The Design of a Rotating Modular Upper Limb Prosthetic Wrist Unit

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This design study investigates a Prosthetic Wrist Unit for upper limb amputations using the Design Thinking methodology. It covers Problem Definition, Information Gathering, Concept Generation and Evaluation, Product Architecture, Configuration Design, Parametric Design, Detail Design, and Production. The study aims to create a small prosthetic wrist unit (50 mm diameter, 50 mm length, less than 125 gr), provides 360° rotation, connects easily with prosthetic hands, enables electric and data transfer, and is controllable via EMG sensors. This research contributes to prosthetic product design, enhancing the quality of life for amputees.

Keywords: Prosthetics, Wrist Unit, Amputation

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INTRODUCTION

Prosthetic hands without wrist rotation struggle to mimic natural hand movements, hindering tasks that need precise hand and object orientation. This limitation affects the prosthetic's usefulness and can frustrate users. The work presented in this article incorporates a motor-controlled wrist unit in the prosthetic hand to address this, allowing for finer hand direction control and more intuitive item handling. The work presented in this article aims to enhance the adaptability and functionality of prosthetic hands through wrist rotation, improving users' quality of life. Details of some of the works that tried to solve these problems can be found in these articles that are given in the references list: Lorenzo et al. [1], Aydoğan et al. [2], Aydoğan et al. [3], Aydoğan et al. [16], Aydoğan et al. [17], Aydoğan et al. [18], Dange [19], Luczak and Rajewski [20], Reyes [21].

Key goals include ensuring the wrist unit can rotate fully and continuously, carry weight, withstand moment and rotational inertia, and remain compact and energy-efficient under various conditions. Additionally, the unit must lock securely, rotate precisely, and integrate with existing prosthetic hand.

The report will cover market and patent search, literature review, problem definition, project planning, conceptual design, and selection of the best concept based on evaluation criteria. The final design stage will detail the properties, calculations, software analysis, manufacturing, and testing plans. The report concludes with a summary of achievements and future improvement suggestions.

PROBLEM DEFINITION

Prosthetic hands without wrist rotation struggle to replicate natural movements and gestures, limiting tasks requiring precise positioning. This deficiency hampers adaptability and functionality, causing user frustration. To address this, the work presented in this article integrates a motor-controlled wrist unit into prosthetic hands, enabling fine hand orientation adjustments for a more natural grip. The goals include ensuring the wrist unit allows full, continuous rotation, locks securely, operates quietly, and is compact, rigid, lightweight, smooth, and affordable. It must be suitable for men, women, and children, allow electricity and data transfer, consume low energy, and handle daily activities. It should withstand various forces and thermal conditions without lubricant leakage. Commercial product information that helps identify wrist unit needs is given below.Table 1: Goals and requirements

STATE OF ART-INFORMATİON GATHERİNG

Commercial Products

Three main prosthetic wrist rotators are easily accessible: Ottobock Electric Wrist Rotator, Fillauer MC ProWrist Rotator, and Ossur i-Limb Powered Wrist Rotator. These products have similar specifications and features with minor differences.

Ottobock Electric Wrist Rotator: The most well-known product due to the company's reputation. Specific details on its working principle, systems, and design are unavailable, but some specifications are known.

Fillauer MC ProWrist Rotator: An alternative to Ottobock, with limited information on its working principle and systems, but some specifications are known.

Ossur i-Limb Powered Wrist Rotator: Another alternative, which has been removed from the company's site, indicating potential discontinuation. Limited specifications are available, without details on its working principle or systems.

Comparison

Due to limited documentation, we could only compare some specifications of the three products, which are similar overall. Fillauer: Faster than the other two, but the speed of the others is sufficient. Ottobock: Approximately 2/3 lighter than the other two, though their weights are also acceptable. Other comparisons are not possible due to limited information. Key specifications include noise level (38.5 dB), operating temperature range (0-40°C), and dimensions. Price information, crucial for affordability, is unavailable. Specifications and product images are shown below.

State-of-the-Art on Related Technologies

In this section, detailed information related to the literature survey is provided. The goal is to offer a comprehensive understanding of various aspects of the project topic. The state of the art on related technologies and mechanisms is examined. The intricacies of different driving and locking mechanisms, as well as the electric transfer mechanism, are explored to highlight their unique characteristics and operational details.

Locking-Transmission Subsystem:

- Gear Mechanisms:

1. Kapelevich et al. [7]: Developed self-locking gears that don't rely on clutch or brake systems, with higher efficiency and less heat generation than worm gears. However, they are costly to manufacture due to specialized tools and new gear profiles.
2. Takayama and Hisamatsu [15]: Created a system using small vibrations to reduce friction in worm gears, enhancing back drivability with minimal force.
3. Popper and Wessen [12]: Designed a meshing system for worm gears allowing almost any reduction ratio, where the driver gear can drive in both directions but not be back driven.

Table 1: Goals and requirements

Goals	Requirement
Full Continues Rotation	360 Degree Endless Rotation
Quiet Operation	< 45 dB
Compact	Diameter < 50 mm, Length < 50 mm
Lightweight	< 150 gr
Fast Working	< 5 s Full Rotation Time
Low Energy Consumption	< 5 W
*Axial Weightlifting Capacity	> 30 kg
Moment Carriage	> 2 Nm
Torque Capacity	> 2 Nm

*Axial Weightlifting Capacity: The maximum weight an individual can lift or support with their arm fully extended in line with the direction of gravity.

Specifications-Products	Ottobock	Fillauer	Ossur
Weight	96 g	168 g	150 g
Speed	17 rpm	28 rpm	15 rpm
Voltage	7.2 V	7.2 V	6-8.4 V
Current	1 A	?	6 A
Length	? mm	70 mm	56 mm
Diameter	? mm	47 mm	? mm
Torque	? in-lb	15 in-lb	? in-lb
Static Load	? kg	22.7 kg (from all ways)	90 kg (axially)
Temperature	? degree C	0-44 degree C	0-40 degree C
Decibel	? dB	38.5 dB (1 m)	? dB
Price	?	?	?

Figure 1: Commercial product information

- Brake Systems:

1. Electro-Mechanical Brake Systems: Despite many patents and designs, no marketed EMB systems exist. They save space and are faster than hydraulic brakes but require a DC motor, making them complex and less favorable, according to Congcong Li et al. [8].
2. Mechanical Brake Systems: These brakes don't need an actuator but are manually activated, like hand tools. A similar locking mechanism is noted in the patents section.
3. Hydraulic Brake Systems: Unsuitable for our design due to maintenance needs and weight issues.

- Pin Lock Mechanism:

1. Designed by Cappello et al. [5], this mechanism uses a cylindrical pin and a step motor to lock the wrist in the pronation/supination axis, adaptable to our design.

- Ball Lock Mechanism:

1. Utilized in micro-switching valves, this system uses steel balls to lock components precisely. However, it requires additional space for solenoids and can cause heating issues, limiting rotation options.

- Multi-Function Myoelectric Hand:

1. A novel self-locking mechanism using a cam-ball clutch, enabling unidirectional power transmission and stability, with four distinct operating modes for driving and locking.

<u>Turning Subsystem:</u>

- Transmission System I: Gill [6] describes a single-degree-of-freedom wrist unit with an actuator module that rotates various components and transmits rotation to the prosthetic hand. The module includes a motor, gears, and bearings, with a planet gear system to minimize backlash.
- Transmission System II: Lorenzo et al. [1] detail a prosthetic wrist with a drive motor and a two-stage cycloidal reduction mechanism. The first stage involves satellite wheels and a central wheel with a reduction ratio of 8:1. The second stage has a cycloidal mechanism with a reduction ratio of 33:1, resulting in a total reduction ratio of 264:1.

Actuator Types: According to Binda (2018) [4], the key criteria for choosing an actuator for a prosthetic wrist are torque, size, and weight. The three main motor types are:

- DC Motors: High RPM, small size, easy to control, high torque at low speeds, and available in brushed (low cost) and brushless (quiet, efficient) variants.
- Step Motors: Low RPM, high torque, precise positioning, but noisy and less efficient than DC motors.
- Servo Motors: High RPM, high torque, larger and heavier, complex control.

Based on literature and commercial products, brushless DC motors are recommended, but all motor types will be considered as the project progresses.

<u>Electrical Transfer Technologies:</u>

Various electrical transfer technologies for rotating interfaces include cable-wrap, goose-neck, twist capsule, slip ring, and rolling contact connector (RCC).

- Cable-wrap and Twist Capsule: Compatible with twisted shielded pairs and have high angular ranges, but they cannot rotate continuously.
- Goose-necks: Can rotate more than 360° but are not suitable due to angular limitations. Detailed information and images are in [9].
- Slip Rings: Widely used for continuous rotation without restrictions, consisting of brush blocks, rotor, and stator. MOFLON's MFS Series [10] is an example of a waterproof slip ring. Slip rings require precise alignment and lubrication to reduce friction and wear.
- Rolling Contact Connector (RCC): Also known as a brushless slip ring, transfers electrical signals across a rolling contact interface, composed of an inner ring, flexible planets, and an outer ring.

Housing & Shielding:

For protection, the wrist unit should have durable, customizable, lightweight housing, ideally made from carbon fiber, which is light yet strong. Epoxy-impregnated carbon fiber sheets allow for customization to meet the different needs of amputees. For moisture protection, the contacts on the wrist coupler should be internally located and shielded by a plastic casing.

CONCEPT GENERATİON

This section covers the conceptual design processes, including concept development and evaluation. Literature, patents, academic papers, and commercial products are reviewed to identify suitable concepts. This investigation expanded our state of art, with findings shared here. Concepts were then evaluated against project requirements using decision matrices. Ultimately, the best concept is presented based on these evaluations.

Concept Development and Presentation

In this section, the work presented in this article is split into subfunctions, and concepts are developed for each subfunction. The functional decomposition method is used for this purpose. Various concepts are created according to functional decomposition. Then, a morphological chart is created with these concepts. Explanations for each concept are also provided.

Explanation of Concepts

Providing Rotation:

- Internal Gear Mechanism: Internal gears have teeth cut into their inner surfaces, engaging with external gears to transmit motion and power. They feature a self-locking mechanism that resists motion under external forces, making them suitable for applications requiring fixed positions and efficient rotational motion.
- Planetary Gear System: This system includes fixed outer and sun gears with multiple planetary gears rotating freely. Motion from the sun gear transfers through the planetary gears and coupling mechanism, providing versatile motion transmission.
- Planetary Gear System with Ball Bearing: Incorporates fixed planetary gears and stationary sun gear, with a ball bearing in the outer part facilitating rotational motion. This system includes a self-locking mechanism, enhancing stability without additional components.

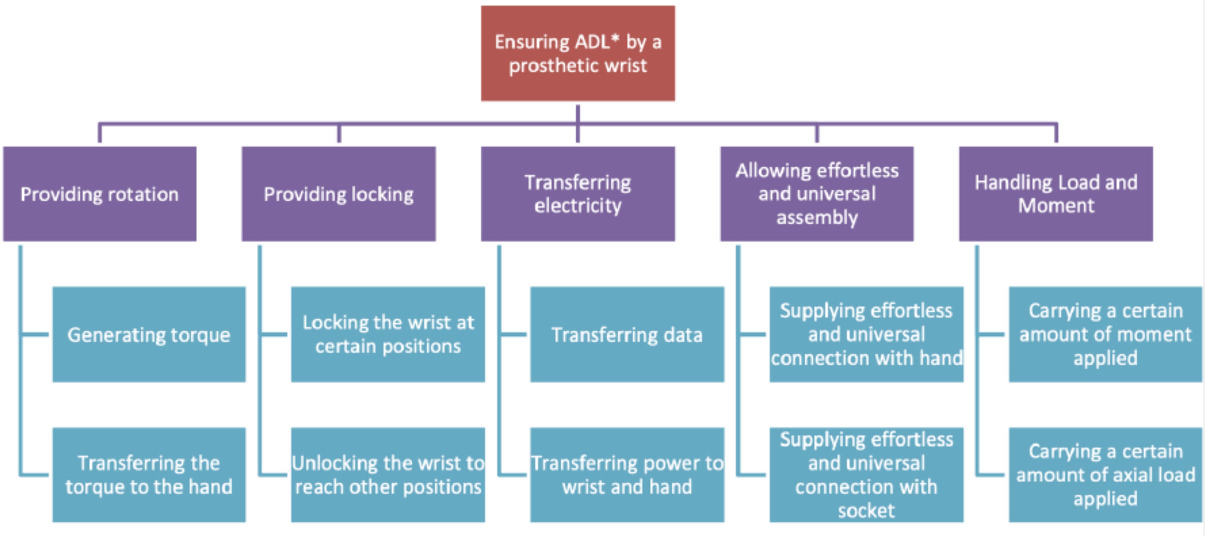

Figure 2: Functıonal decomposıtıon

- Harmonic Drive System with Ball Bearings: Utilizes an elliptical rotating gear and a circular outer gear to create a rotational drive. Ball bearings rotate to sustain the motion of the elliptical gear, providing efficient and self-locking operation.
- Harmonic Drive System with Frictional Contact: Rotational energy from the motor transfers to an elliptical gear through frictional contact. This system features a harmonic drive between the elliptical and circular gears, offering self-locking capabilities.
- Cycloidal Drive: Composed of an input shaft, eccentric bearing, two cycloidal disks, and a housing with pins and rollers. Eccentric motion drives the cycloidal disks, producing reverse rotation at reduced speeds. It includes a self-locking mechanism for stability [11].
- BLDC Motor: Brushless DC motors are commonly used for their high efficiency and precise control in prosthetic applications.
- Servo Motor: Servo motors are favored for position control due to their accuracy and ability to maintain set positions, details are in [13].

These mechanisms vary in design and application, offering different advantages for achieving rotational motion and stability in prosthetic designs.

<u>Locking Mechanisms:</u>

- Ball Locking Mechanism: This mechanism uses balls and holes in a rigid body. When the motor rotates, the balls move into place within the rotating part, locking the system. Solenoids and springs control the ball motion: the solenoid helps balls enter holes during rotation, and the spring locks them in place afterward. Disadvantages include increased energy consumption and potential damage to components due to solenoid heat.
- Pin Locking Mechanism: This system employs a pin-to-lock gear mechanism controlled by a solenoid. The pin disengages from the gear gap when the solenoid activates, allowing easy rotation. After rotation, the solenoid deactivates, and the pin locks the mechanism in place. Compared to ball locking, it offers more precise locking locations but shares the drawbacks of energy consumption and solenoid heating.
- Worm Gear Lock Mechanism: Worm gears prevent back driving, enabling them to lock when external force is applied. Positioning the worm gear perpendicular to the turning table can complicate design due to space requirements, while positioning it parallel resolve some issues but may necessitate specially manufactured components.
- Harmonic Drive Lock Mechanism: Harmonic drives transmit torque through a pure couple, allowing for torque sensor integration without radial force interference. This feature enables back-drivability for compliant movements in robotic applications, though high-ratio harmonic drives lack back drivability.
- Pad Brake Lock Mechanism: Like car disk brakes, a pad brake can be applied to the turning table or gears. This requires an actuator and significant space. To conserve energy, it should only be released when turning the wrist, posing design challenges.

These mechanisms offer various locking solutions with specific advantages and challenges in prosthetic applications.

<u>Transferring Electricity:</u>

- Slip Ring: A slip ring facilitates continuous rotation in machinery by transmitting power and signals between stationary and rotating parts. It comprises a rotor (rotates with the machinery) and a stator (stationary structure), forming band-pass circuits for independent electrical transmission. Key components like connectors ensure reliable operation, according to Santoro et al. (2009) [14].
- Capsulated: Protects wires by enclosing them, preventing damage—a common method for wire protection.
- Pancake Slip Rings: Organizes conductors in concentric rings on a flat disc aligned with the shaft, compact but prone to wear and debris accumulation along its axis.
- Through Bore: Features a central opening allowing cables to pass through, ideal for applications needing uninterrupted 360-degree rotation, ensuring low electrical noise and reliable connections.
- Mercury-Wetted: Uses liquid mercury for stable, low-resistance connections, though safety concerns due to toxicity require careful handling.
- Rotating Contact Connector (RCC): Utilizes rolling contact for electrical signal transmission, reducing parasitic torque and ensuring stable operation with low inter-contact resistance. Materials like beryllium copper and aluminum alloys optimize endurance and conductivity.
- Cable Wrap: Clock-spring configuration compatible with twisted pairs, offering a significant angular range (100°-700°) for rotational applications.

These technologies offer diverse solutions for continuous rotational applications, each with specific advantages and considerations.

Allowing Effortless and Universal Assembly:

- Commercial and Magno Flex Connectors: Commercial products typically use standard modules for wrist-to-hand connection, involving a push and small turn for coupling. Magnetic locks automatically connect by aligning the wrist tip with a conical shape using magnetic fields, suitable mainly for lower body prosthetics due to space requirements.
- Rotary-Pin Type Connection: This mechanism employs a spring plunger lock housed in a cylindrical body. It ensures secure locking with a spring-loaded plunger that can be easily engaged or disengaged, offering simplicity and functionality for securing components in wrist and hand applications.
- Push-and-Turn Locking Mechanism: Like those on medication containers, this mechanism requires downward pressure and simultaneous rotation to open. It provides secure access while incorporating child-resistant features, suitable for ensuring safe and easy assembly in wrist systems.

CONCEPT EVALUATİON

In this section, evaluation criteria and weighting factors are created according to the problem definition and project requirements. More specific criteria for each subfunction are also established. Four decision matrices for each subfunction are made based on these criteria, and unsatisfactory solutions are eliminated. With the satisfactory solutions, complete design concepts are created. The best concept is then chosen from these according to the decision matrix.

Evaluation Criteria

Design Criteria for General Concept:

- Locking Capability: Essential for daily activities like handling objects such as glasses, forks, or spoons.
- Full Rotation: Overcomes the limitation of typical prosthetic arms by providing complete wrist rotation.
- Rotation Time Limit: Rotation speed must be optimal for practical use.
- Energy Consumption: Must be efficient to ensure suitable battery life without adding excessive weight.
- Noiseless Running: Operation should be quiet to avoid disturbing the user.
- Load Carriage: Capable of handling up to 30 kg, meeting user needs and requirements.
- Ease of Assembly: Easy to assemble and disassemble, ensuring user-friendly application.
- Operating Under Different Thermal Conditions: Should function reliably in various climates and temperatures.
- Cost: Affordable pricing to make the product accessible.
- Manufacturing: Production should be straightforward and align with company capabilities.
- Angular Precision: Stops accurately in desired positions during rotation.
- Compact and Lightweight Design: Must be lightweight and compact for user comfort and practicality.
- Lifetime: Expected to be durable, with a minimum operational lifespan of 2 years.
- Rigidity: Ensures structural integrity throughout its lifespan.

Design Criteria for Sub-Functions:

- Turning Sub-Function Criteria:

1. Angular Precision: Ensure precise positioning capability for daily life activities.
2. Rotation Time Limit: Rotation speed should be efficient for practical use.
3. Full Rotation: Provide unrestricted rotation like a human arm.
4. Ease of Production and Cost: Ensure cost-effective and easy manufacturing.
5. Noiseless Running: Operation should be within acceptable noise limits.
6. Providing Enough Torque: Capable of handling tasks like turning while holding objects.
7. Compact and Lightweight: Design should meet size and weight restrictions.

- Locking Sub-Function Criteria:

1. Locking Time Limit: Ensure quick and efficient locking/unlocking.
2. Noiseless Locking: Operation should be quiet to meet noise limits.
3. Need for More Actuator: Minimize additional space and weight for extra mechanisms.
4. Self-Locking Capability: Provide reliable self-locking without additional components.
5. Compact and Lightweight Design: Ensure the design meets size and weight constraints.
6. Ease of Production and Cost: Focus on easy production and affordability.

7. Angular Precision: Precise locking for user convenience.

- Electric and Data Transfer Sub-Function Criteria:

1. Continuous Full Rotation: Ensure cables and transfer elements allow unrestricted movement.
2. Transferring Data and Electricity: Enable seamless transfer of power and data to prosthetic hand components.
3. Assembly: Facilitate convenient assembly of electrical and mechanical components.
4. Cost: Ensure affordability of electronic components for commercial viability.
5. Compact: Design should be compact to fit limited space requirements.

- Assembly Sub-Function Criteria:

1. Universal: Compatible with various prosthetic hand brands without modification.
2. Ease of Assembly: Designed for easy assembly to accommodate users with disabilities.

Best Concept

The decision of the best concept is chosen by the given below method. According to the created sub-function design criteria, the best sub-function mechanisms are decided. Then, with these chosen sub-function mechanisms, 12 concepts are created. According to the created concept design criteria, the best concept is decided. The decided mechanisms and concepts given below. The assembly mechanism has 2 different mechanisms. The decided assembly mechanism is a standard commercial mechanism, however, to achieve a unique mechanism, a second assembly mechanism was created inspired by a quick hydraulic coupling mechanism.

Hypocycloid Mechanism: The design enables a 360-degree rotation through an elliptical object in the center engaging with internal gears, which push against stationary external gears. This interaction provides a natural and comprehensive range of motion, ensuring seamless and precise control.

Self-Locking Gear Ratio: The gear ratio ensures the prosthetic wrist locks securely in position without external mechanisms, enhancing precision, safety, and stability.

Pancake Slip Ring Mechanism: A flat, disk-shaped pancake slip ring enables continuous electrical power and data transfer between stationary and moving parts, ensuring uninterrupted flow of electrical signals and data for the prosthetic's components.

Commercial Assembly Mechanism: To enhance durability and user-friendliness, a commercially available assembly mechanism is combined with the self-locking hypocycloid mechanism, minimizing wear and tear and ensuring long-term reliability.

Renewed Assembly Mechanism: A mechanism inspired by the hydraulic quick connect (HQC) system has been designed with a key difference: the balls are located inside the mechanism, unlike the external placement in traditional HQC systems. This mechanism operates by pushing the balls through a channel that restricts their axial movement. The balls secure hand unit and wrist unit in place, ensuring a stable connection.

PRODUCT ARCHİTECTURE AND DETAİL DESİGN

After the concept decision, the product design details are determined. Then, according to determined architecture, configurations and parameters, detailed design is made. Initially, the physical elements are arranged to carry out the intended functions, forming the architectural design. Following this, the first complete design is created, known as the configuration design. Subsequently, final dimensions, materials, and tolerances are determined during the parametric design phase. Finally, detailed drawings and specifications are produced in the detail design stage. Each phase builds on the previous one, refining the product design until it is ready for production.

Properties of Designed System

To start with, the product features a unique and innovative coupling design. This concept was adopted from hydraulic systems known for their high safety factors. It is believed that a similar approach could be implemented in this design. Additionally, a different drive system for the wrist unit was utilized, specifically a hypocycloidal drive system, unlike the commonly used harmonic drive in other products on the market. The hypocycloidal drive system offers potential advantages in terms of backlash level and lifespan. Furthermore, a different method for electric and data transfer was implemented using a pancake slip ring. These changes were necessary due to the design layout in the casing. The combination of these sub-mechanisms can be seen in the figures below.

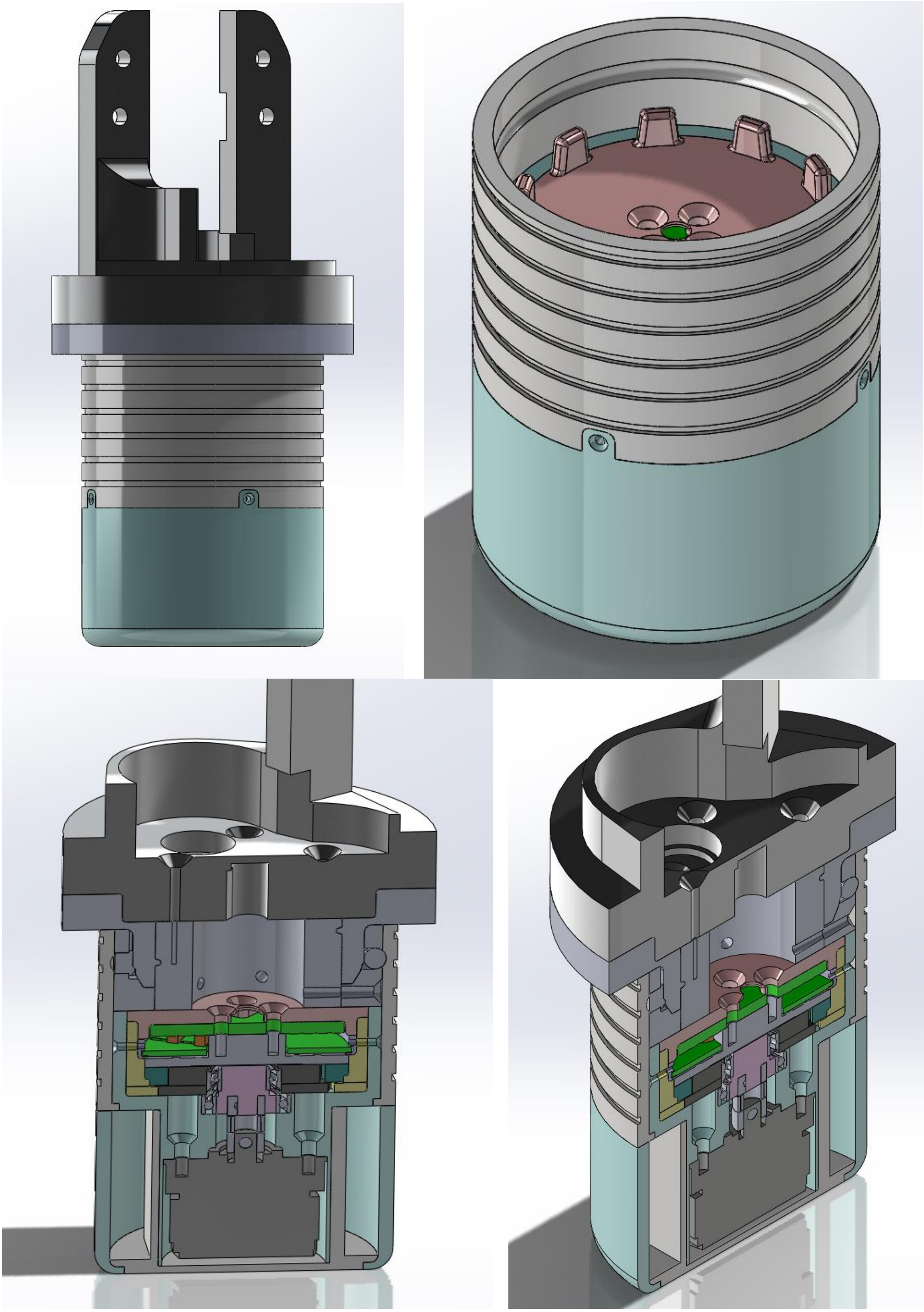

Figure 3: Model views

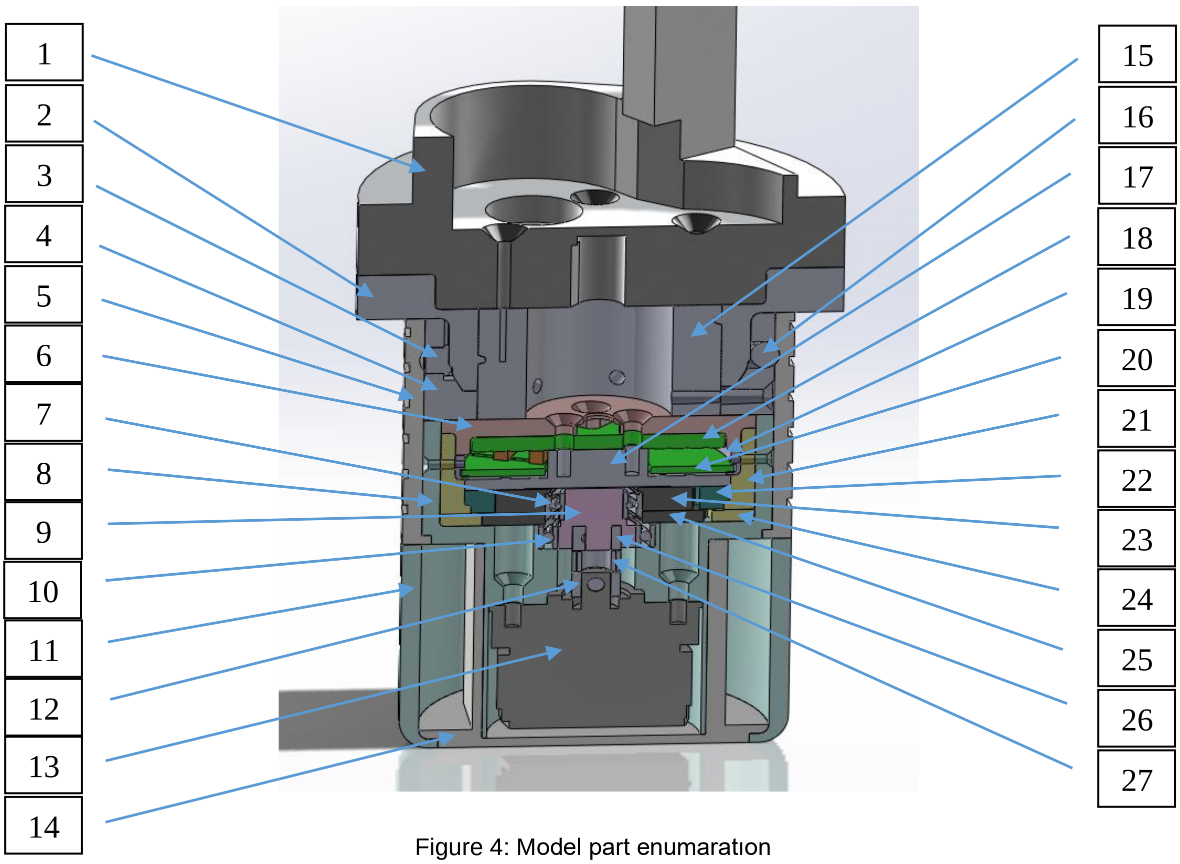

Figure 4: Model part enumaratıon

Table 2: Part names and numbers

Part Number	Part Name	Part Number	Part Name
1	MYO Hand Body	15	Slipring Socket
2	Bearing Balls Trigger	16	Bearing Balls
3	Balls Trigger Holder	17	Turning Transfer
4	Bearing Balls Holder	18	Turning Circular Circuit
5	Arm Connector	19	Stationary Circuit Holder
6	Turning Transferer for Hand	20	Stationary Circular Circuit
7	Bearing 1	21	Gear Bed
8	Main Body	22	Outside Top Gear
9	Excentric Rotation Trigger	23	Inside Top Gear
10	Bearing 2	24	Outside Bottom Gear
11	Body Cover	25	Inside Bottom Gear
12	Coupling Part 1	26	Coupling Part 2
13	BLDC Motor	27	Flexible Coupling Part
14	Flexible Circuit Bed		

Engineering Calculations

The detailed design of the system is completed before starting the manufacturing of the prototype system. In the engineering calculation, weight and dimension of the system; used as optimization criteria. The optimization process is realized, according to BLDC motor parameters, to achieve the necessary speed, torque, angular precision and energy consumption values, needed reduction ratio is determined; also, this optimization process consists of the determination of the gear mechanism's gear teeth values to achieve this reduction ratio. According to calculations, the necessary reduction ratio comes around 300. Thanks to hypocycloidal gear mechanism, in the place of 35 mm diameter and 6 mm height, design achieved this reduction ratio. This gear mechanism's 4 gears have around 30 teeth per gear, according to optimization and working principle, some has a little mor some have a little less tooth.

Analysis Results

To validate the design, some analyses are conducted. These analyses are made for force and momentum carriages, and capacity of torque that the wrist unit can apply, strength of the gear mechanism and gear tooths. Also, some tests are conducted which are made for turning speed, energy consumption values, noise decibel values, etc. According to results of these analyses and tests, future works are determined. Most of the results are satisfactory, but since this product is a prototype, some of the design parameters must be improved. These are decibel values, energy consumption values and torque capacity. The result can be seen in the Discussion-Conclusion Part, Table 3.

PRODUCTİON

The final system has nearly 50 parts. Most of these parts can be produced by machining operations. Some of these parts need to be metal and some others plastic. According to system criteria Aluminum 7075 T5 was chosen as metal material, and POM-C was chosen as plastic. Another material is used for slider bearing and the material is iglidur. With machining of these materials, most of the parts produced thanks to facilities of Proted Prosthetics & Orthotics INC. Some other parts like bearings, screws, pancake PCB, pancake connectors, BLDC motor, etc. purchased. Also, some parts are manufactured by 3D printing with the use of TPU 85A, PLA, etc. One of the most important aspects of the production Is that the hypocycloidal gears are produced by wire erosion with Titanium.

DİSCUSSİON-CONCLUSION

As a result of the studies conducted, a prototype at the product level has been developed. While the prototype meets most of the expected requirements, some deficiencies have been identified. The most critical issues affecting the system's functionality are the insufficient torque transmitted to the hand unit and the high noise and vibration occurring when the wrist unit is operating. To address these critical issues, special lubrication preferences, gear material preferences, mechanism tolerance preferences, mechanism dimension preferences, and some design preferences will be modified. You can see the outputs obtained in the table below.

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ÖZET

Bu tasarım çalışması, Üst Ekstremite Amputasyonları için Protez Bilek Ünitesini araştırmaktadır ve Tasarım Odaklı Düşünme metodolojisini kullanmaktadır. Problem Tanımı, Bilgi Toplama, Kavram Oluşturma ve Değerlendirme, Ürün Mimarisi, Konfigürasyon Tasarımı, Parametrik Tasarım, Detay Tasarımı ve Üretim adımlarını kapsamaktadır. Çalışma, küçük (50 mm çap, 50 mm uzunluk, 150 gr'dan az), 360° dönebilen, protez ellere kolayca bağlanabilen, elektrik ve veri transferi yapabilen, EMG sensörleri sayesinde kas hareketleriyle kontrol edilebilen bir protez bilek ünitesi yaratmayı amaçlamaktadır. Bu araştırma, ampütelerin yaşam kalitesini artırarak protez ürün tasarımına katkıda bulunmaktadır.

Table 3: Output

Goals	Requirement	Output
Full Continues Rotation	360 Degree Endless Rotation	360 Degree Endless Rotation
Quiet Operation	< 45 dB	Not satisfied
Compact	Diameter < 50 mm Length < 50 mm	Diameter = 40mm Length = 37 mm
Lightweight	< 150 gr	Around 100 gr
Fast Working	< 5 s Full Rotation Time	2-4 s
Low Energy Consumption	< 5 W	Around 4 W
Axial Carriage	> 30 kg	> 45 kg
Moment Carriage	> 2 Nm	Around 4 Nm
Torque Capacity	> 2 Nm	Not satisfied

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