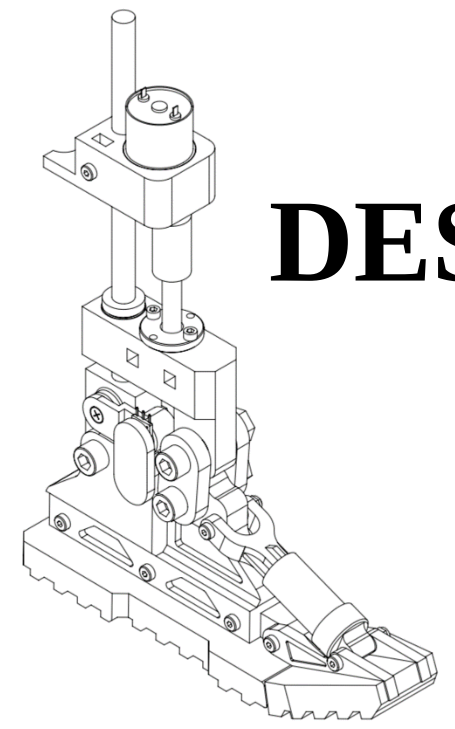

DESIGN OF A ROBOTIC FOOT PROSTHESIS

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ABSTRACT

This graduation project aims to develop a robotic foot prosthesis that replicates the natural movement of a human foot, enhancing mobility and gait for individuals with lower limb amputations. The design incorporates a slider-crank mechanism, known for generating reciprocating motion, and integrates a spring-damping mechanism for improved shock absorption and gait dynamics. The offset slider-crank mechanism is utilized to achieve complex motion profiles, expanding the range of motion and accurately replicating natural foot movements. The report presents detailed calculations for function generation synthesis, as well as comprehensive analyses of kinematics, dynamics, design considerations, and optimization techniques employed. Through the integration of mechatronics engineering principles, innovative mechanisms, and emerging technologies, this project aims to contribute to the advancement of robotic foot prostheses that closely emulate the natural motion of a human foot.

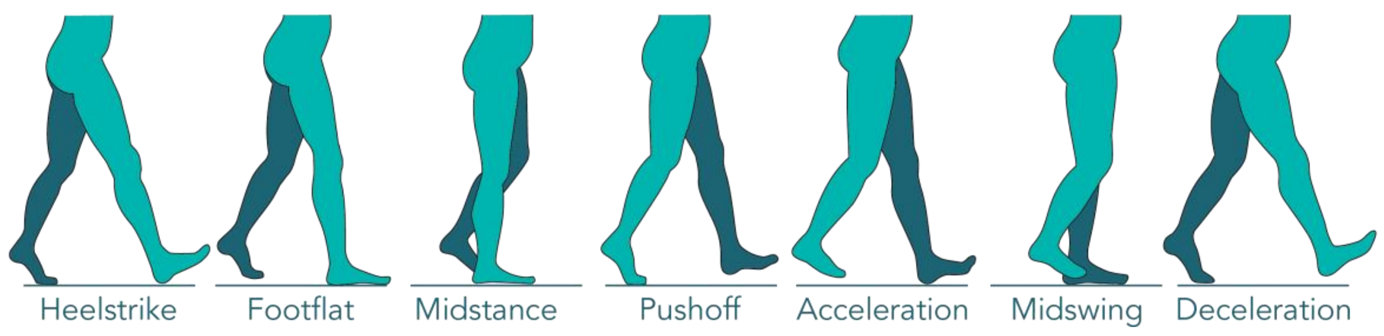

Figure 1. Gait Cycle [6]

SYNTHESIS

We focus on the function generation synthesis of an offset slider-crank mechanism. Function generation refers to the process of designing a mechanism that can produce a desired motion profile, typically described by a mathematical function.

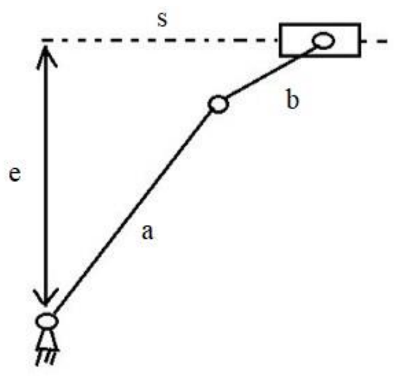

Figure 2. Offset Slider-Crank Mechanism

$$\vec{e}+\vec{a}+\vec{b}=\vec{s}$$

$$\frac{a^2-b^2+e^2+{s_0}^2}{2as_0}+\frac{e}{s_0}sin\theta+\frac{1}{a}s+\frac{1}{s_0}(-s\,cos\theta)+\frac{1}{as_0}\frac{s^2}{2}-cos\theta=0$$

$$\lambda=P_4=P_2P_3 \qquad P_i=l_i+\lambda m_i$$

$$(l_0+\lambda m_0)f_0+(l_1+\lambda m_1)f_1+(l_2+\lambda m_2)f_2+(l_3+\lambda m_3)f_3+\lambda f_4-F=0$$

$$l_0{f_0}^i+l_1{f_1}^i+l_2{f_2}^i+l_3{f_3}^i-F_i=0$$

$$\begin{bmatrix} {f_0}^1 & {f_1}^1 & {f_2}^1 & {f_3}^1 \\ {f_0}^2 & {f_1}^2 & {f_2}^2 & {f_3}^2 \\ {f_0}^3 & {f_1}^3 & {f_2}^3 & {f_3}^3 \\ {f_0}^4 & {f_1}^4 & {f_2}^4 & {f_3}^4 \end{bmatrix}_{4x4} \begin{bmatrix} l_0 \\ l_1 \\ l_2 \\ l_3 \end{bmatrix}_{4x1} = \begin{bmatrix} F_1 \\ F_2 \\ F_3 \\ F_4 \end{bmatrix}_{4x1}$$

$$m_0{f_0}^i+m_1{f_1}^i+m_2{f_2}^i+m_3{f_3}^i+{f_4}^i=0$$

$$\begin{bmatrix} {f_0}^1 & {f_1}^1 & {f_2}^1 & {f_3}^1 \\ {f_0}^2 & {f_1}^2 & {f_2}^2 & {f_3}^2 \\ {f_0}^3 & {f_1}^3 & {f_2}^3 & {f_3}^3 \\ {f_0}^4 & {f_1}^4 & {f_2}^4 & {f_3}^4 \end{bmatrix}_{4x4} \begin{bmatrix} m_0 \\ m_1 \\ m_2 \\ m_3 \end{bmatrix}_{4x1} = \begin{bmatrix} -{f_4}^1 \\ -{f_4}^2 \\ -{f_4}^3 \\ -{f_4}^4 \end{bmatrix}_{4x1}$$

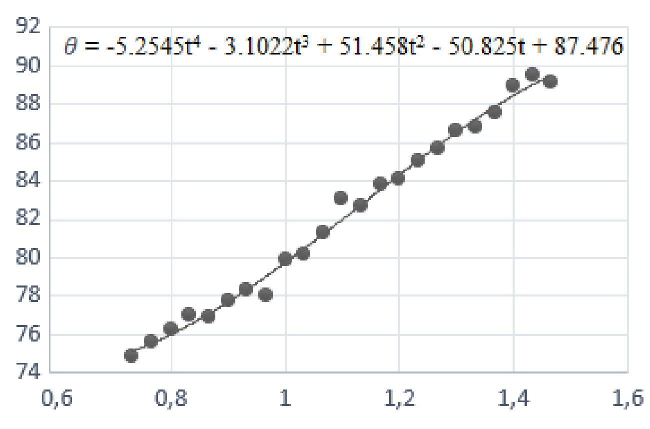

Figure 3. Angle-Time Graph

Time(s)	Angle	Slider Position x-axis
$t_1=0.767s$	$\theta_1=75°$	$s_1=80mm$
$t_2=0.967s$	$\theta_2=79°$	$s_2=60mm$
$t_3=1.167s$	$\theta_3=83°$	$s_3=40mm$
$t_4=1.367s$	$\theta_4=87°$	$s_4=20mm$

Table 1. Precision Points

KINEMATIC ANALYSIS

$$\theta_4=\sin^{-1}\left(\frac{-r_2-r_3\sin\theta_3}{r_4}\right)$$

$$\begin{bmatrix} -r_3\sin\theta_3 & -r_4\sin\theta_4 \\ r_3\cos\theta_3 & r_4\cos\theta_4 \end{bmatrix}\begin{bmatrix} \dot{\theta}_3 \\ \dot{\theta}_4 \end{bmatrix}=\begin{bmatrix} \dot{r}_1 \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} -r_3\sin\theta_3 & -r_4\sin\theta_4 \\ r_3\cos\theta_3 & r_4\cos\theta_4 \end{bmatrix}\begin{bmatrix} \ddot{\theta}_3 \\ \ddot{\theta}_4 \end{bmatrix}=\begin{bmatrix} \ddot{r}_1+r_3\dot{\theta}_3^2\cos\theta_3+r_4\dot{\theta}_4^2\cos\theta_4 \\ r_3\dot{\theta}_3^2\sin\theta_3+r_4\dot{\theta}_4^2\sin\theta_4 \end{bmatrix}$$

DYNAMIC ANALYSIS

Dynamic analysis plays a crucial role in understanding the dynamic behavior of mechanical systems. Dynamic analysis delves into the forces, torques and accelerations acting on the mechanism. By doing the dynamic analysis we found required motor power as 12Watt. For this Project we choose KGB37-12V-60rpm DC motor (*Figure 4*).

Figure 4. DC Motor

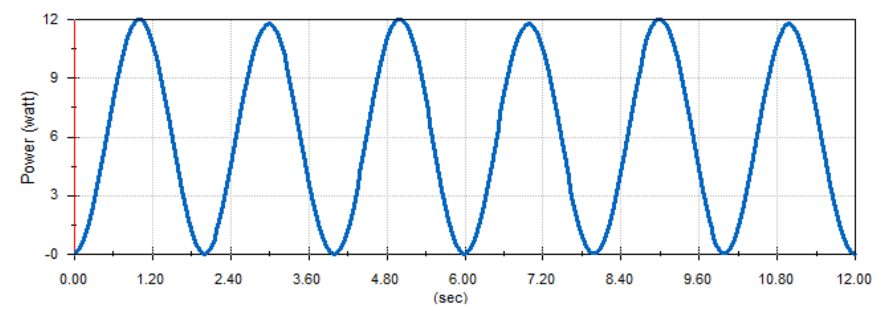

Figure 5. Required Power for Mechanism

DESIGN

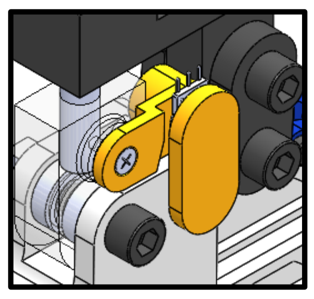

Figure 6. Measurement Mechanism

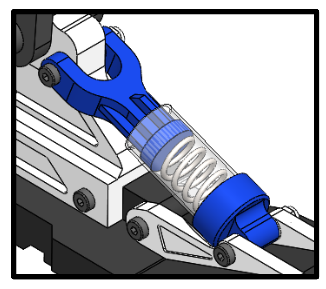

Figure 7. Spring-Damping Mechanism

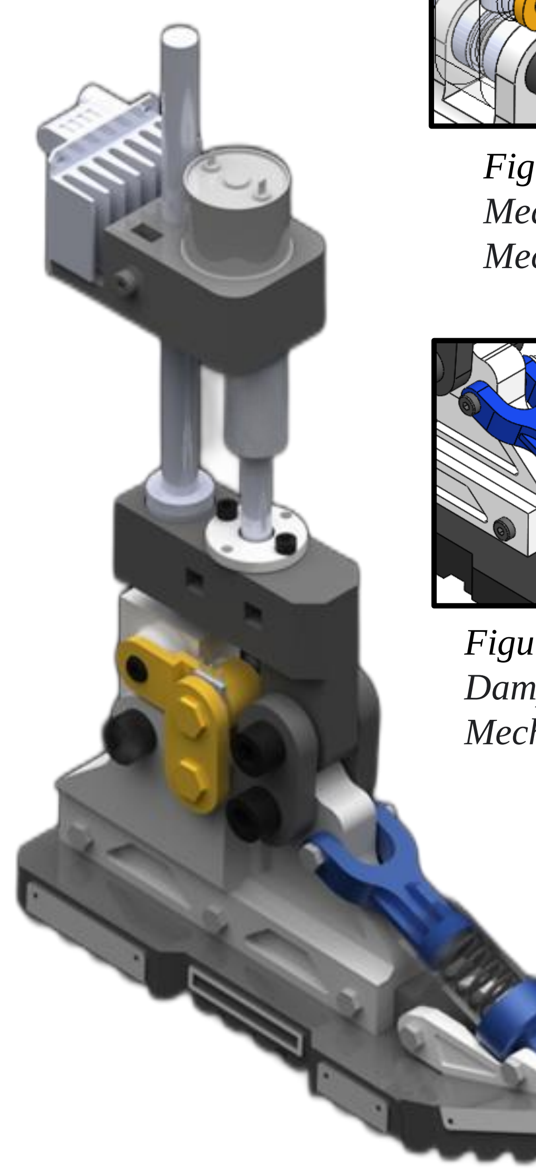

Figure 8. Robotic Foot Prosthesis

The design of the robotic foot prosthesis (*Figure 8)* consists of several main parts, including the foot, the movement mechanism, the spring damping mechanism (*Figure 7*) and the measurement system (*Figure 6*). The foot is designed to mimic the natural movement of a human foot with heel, arch and toe. The ankle joint is a hinged joint that allows the foot to rotate up and down. The movement mechanism is based on a slider-crank mechanism that converts the rotational motion of a motor into linear motion to drive the movement of the foot. A lead-screw has been preferred for the slide system in order to keep the system as compact as possible. The spring-damping mechanism consists of a spring and a damper that work together to absorb shock and improve the gait of the user. The measurement system consists of potentiometer and parallelogram mechanism that measure the angle of the foot during each step.

CONCLUSION

The successful design and assembly of the robotic foot prosthesis marked a significant achievement in the field of mechatronics and prosthetics. In conclusion, the developed robotic foot prosthesis holds great potential for improving the quality of life for individuals in need of a foot prosthesis. The combination of slider-crank mechanism and measurement system, with traditional engineering principles has resulted in a functional and effective solution. This project exemplifies the successful integration of mechatronics and prosthetics, showcasing the benefits of merging scientific advancements with practical application in addressing real-world challenges.

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