Hydraulic Ankle Foot Orthosis

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1 Background

Hydraulics is traditionally used in large-scale machines such as excavators [1]. It is well-known for its high power-to-weight ratio characteristic. To explore whether this characteristic holds in small-scale devices, an ankle-foot-orthosis (AFO) was selected as an example application. An AFO is a device to help people who cannot lift their toes or cannot push off during walking. The hydraulic-AFO (HAFO) being developed is a powered orthosis that can provide better assistance compared to those passive orthosis available in the market. For example, the powered AFO can provide direct assistance during the propulsive phase of gait; it is also capable of adapting different walking conditions [2].

The AFO example is challenging because of these requirements:

- Function: 90 N-m torque and 250 deg/s angular velocity are required [3] for level walking.
- Weight: less than 1 kg to minimize its impact on ankle dynamics.
- Packaging: the system needs to fit underneath regular pants.

The HAFO prototype is intended to provide insights into the capabilities and limitations of small-scale hydraulics and to enable creating design guidelines for tiny hydraulics.

2 Methods

To identify the capabilities and limitations of available hydraulic components, the first version HAFO was constructed using the smallest off-the-shelf components, as shown in Figure 1. A Lithium Polymer battery (ThunderPower, TP-2250-6SP30) was used for the energy source. An electric motor (Maxon, 370426) driven pump (Takako, 0.4 cc Axial Piston) was used to drive a hydraulic cylinder (Bimba, H-092-DZ), which generates torque by acting on a 14 cm moment arm.

Figure 1: Version 1 HAFO

Hydraulic hoses were used to route hydraulic fluid from the pump to the cylinder. Two check valves were used to compensate the volume difference between two cylinder chambers and to prevent piston hard stop.

The cylinder actuation direction – either pulling or pushing – and the speed were controlled by regulating the electric motor. The hydraulic pump is bi-directional, which facilitates the direction control.

The HAFO output torque was measured using a known load, which is connected to the front part of the shell through a pully-cable assembly. The HAFO output speed was measured using a potentiometer that is connected to the cylinder rod.

3 Results

The specifications of the components are shown in Table 1. The pump was not run at its maximum pressure, 2000 psi, due to the cylinder being rated for 500 psi.

Table 1: Component specifications for version 1 HAFO

Comp	Manufacturer	Key Spec	Wt (g)
Battery	Thunder Power RC	2250 mAh	351
Motor	Maxon Motor	50 W	260
Pump	Takako Industries	0.4 cc/rev	270
Cylinder	Bimba Manufacturing	27 mm bore	250
Hoses and valves	McMaster-Carr		1825
Shell	N/A		745

The HAFO provides 94 N-m by running the electric motor at its maximum torque, in which case the pump operates at 350 psi and 65% efficiency. The maximum speed is 10 deg/s, smaller than required. This is due to the mismatch between the pump and the cylinder with the cylinder bore being too big for the small pump displacement.

The system weighs 3.7 kg, which is heavier than required. One half of the weight is in the hoses and the valves. Additionally, the system cannot fit underneath a regular pant due to the large moment arm and the bulky hoses and valves.

4 Interpretation

To achieve the functionality of a normal ankle, and to make the system sufficiently compact, the hydraulic cylinder and pump must be customized and integrated. The component customization will enable taking full advantage of each component, while the component integration will eliminate the hoses.

The motivation for looking at hydraulics is that the HAFO can operate at much higher pressure than the previously developed pneumatic AFO [4], so potentially it can provide full assistance to the subject.

References

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