Development of a Wearable Hybrid-Passive Ankle-Foot Orthosis for Rehabilitative and Assistive Applications

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Research question: Develop an energy efficient ankle-foot orthosis in order to provide assistance during the stance phase shortly before toe off, the peak energy portion of the gait.

Introduction:

- During normal walking, there is significant power required in the ankle to propel the body forward just before toe-off.
- In the case of the elderly or those with neuromuscular disorders, this may be unachievable.
- This research tracks the development of a wearable hybrid-passive ankle-foot orthosis mechanism in order to assist the human ankle during normal walking.
- The mechanism uses a small motor to change the mechanical stiffness of the mechanism and is the means of control for assistance.

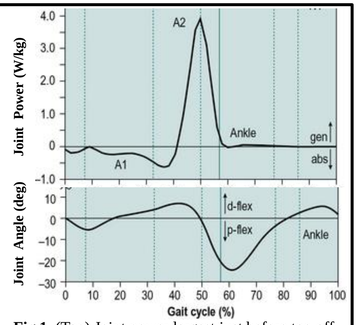

Fig 1. (Top) Joint power largest just before toe-off. (Bottom) The ankle angle dorsiflexes after heal strike. (2016, December 26). Normal gait., from https://musculoskeletalkey.com/normal-gait/

System Design:

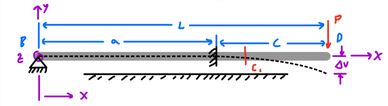

Fig 2. Moving fixed-end cantilever beam increases stiffness proportional to the distance a^3 from this point on referred to as a leaf spring.

- Multiple leaves around a rotor act as a torsion spring.
- Stiffness is set by the rotary cam position set by the small motor

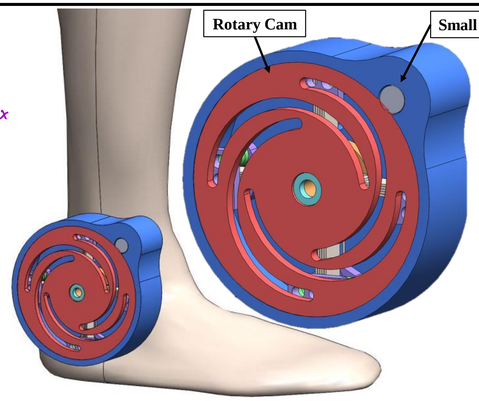

Fig 3. Scale size of the first iteration of the hybrid passive device. Showing the variable stiffness mechanism.

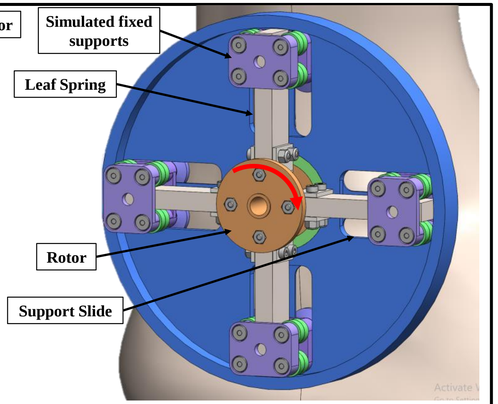

Fig 4. Internal variable stiffness mechanism shown. As the rotor (orange) rotates, the leaves are deflected and provide a counter torque based on the position of the movable supports (purple).

Results:

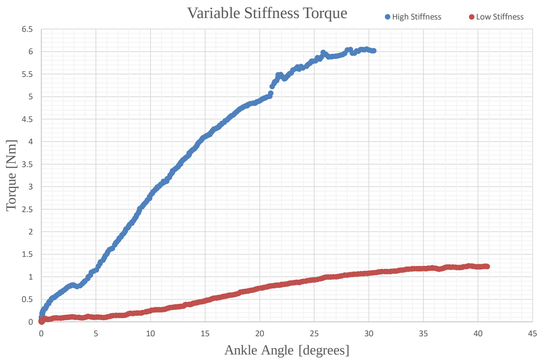

Fig 5. Torque vs angular displacement curve. The slope corresponds to torsional stiffness for the high stiffness setting (blue) and low stiffness setting (red). Nearly 7x increase in stiffness.

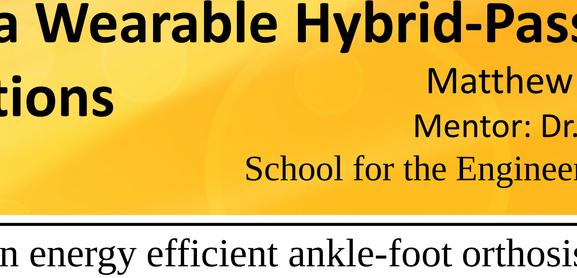

Fig 6. Torque testing setup involving a precision angle encoder, load cell, the variable stiffness device fixed. All data is measured and stored on a microcontroller.

- The position of the simulated fixed supports are manual moved.
- Force and angle are measured by moving the torque arm.
- The torque is determined by the known moment arm (blue).

Obstacles Faced:

- The size constraint of a high torque device for the ankle is a challenging.
  - Currently the device is small compared to other devices.
- The model designed in ANSYS predicted a much larger torque than what is seen experimentally.
  - The root cause of this will be a topic of future work.
- There is significant friction with this first iteration which leads to inefficiencies.

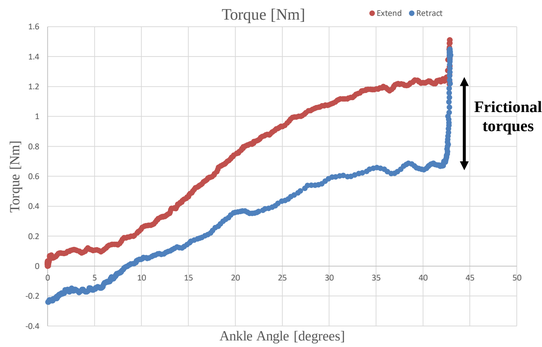

Fig 7. The torque during extension is much larger than it is during retraction. This is not a feature of normal springs and is likely due to frictional losses causing back torques.

Future Work: The device will later be used in human studies of the ankle to demonstrate improved energy cost. Before that, frictional losses will need to be significantly reduced. Then, a motor will be selected, and alternative mechanisms will be investigated and compared.

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