The BackpacKings

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Walking with a heavy backpack on one's back for long periods of time can cause health problems as well as fatigue. The amount of metabolic energy expenditure to carry a backpack can theoretically be reduced to decrease physical exertion while walking by using a suspended load backpack system. This system utilizes a spring/mass/damper system to reduce the dynamic load that the user feels while walking. This is achieved by suspending the backpack load on a spring system that oscillates out of phase with the user's walking frequency. Although this kind of backpack has been developed previously, the backpack designs to date have been limited by frictional losses and poor adjustability.

Our team, the BackpacKings, was tasked by our customers with evaluating alternative backpack designs and constructing a working prototype that meets their needs. We derived our engineering specifications by using our customer requirements that were outlined to us. Our main requirements for our project were: (1) the suspended backpack system utilizes a spring/mass/damper system, (2) the backpack load oscillates as close as 180 degrees out of phase of the typical walking frequency of an average human, and (3) there is low friction between the frame and the vertical constraints.

We investigated using linkage systems or carriage/rail systems with our suspended-load backpack design. We decided not to use a rail system because an appropriate one would cost approximately ½ of our budget. Instead, we utilized a four-bar linkage to facilitate the oscillations of our load; it was less expensive which allowed for more prototyping and revisions. Once our design concept was finalized, we derived a differential equation to find the correct type of spring. Next we designed the CAD model, selected the correct springs, bearings, etc. for our prototype, and then constructed our prototype. Following construction, we tested the prototype to confirm that it is oscillating out of phase with the user and satisfy our engineering specifications.

Our main challenge for this project was to get the load on the backpack to oscillate between 135 and 180. If the backpack load oscillated below 135 degree phase with the user, the backpack would create a greater impact on the user than a non-oscillating load. Another challenge was to minimize and predict the frictional losses. The more energy that was lost in the oscillations of our load, the less energy that the user would be able to save. Frictional losses caused us to redesign our thrust washers and steel cable. Our prototype washers were not hardened, allowing the thrust ball bearings to wear grooves in them. We replaced them with hardened washers after careful analysis. The steel cable was too stiff, it didn't follow the pulleys well and put enough force on one pulley to squeeze the grease out of its bearings. Replacing the cable with a static line rope solved our flexibility vs. strength requirements. Minimizing the friction was critical because it negatively effects on the dynamic properties of the load's oscillations.

To see if our technical specifications were validated we tested our design by having our subject walk on a treadmill with a 45lb weight plate on the backpack. We videotaped our subject walking, and gathered data from the footage using tracking software. The data was put into MATLAB and analyzed to determine our phase lag. The largest phase lag we were able to achieve in testing was 111.8 degrees; not sufficient to meet our specification of 135 to 180. All ranges of 5 – 25 kg were able to reach proper equilibrium on the backpack, however time constraints did not permit us to test the backpack at those weights.