# PROSTHETIC PYLON EMULATOR FOR CONTROLLING STIFFNESSES UNDER GAIT LOADING

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**Introduction:** Individuals with lower-limb amputation are at an increased risk of musculoskeletal disorders [1], possibly due to overcompensation in their sound limb [2] or due to inadequate attenuation of impact loads on the prosthetic limb [3]. Prosthetic shock-absorbing pylons (SAPs) have been shown to reduce work done on the sound limb [4] and reduce impact forces on the prosthetic limb [5]. However, these SAP resultant benefits are affected by material properties, such as stiffness [4]. Considering the implications of SAP stiffness on gait performance [4], there is a critical need for systematic evaluation of SAP properties and end-user outcomes. One valuable tool may be prosthetic emulator technology [6-8], which, using a cable-driven actuator, can simulate an extensive range of SAP mechanical properties (e.g., stiffness, damping). Expanding prosthetic emulator technology to include pylons will enable systematic gait studies of SAPs. Thus, the purpose of this study is to 1) design a new pylon emulator (PE) and 2) perform preliminary testing to evaluate the PE's capacity to vary stiffness under gait loading.

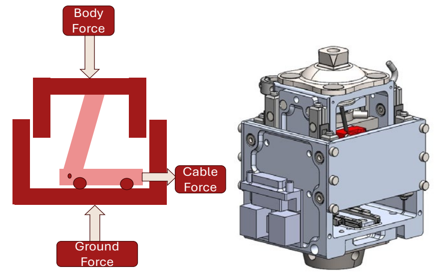


**Figure 1:** Diagram (left) of the inner carriage of the pylon emulator (right). The body force and the ground force compress the pylon, while the cable force from the actuator extends the pylon.

**Methods:** The PE's design consists of an upper and lower portion connected by frictionless square bearings [9] (Humotech, Pittsburgh, PA, Fig. 1). A cable from the actuator is connected to a rolling carriage on the lower portion of the pylon. A hinge joint connects the carriage to the upper portion to resist compression from opposing ground reaction force and body weight. As loading is applied during the stance phase of gait, an inline load cell returns axial load measurements to the controller [9]. The actuator releases the cable, allowing displacement proportional to the applied force. A string potentiometer returns the displacement to complete the feedback loop to the controller for real-time adjustments to control the pylon stiffness during the gait loading and unloading phase. To perform preliminary testing of the PE, we set the PE's control parameters to achieve two desired stiffnesses (167 kN/m and 125 kN/m) to emulate a passive SAP [10]. We also set the PE as an idealized spring with zero net work (i.e., 100% energy return). This study, considered development work and not human testing subjects, had one healthy participant walk on a level treadmill at 0.8 m/s for 2 minutes using the PE with a bent knee adapter. The force and displacements from each gait cycle and condition were recorded for comparison to the desired stiffness.

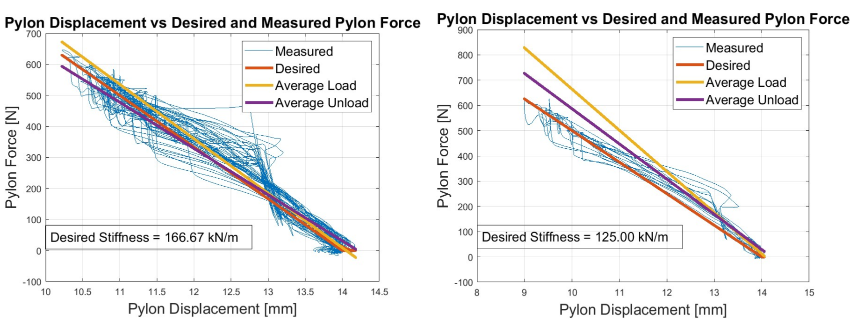


**Figure 1:** Pylon Displacement [mm] vs Pylon Force [N] for a desired stiffness of 167 kN/m (left) and 125 kN/m (right). The desired slope is the input stiffness (red line), while the average load (yellow line) and unload (purple line) is the actual stiffness of the gait testing during loading and unloading, respectively.

**Results & Discussion:** The average measured stiffness was 175.5 $\pm$ 13.3 kN/m for the desired stiffness of 167 kN/m (Fig.2 left) and 163.0 $\pm$ 26.4 kN/m for the desired stiffness of 125 kN/m (Fig. 2 right). As a result, there was a percent error of 5.1 $\pm$ 0.4 % for the desired stiffness of 167 kN/m and 30.4 $\pm$ 4.9 % for the desired stiffness of 125 kN/m. The more compliant spring had a greater percent error in spring stiffness, which may be explained by the propagated gain error (overcompensation in displacement for a change in force) that occurs when greater displacements are needed for a smaller change in force inputs. Although 100% energy return conditions were implemented, the percent energy return was 89.6 $\pm$ 22.0% for the desired stiffness of 167 kN/m and 94.6 $\pm$ 240.6% for the desired stiffness of 125 kN/m. Both stiffness conditions resulted in energy loss, likely from the controller gains underdamped tuning and Coulomb damping. The controllers' proportional and damping gain is being further tuned to improve accuracy in achieving a desired stiffness and energy return.

**Significance:** This proof of concept study will lay the foundation for further studies on a PE with several stiffness cases, power loss or return, and various participants with leg amputations. Validation of the performance of the PE will open doors for clinical use and allow prosthetists to effectively prescribe SAPs to patients based on their individual needs to reduce the risk of musculoskeletal disorders.

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**References:** [1] Burke et al. (1978), *Ann Rheum Dis* 37(3); [2] Nolan et al. (2000), *Prosthet Orthot Int* 24(2); [3] Breakey et al. (1976), *Orthot Prosthet* 30(3); [4] Maun et al. (2021), *J Neuroeng Rehabil* 18(1); [5] Gard et al. (2003), *J Rehabil Res Dev* 40(2); [6] Caputo et al. (2015), *IEEE Int Conf Robot Autom* 2015; [7] Caputo et al. (2014), *J Biomech Eng* 136(3); [8] Caputo et al. (2022), *J Prosthet Orthot* 34(4); [9] Chen et al. (2024), *US Prov Patent App* 63/557,515.