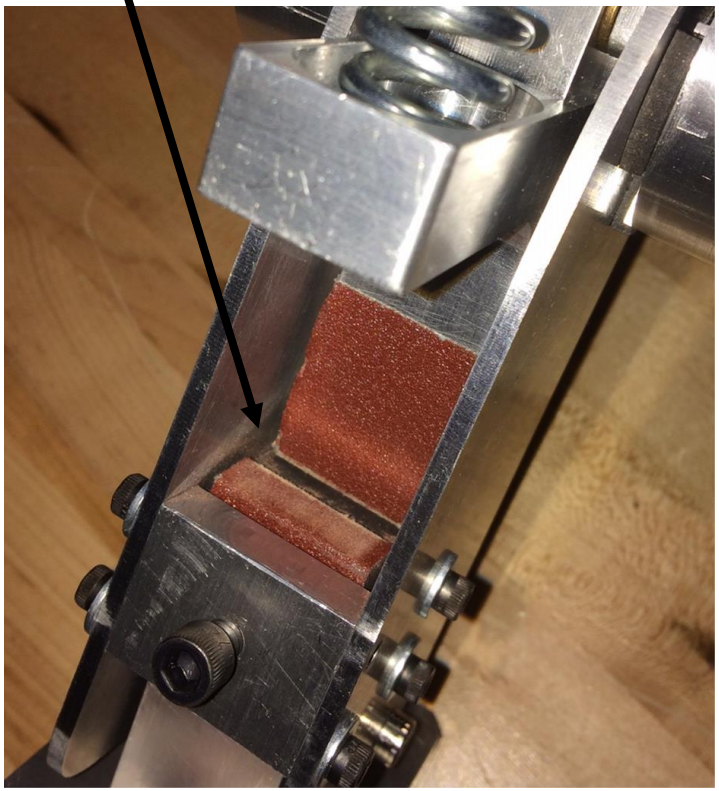



ESF mechanical component

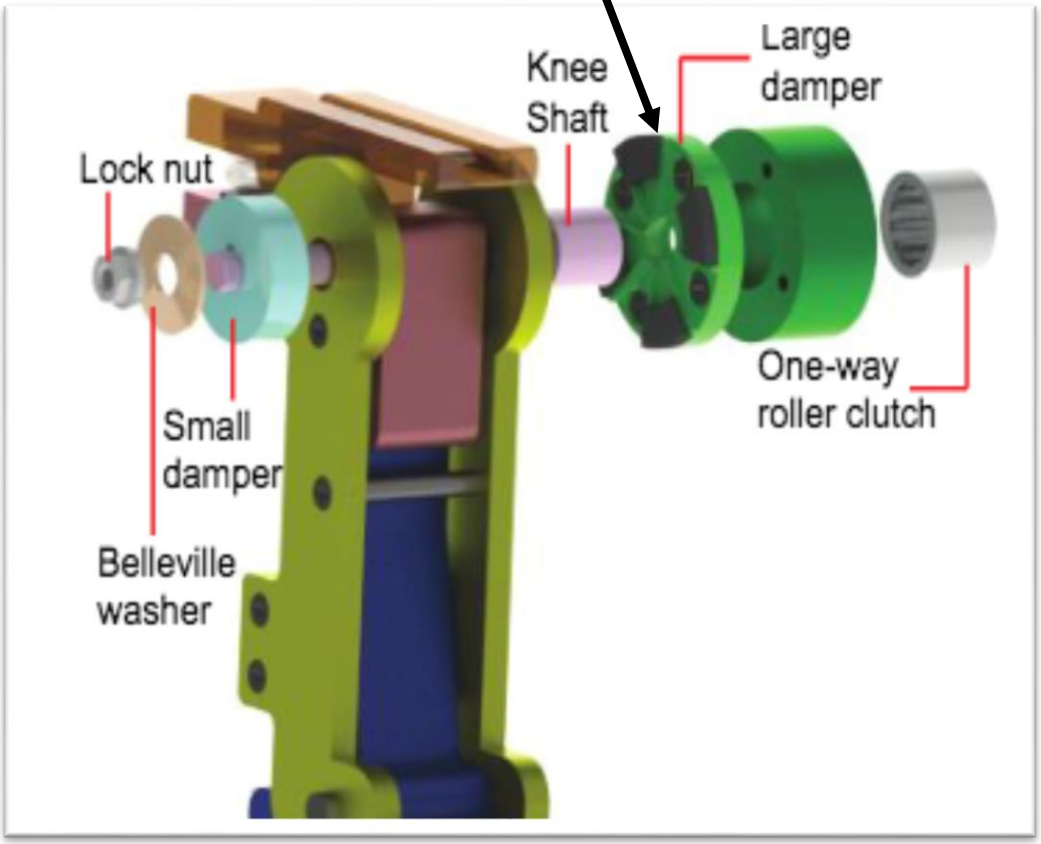


# Issues with Previous Design

Friction based latch

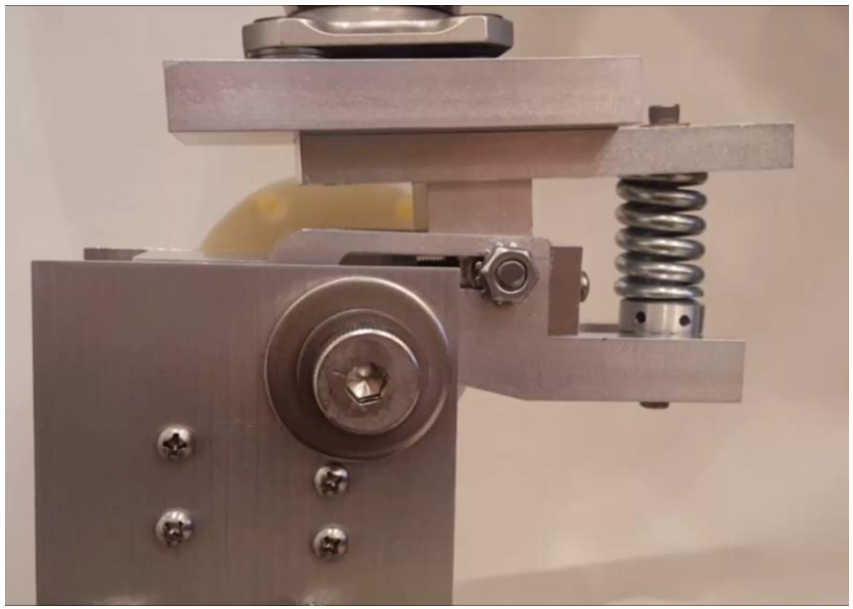


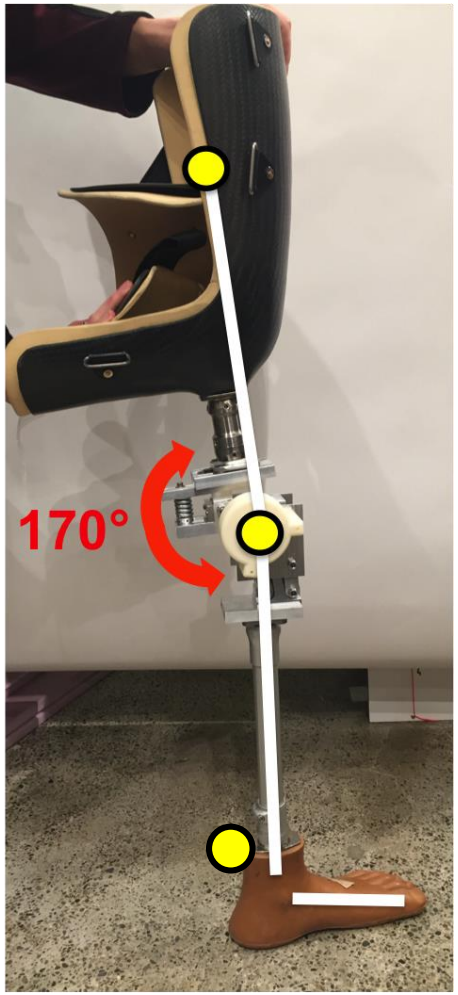
Brake pads



# Early Stance Flexion

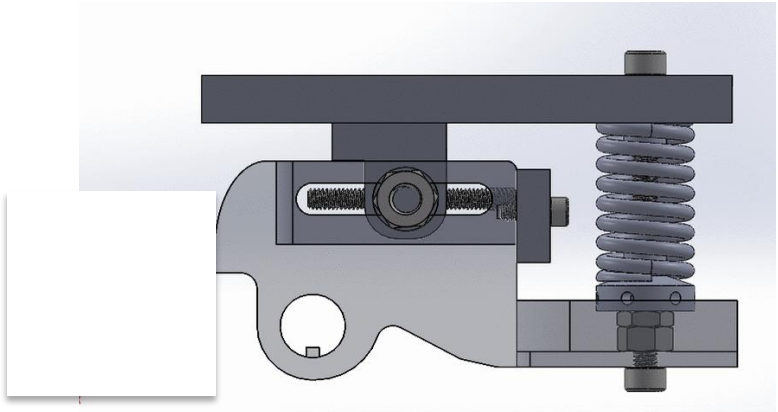
- Necessary for able bodied gait, and metabolic efficiency
- Not present in any current developing world prosthesis



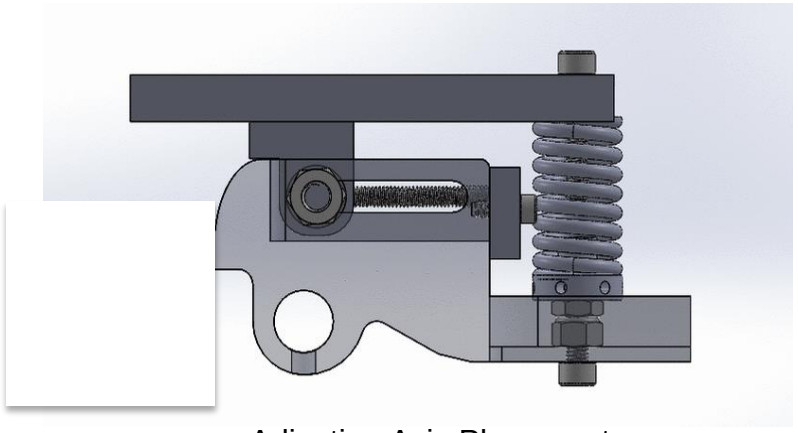


# Force Profile Modularity

- Increasing force required for flexion up to 5 N-m
- Flexion axis can be moved 3.2 cm
  - This accounts for a wide range of GRF profiles among amputees



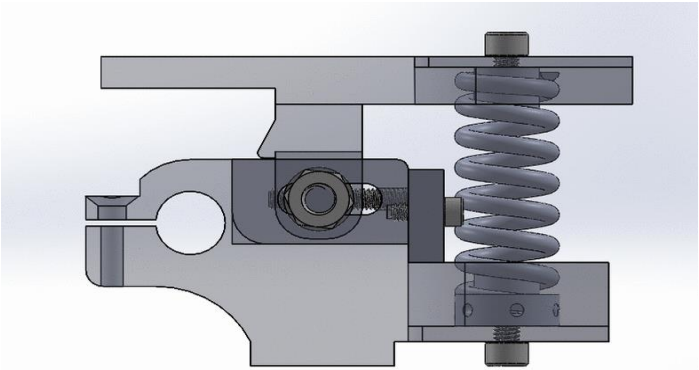
Adjusting Spring Preload



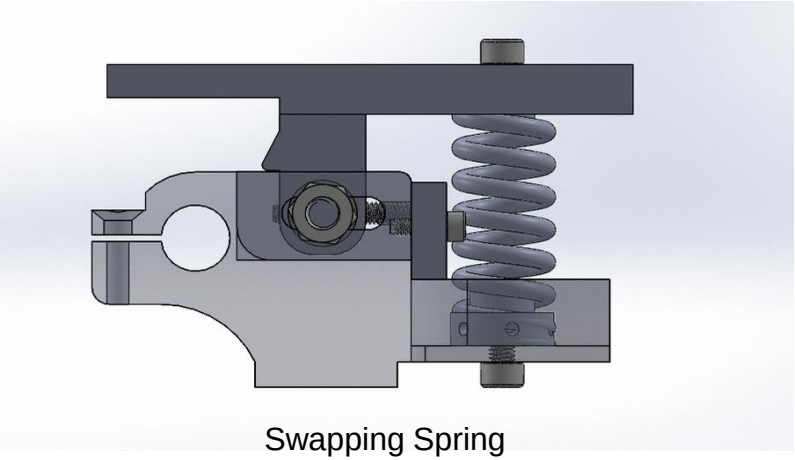
Adjusting Axis Placement

# Stiffness Modularity

- Moment arm can increase 2.3x
- Torsional stiffness of 0.8 – 7.0 N-m/kg-rad
  - covers calculated ideal 2.96 N-m/kg-rad
- Flexion angles of 4 – 22 degrees



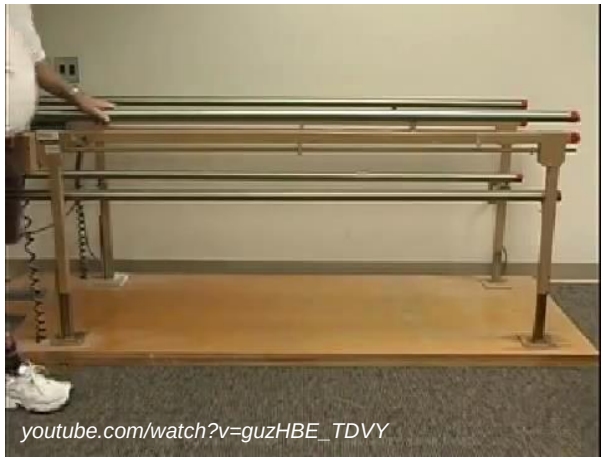
Adjusting Spring Location



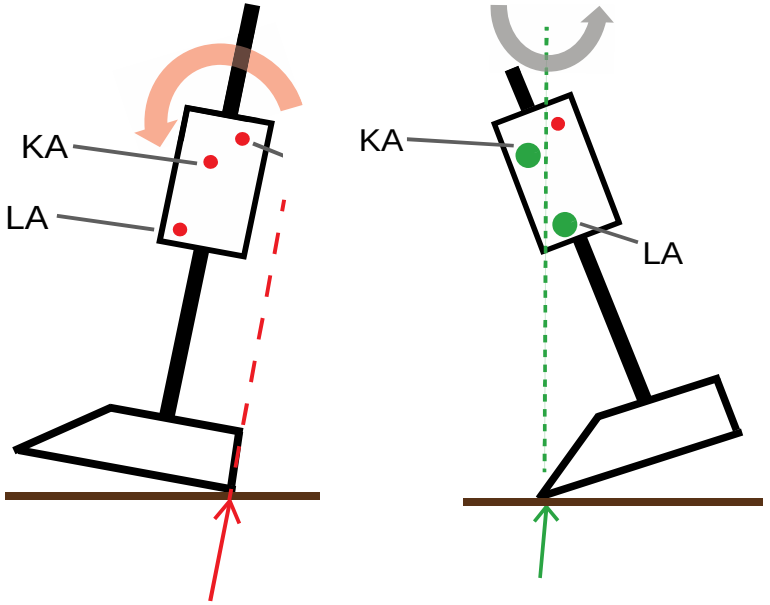
Swapping Spring

# Latch Provides Early Stance Stability

Risk of buckling

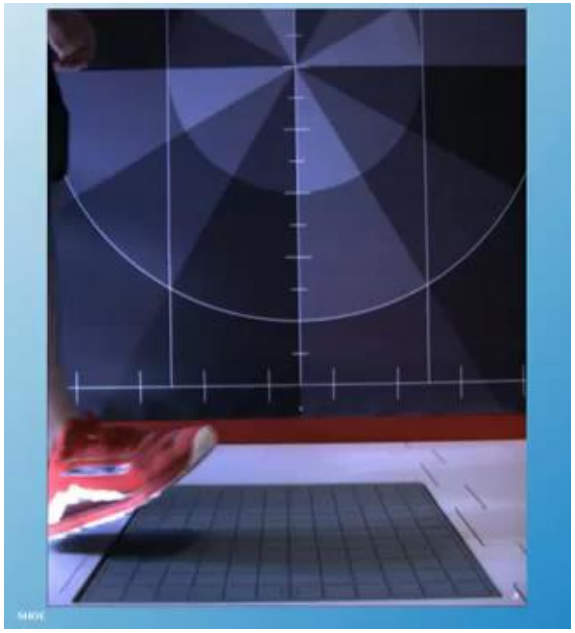


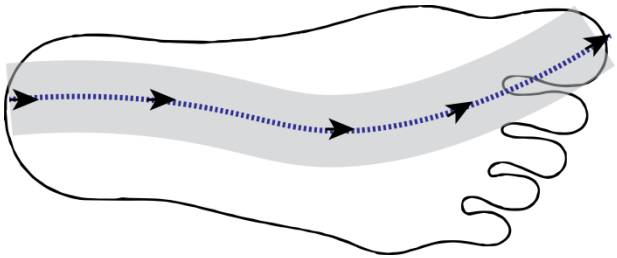

Locking axis can control latch

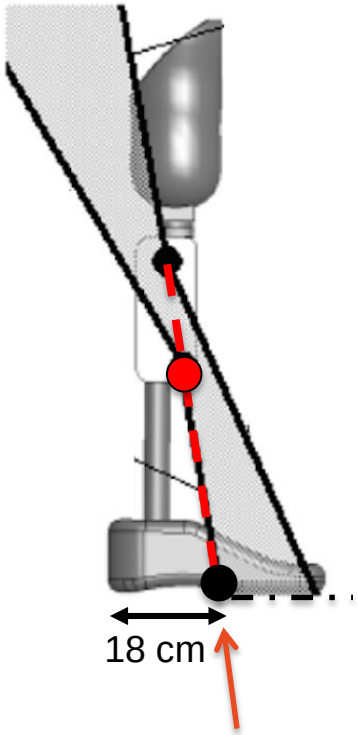


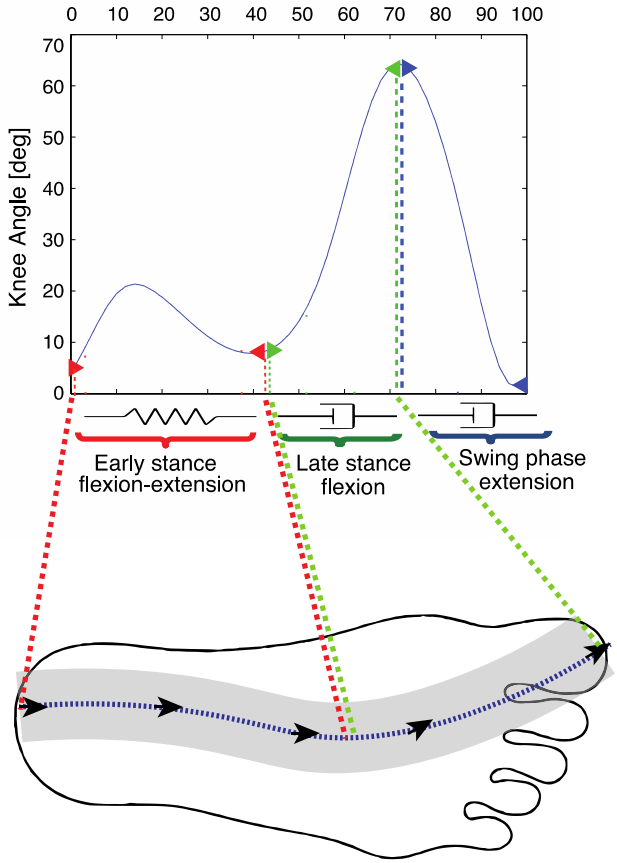

Solution to prevent buckling:
Use ‘locking axis’ position to control latch engagement

# Placement of Locking Axis



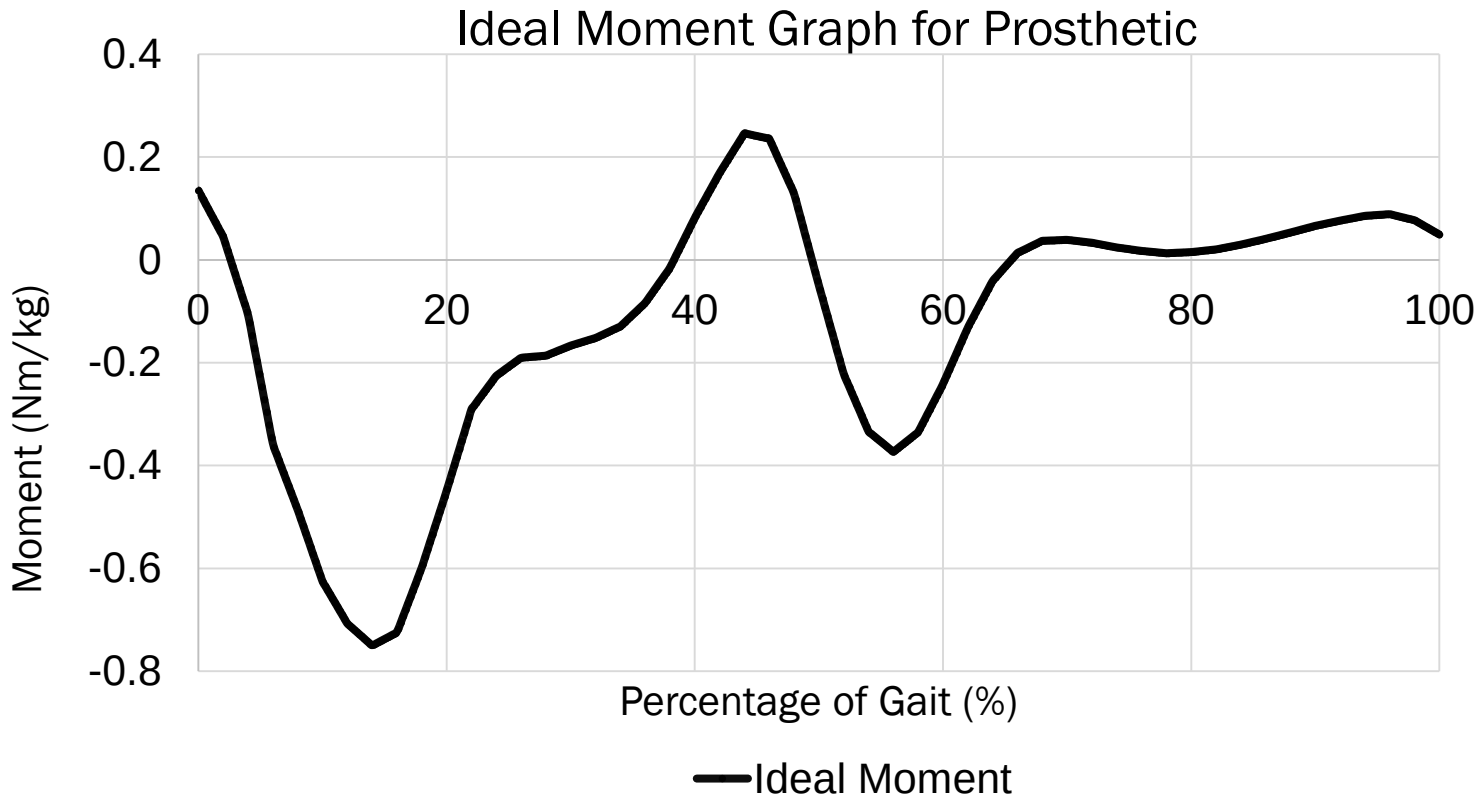





GRF transition point chosen as GRF COP when we want knee to unlock

# Damping the Knee for Able-Bodied Gait




| | Frictional Paramater | Cadence | | |
|---|---|---|---|---|
| | | Slow | Natural | Fast |
| Flexion Damping | b (N*m/kg) | 0.28 | 0.29 | 0.42 |
| Extension Daming | b (N*m/kg) | 0.039 | 0.069 | 0.078 |

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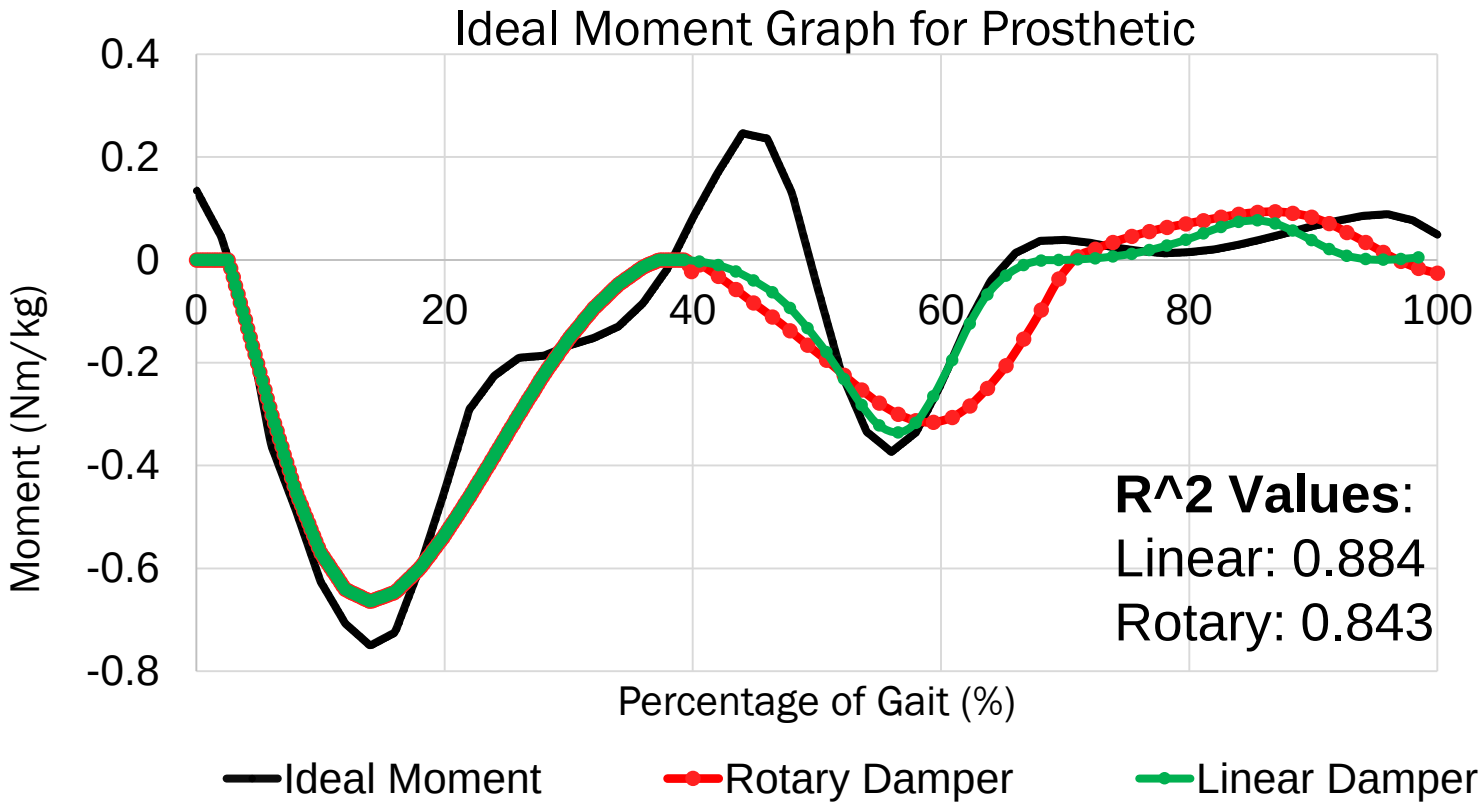


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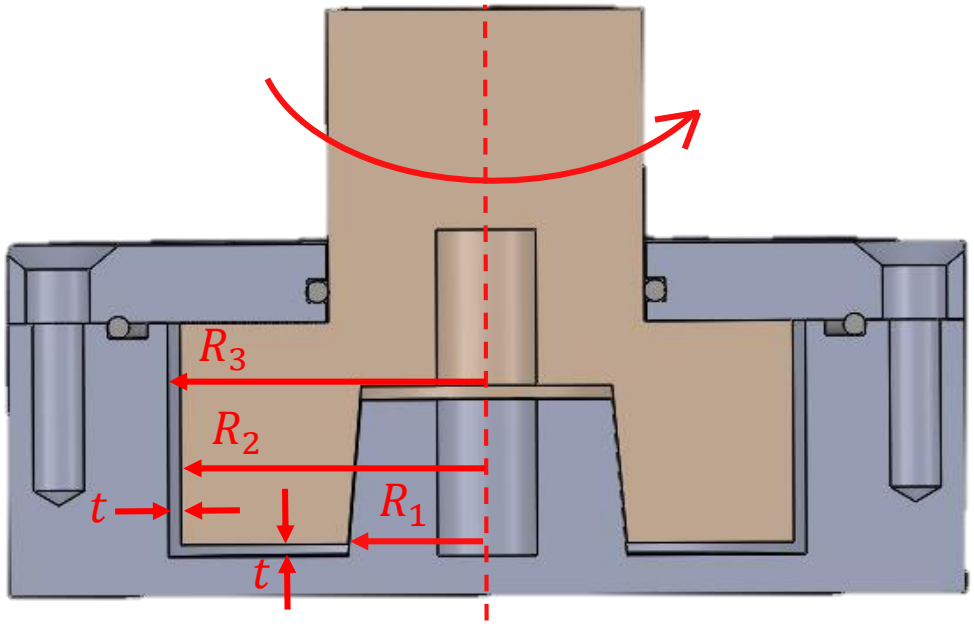
# Justification for Moving to Rotary Damper

- **Simple integration** into knee design with other components
- **Minimizes leakage** (the only dynamic seal is the rotating one, better than sliding seal on the linear damper)
- **More compact** (dimensions are smaller because of high viscosity liquid)
- **More innovative**, compared to the existing designs of knees using viscous dampers
- **Simple in design**, no accumulator
- **Lower cost**

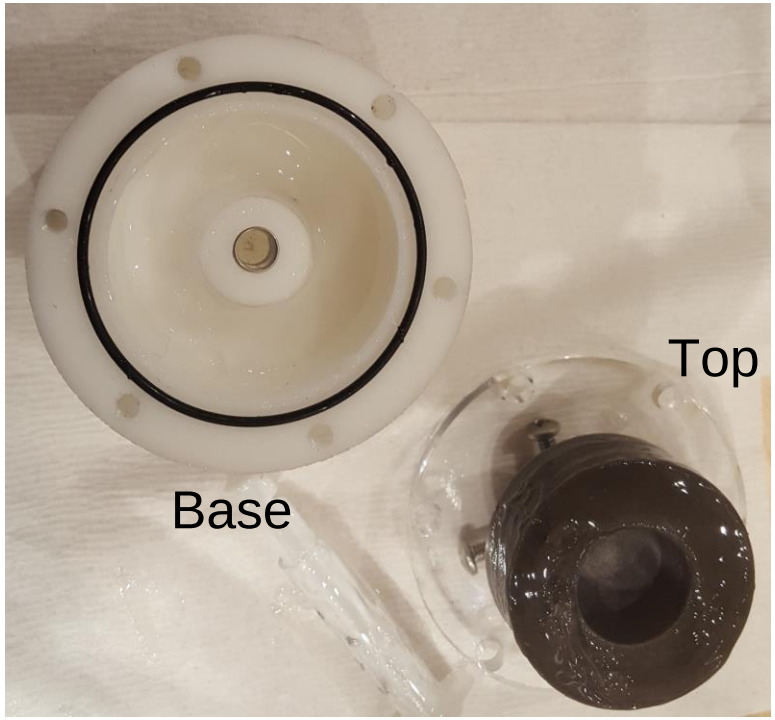
# Rotary Damper Design and Build




$$T = 2\pi\mu\omega l\frac{R_3^3}{t} + \pi\omega\mu\left(\frac{R_2^4}{2t} - \frac{R_1^4}{2t}\right)$$

$$\Rightarrow \quad T = \pi\mu\omega\left(2l\frac{R_3^3}{t} + \left(\frac{R_2^4}{2t} - \frac{R_1^4}{2t}\right)\right)$$

$$\Rightarrow \quad \frac{T}{\omega} = B_{viscous} = \frac{\pi\mu}{t}\left(2lR_3^3 + \left(\frac{R_2^4}{2} - \frac{R_1^4}{2}\right)\right)$$



# Rotary Damper Testing Showed Positive Results

| Angular Velocity (rad/sec) | Calculated Torque from equation (Nm) | Physical Test (Nm) |
|---|---|---|
| 3.14 | 2.67 | ~3 to 4 |
| 6.28 | 3.05 | ~4 to 5 |

Possible Sources of Error:

- Apparent fluid viscosity was estimated from a shear-thinning graph
- The physical test did not have constant angular velocity since human motion was used
- Static friction could not be calculated with the torque wrenches

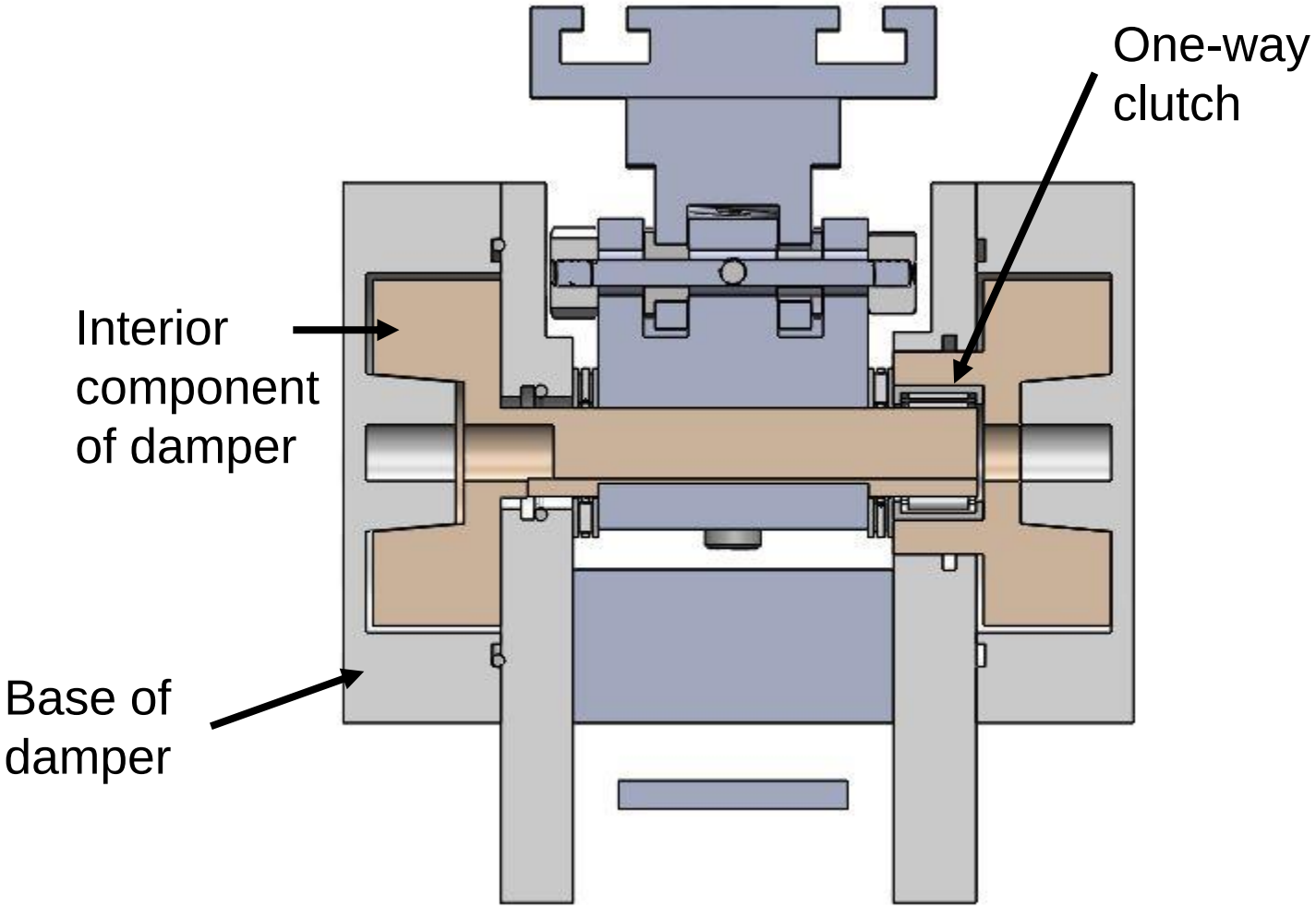
# Ways to Improve the Rotary Damper

Things to Improve:
- Bi-directional damping
- Two dampers with a one-way clutch

Optimizing design:
- Concentric circles
- Decrease thickness between walls

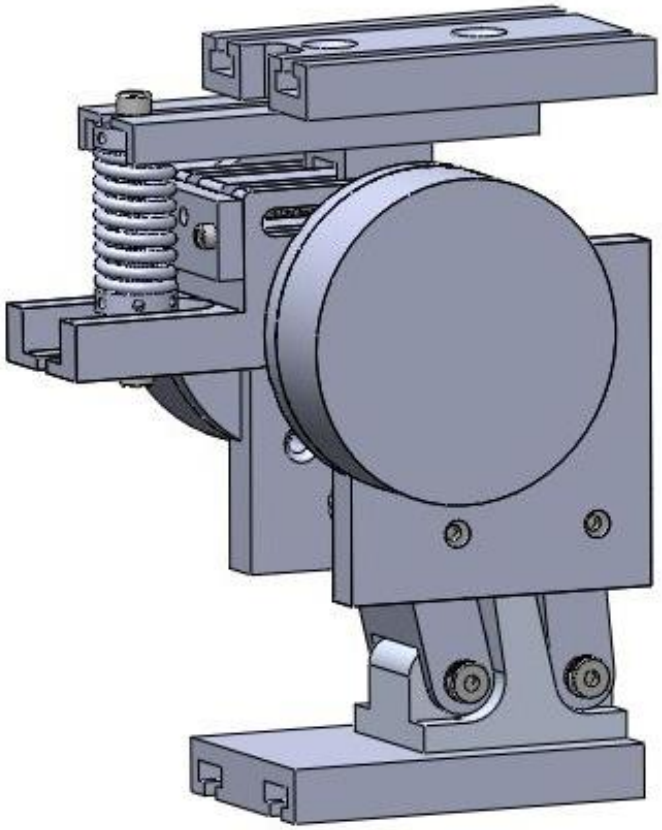
*Disassembled ACE rotary damper*

# Damper Integration



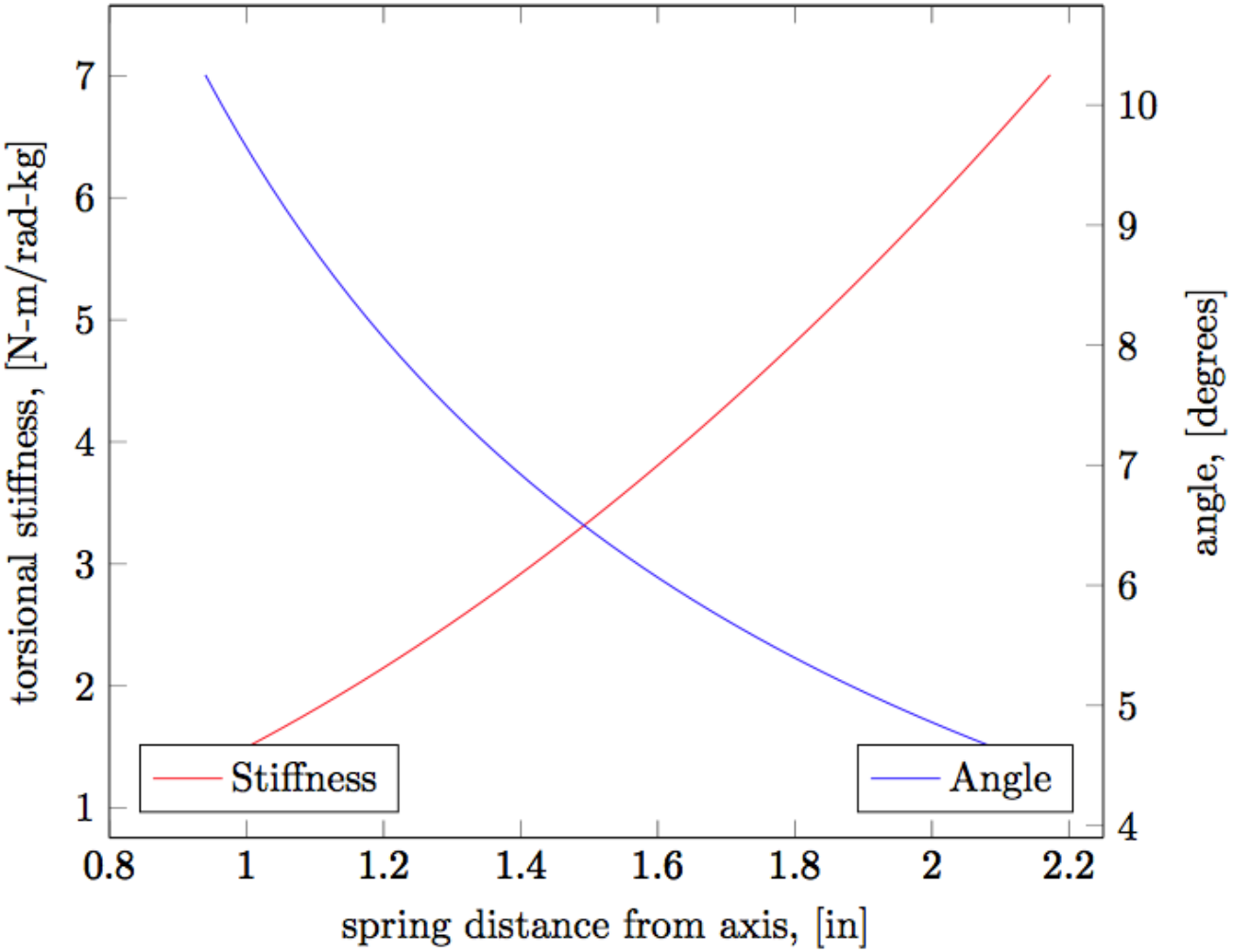
# Testing

- Latch was well accepted
- Damping is more than is wanted

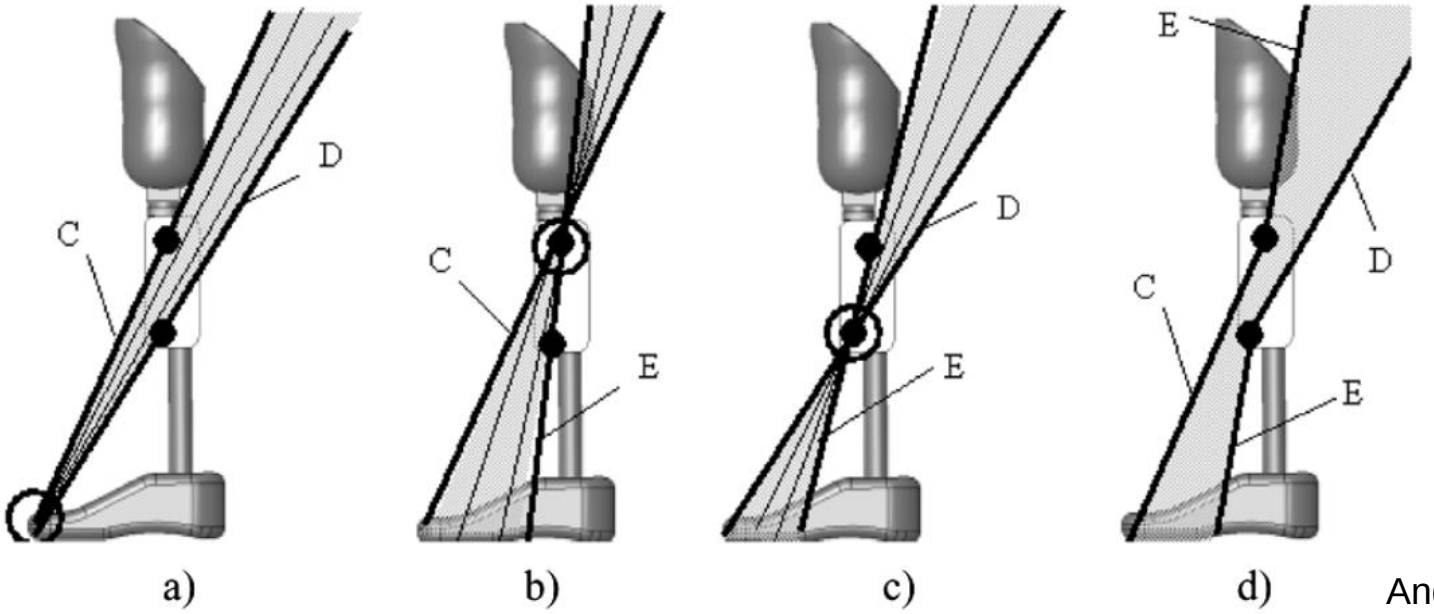


# QUESTIONS?

# ESF Stiffness and Angle Trade-off (k = 140 N/mm)



# Stability Zone




Andrysek, 2005

Unlocks latch and flexes knee

Unlocks latch

Flexes knee

Superpose for overall region of instability

# Another Possible Solution to Rotary Damping

Alternate concept:

- Rotary damper with orifice
- Can use Newtonian fluid
- Can use one way valve for bi-directional damping