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ME 486

Individual Technical Analysis 2

Belt Drive Design & Component Selection

1 Introduction

The purpose of this report is to provide an in-depth analysis of a specific element of the Biomechatronic Hip Exoskeleton Team (BHET) capstone project. The following sections will cover an overview of the project, followed by the individual analysis topic selection, process, calculations, results, and conclusions of the analysis.

2 Project Summary

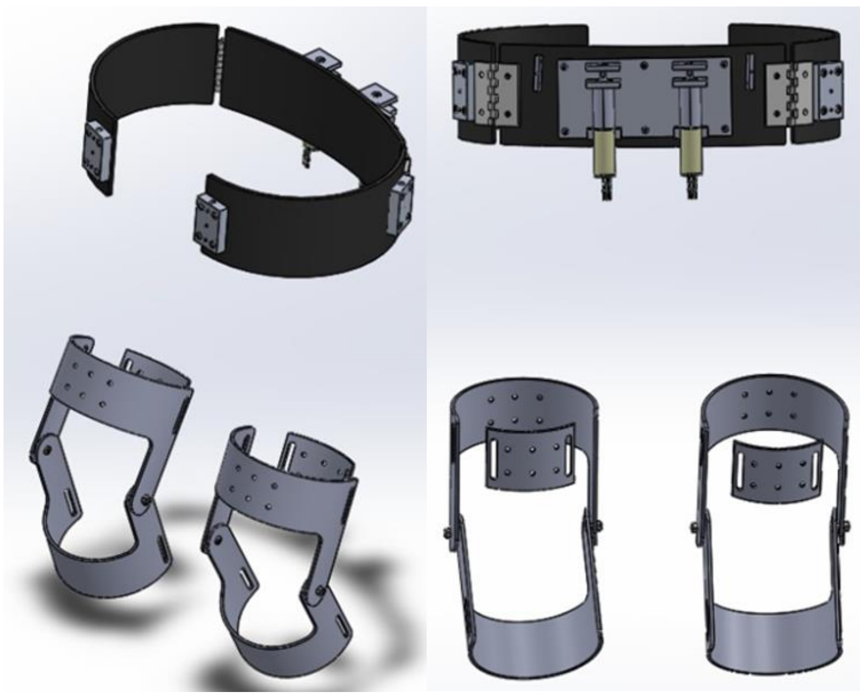

Figure 2.1 Hip Exo current revision

3 Analysis Topic

Tension in the cables is produced through two brushless DC motors. The output of the motors is transferred through a gear reduction to achieve the torque necessary to actuate the cables. The final output of the drivetrain is a dual pulley that the actuation cables are attached. The output of the gearhead transfers torque through a timing belt to a parallel shaft that drives the cable pulley.

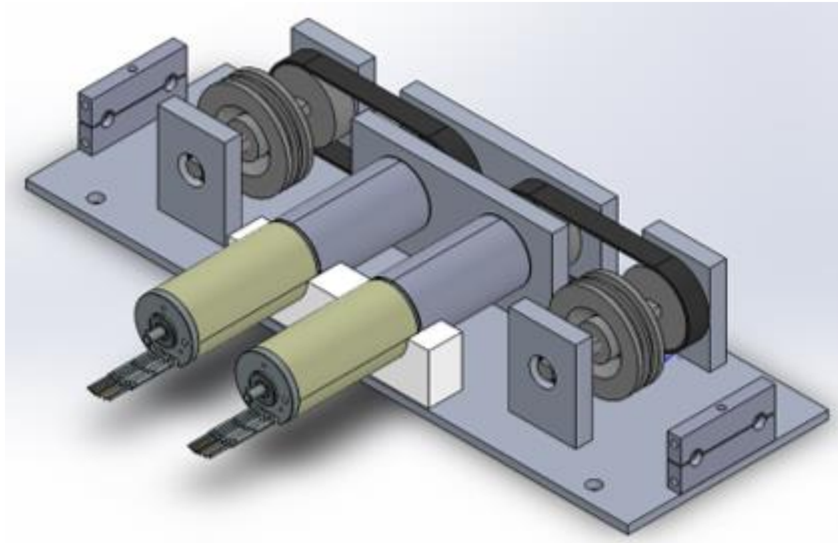

Figure 3.1 Motor Mount assembly

The belt drive will serve two purposes in the BHE design: Provide a final torque multiplier and allow for more optimized placement of the drive pulley. The decision to move the drive pulley to a parallel shaft will also add modularity to the design, allowing the final reduction ratio to be easily changed by replacing the output timing pulley using stock parts.

The focus of this paper is the output shaft of the belt drive. The analysis will cover the loads placed on the shaft and the calculations performed to ensure the shaft will meet the design requirements.

Table 3.1 Design decisions for BHE timing belt drive design

Design Decision/Component	Factors Effecting Decision
Center Distance	Drive Pulley Diameter, Driven Pulley Diameter Spatial Constraints
Peak Torque	Gearbox output torque, Manufacturer Correction Factors
Drive Pulley Diameter	Peak Torque, Spatial constraints

Table 3.1 shows the various factors which must be considered. It is apparent that many of these factors are interdependent.

4 Calculations

The design decisions and component selection

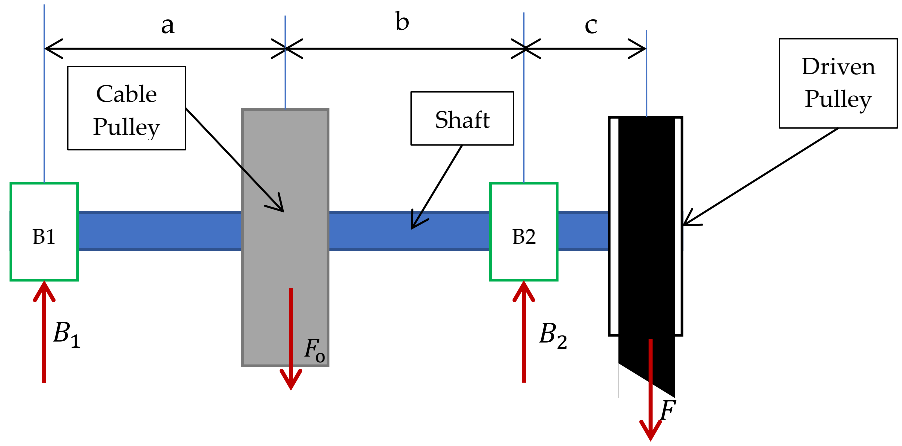

Figure 4.1 Force diagram of output shaft

4.1 Assumptions

1. Calculations will be based on peak torque/speed of the motor gearhead.
2. Frictional losses from bearings will be ignored
3. Timing belt tension ratio of 5:1, [2]
4. The output torque required for the cable pulley is based on the smaller pulley diameter, because the force
5. Axial loads are neglected, per distortion energy failure theory
6. The shaft design will be straight with constant diameter, therefore the stress-concentration factors will be set to a value of 1.

4.2 Peak Torque on Driven Pulley (T_{peak})

Table 4.1 Input values for belt drive design

Input	Value	Units	Symbol
Gearbox Max input speed	12000	rpm	n_i
Motor Nominal Torque	45.1	mNm	T_i
Gearbox Efficiency	0.59		E_g
Absolute Gearbox Ratio	$\frac{4617}{52}$		R
Torque from drive pulley	2.36	Nm	T_{p1}
Required torque on output shaft	5.6	Nm	
Drive Pulley Pitch Diameter	28.6	mm	d_{p1}
Driven Pulley Pitch Diameter	68.8	mm	d_{p2}

The peak torque and speed applied to the driven pulley is calculated by [1]:

$$T = T_i E_g R \left(\frac{1m}{1000mm}\right) \quad 1$$

$$n_o = n_i R \quad 2$$

The load transferred by the timing belt [1]

$$T_T = \frac{2.5T}{d_{p1}} \quad 3$$

$$T_S = \frac{0.5T}{d_{p1}} \quad 4$$

Shaft load analysis [1]

$$B_1 = \frac{Fb}{a} \quad 5$$

$$B_2 = \frac{F_0 a + F(a+b+c)}{(a+b)} \quad 6$$

Shaft stress analysis was performed by calculating the combined Distortion Energy theory loads, using Goodman failure criteria [2]:

$$\frac{1}{n} = \frac{\sigma_a'}{S_e} + \frac{\sigma_m'}{S_{ut}} \quad 7$$

$$\sigma_a' = \left(\left(\frac{32K_f M_a}{\pi d^3}\right)^2 + 3\left(\frac{16K_{fs}T_a}{\pi d^3}\right)^2\right)^{1/2} \quad 8$$

$$\sigma_m' = \left(\left(\frac{32K_f M_m}{\pi d^3}\right)^2 + 3\left(\frac{16K_{fs}T_m}{\pi d^3}\right)^2\right)^{1/2} \quad 9$$

Where σ_a' and σ_m' represent the fluctuating von Mises stresses, M is the bending moment, and T is the torque. The subscripts m and a indicate alternating or midrange loading. K_f and K_{fs} are bending and torsional fatigue stress-concentration factors, as mentioned in the assumptions these have been set to a value of 1 for this analysis. S_e is the endurance modified endurance stress limit and S_{ut} is the material ultimate tensile strength.

5 Results

The belt tooth profile was selected using tabulated data from the manufacturer, which rates the torque transfer capability based on operating rpm, tooth profile, pitch diameter, and belt length. Using the manufacturer's specifications for the motor as the torque requirement, the timing profile GT3 with a 3mm pitch and a width of 6mm was selected. It should be noted that this also influenced the timing pulley sizes, initial calculations were performed using arbitrary pulleys that provided the desired reduction, the pulley sizes in Table 4.1 reflect the final components selection.

Results of the shaft stress analysis are shown in Table 5.1 below.

Table 5.1 Result for shaft stress analysis

Parameter	**Value**	**Units**
S_y	290	Mpa
S_e	229.87	Mpa
σ_a'	116.73	Mpa
τ_m'	48.96	Mpa
d_{min}	7.69	mm

As shown in Table 5.1, the minimum diameter of the shaft is 7.69mm.