MECHANICAL TESTING TO CHARACTERIZE THE PERFORMANCE OF SHOCK ABSORBING PYLONS USED IN TRANSTIBIAL PROSTHESES

Jocelyn S. Berge[1,2], Glenn K. Klute[2,3], Carol F. Kallfelz[2], Joseph M. Czerniecki[2,4]

[1]Bioengineering Department, [2]VA RR&D Center of Excellence For Limb Loss Prevention & Prosthetic Engineering, [3]Electrical Engineering Department, [4]Rehabilitation Medicine Department

Introduction

High frequency load components arising from heel strike during locomotion are thought to be responsible for the deleterious effects observed on the residual tissue and structures of lower limb amputees. To ameliorate these problems, prosthesis manufacturers have developed vertical shock absorbing pylons intended to attenuate the shock loads transmitted to the residual limb from the prosthesis during locomotion. Although prescribed to enhance comfort during walking and high impact activities, to date, the performance and efficacy of shock absorbing pylons is not well understood.

Research conducted on both humans and animals suggests that repetitive loading in general, and high frequency repetitive loading in particular, can be harmful to the musculoskeletal system. Such loading has been implicated in the initiation and progression of osteoarthritis, prosthetic joint loosening, low back disorders, and inflammatory autolysis of the skin leading to ulceration [1].

Several studies have attempted to characterize different types of shock absorbing pylons using human test subjects and/or mechanical test instruments [2,3], however, none have specifically measured the ability of a pylon to attenuate load as a function of frequency.

The purpose of this study was to measure the ability of two commonly prescribed shock absorbing pylons to attenuate load at frequencies enveloping those observed during human locomotion. The two pylons tested were the ICON™ Shock Pylon (Flex-Foot Inc., Aliso Viejo, CA) and the TT (Telescopic Torsion) Pyramid Pylon (Blatchford Endolite, Basingstoke, Hampshire, UK).

Methodology

The ICON™ Shock Pylons were outfitted, by the prosthetist, with i4, i5, i6, and i7 springs and the TT Pylons with Purple, White, and Black springs for testing. To objectively characterize the performance of each ICON™ Shock Pylon and TT Pylon, two sets of tests were performed using servo-hydraulic material testing systems (MTS Systems Corporation, Eden Prairie, MN), a pseudo-static loading and unloading test and dynamic cyclic testing.

From the pseudo-static loading and unloading test, a spring constant (k) for each pylon was determined and used to calculate the non-dimensional force results discussed below. From the dynamic cyclic testing, sinusoidal inputs were used to obtain an output non-dimensional force as a function of frequency.

Pseudo-static Loading and Unloading Test

Pseudo-static loading and unloading was performed on a MTS (Model 858 Bionix). The MTS was programmed to follow a 0.5 mm/s loading ramp starting at 0 mm and ending at 15 mm or 12.5 mm followed by a return ramp ending at final displacement of 0 mm for the ICON™ Shock Pylons and TT Pylons, respectively.

Dynamic Cyclic Testing

The dynamic cyclic testing was performed on a MTS (Model 810 High Rate). The material testing system was programmed to generate five sinusoids, starting at 1 mm offset, at each of the frequencies and peak-to-peak displacements listed below (Table 1).

Frequency (Hz)	Step Size (Hz)	Peak-to-peak (mm)
0.1, 0.5-4	0.5	9
5-15	1	3
16-25	1	2
26-35	1	1
36-45	1	1
46-55	1	1
60-100	5	1 (except i5, 0.5)

Table 1. Dynamic Cyclic Testing Matrix.

Results

The loading and unloading curves were fairly linear over the displacement range for the all the pylons tested.. A least squares linear fit of the loading and unloading curves was performed to determine the spring constant for each pylon. The calculated spring constants for the ICON™ Shock Pylons with i4-i7 springs were 74, 84, 96, and 112 N/mm, respectively. The calculated spring constant for the TT Pylons with Purple, White, and Black springs were 80, 110, and 140 N/mm, respectively.

Using the steady state (typically the 3rd peak of the sinusoid) peak displacement and the corresponding force from the dynamic cyclic testing data and the linear spring constants from the pseudo-static tests, non-dimensional force vs. frequency plots were obtained (Figures 1 and 2). This non-dimensional variable was developed to allow for quantification of damping present while also taking into account the nature of the testing, in which the displacement and therefore force varied with frequency. Equation 1 was used for calculating the non-dimensional force variable.

$$\mathrm{Force}_{nd} = \frac{k\, x_{measured}}{F_{measured}} \qquad (1)$$

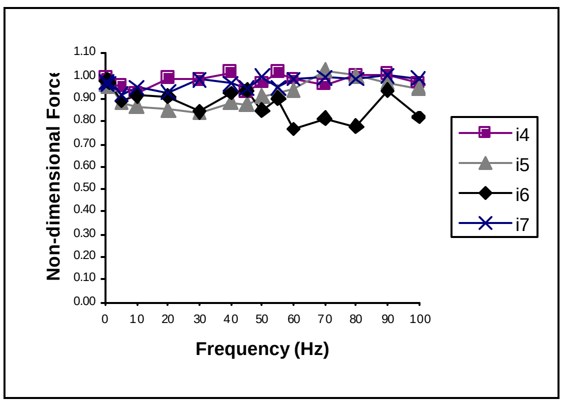

Figure 1. Non-dimensional Force vs. Frequency for the ICON™ Shock Pylons with i4-i7 springs.

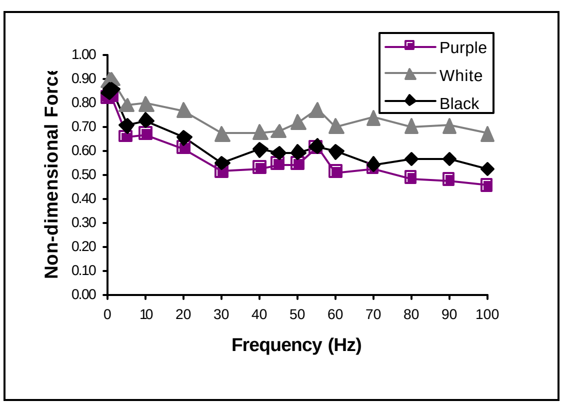

Figure 2. Non-dimensional Force vs. Frequency for TT Pylons with Purple, White, and Black springs.

Discussion

Each pylon tested formed a hysteresis loop with a different spring constant value for the loading and unloading curves. The rectangular shape of the hysteresis loop indicated the presence of coulomb damping at loading rate of 0.5 mm/s.

Figure 1 shows that the ICON™ Shock Pylons have very little damping. The TT Pylons (Figure 2) have more damping than the ICON™ Shock Pylons and the damp ing tends to increases with increasing frequency.

Figure 1 shows that the ICON™ Shock Pylons have little force attenuation over the whole frequency range tested independent of the spring installed (possible exception i6 spring). The TT Pylons (Figure 2) have more attenuation than the ICON™ Shock Pylons and the attenuation changes depending on the spring installed.

Future human subject research will examine how the foot ground reaction forces, knee angle at foot contact, and walking velocity compare for amputees wearing a rigid pylon versus a TT Pylon. The acceleration transmissibility during walking for both pylons will also be defined. This knowledge coupled with mechanical testing data will be used to help determine the "shock" transmitted to the residual limb over the frequency range contained within a typical ground reaction force signal. Further research is needed to determine the magnitudes of attenuation needed, over the frequency range, to protect residual limb tissue.

References

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