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CONSTRUCTION OF A JOINT MECHATRONICS OF ELBOW WITH MOVEMENTS OF FLEXION - EXTENSION AND PRONOSUPINATION OF THE FOREARM

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***Abstract** - this project features the design and construction of an elbow joint, which can be controlled by electrical signals of voltage ranging between 0 to 5 volts, whose value is proportional to the desired angle it, and is capable of simulating the movements of flexion extension and pronosupination of the forearm.*

With anthropometric measures for its design, is the selection of the different actuators used in elbow joint. A CAD software is then used to perform a virtual model; an analysis of joint efforts, which allows to verify that the design is capable of withstanding the loads proposed in the project.

Completed the process of mechanical design of the prototype of prosthesis elbow, is the design and implementation of electronic control system, to govern the movements to be carried out. Finally are evidence of performance and calibration of each one of the different movements.

1. INTRODUCTION.

According to the census conducted by the National Council of disability equality (CONADIS) in September of 2014 in the Ecuador there are about 397.233 people with disabilities, of which 193.905 have physical disabilities, are in Ibarra in Imbabura 4.620 and 2.402[1, 2].

Amputations are one of the oldest surgical and irreversible practices carried out by humans, either because of congenital diseases, accidents, bad labor practices, wars etc.

Amputation of any Member cause a great impact on the life of a person, demonstrating, through the isolation from society for fear of not being accepted, taking the person to a State of deep depression and low self-esteem.

But not only affects the psychological part, also influences the employment status, due to the time of rehabilitation that needs to recover, losing the support of his family and becoming more dependent on others.

All these problems are encouraged to investigate how to improve the quality of life of people with amputations; replace lost limbs in some form, resulting in the creation of the prosthesis.

At present many centers of research around the world, proposed the creation of different types of prosthesis either mechanical or myoelectric, latter being which are emerging with force because of its great capacity for such movements operation that makes the human body [3].

Unlike the purely mechanical prostheses, they need a harness to be operated, the only myoelectric need a muscle myoelectric signal, and thus providing comfort are more aesthetic. With regard to the functionality these prostheses allow a greater range of motion.

For this reason it proposes the creation of elbow joint which will play elbow, flexion-extension and discussed of the forearm, movements in the future to develop a functional transhumeral prosthesis, integrating arm, elbow, forearm and hand, at a reasonable cost to reach of all and of excellent quality

2. MATERIALS AND METHODS

2.1 ANTHROPOMETRY OF THE UPPER LIMB

The study of Anthropometry of the upper limb, for this was essential for the design of elbow joint, was taken as a reference to seniors to 18 years and 70 kg; It showed average anthropometric measures, shown in Table1 [4].

Table 1. Anthropometric measures

Anthropometric measures.	
Weight a person	70kg
Arm length	0.243m
Arm width	0.09m
Forearm weight	1.12kg
Hand weight	0.49kg

2.2 FEATURES

Elbow Joint which was designed in compliance with the following technical specifications: the movement of flexion - extension is between 0° and 120° with a speed of 10 rpm, the movement discussed between 0 ° to 180°, and a mass of 1.3 kg.

METERIALS SELECTION.

The material used to manufacture was of polyester resin, which has the mechanical properties, which are described in table 2 [5].

Tabla 1 Properties of resin

Mechanical properties of polyester resin.		
Density	1.2 – 1.3	g/cm^3
Tensile strength	25 - 50	MPa
Modulus of elasticity	1171	MPa
Yield strength	44	MPa
Elastic limit	29.6	MPa

2.3 ACTUATORS SELECTION

Joint account with two different movements for that reason chose two actuators, a servo motor to the discussed and a DC motor with gearbox coupled to a system of transmission of power to the flexion-extension.

2.3.1 SERVOMOTOR SELECTION

To determine the necessary torque for rotation of the hand, he performed it using Equation 1. Obtaining a value of 0.08 Kg*m ^ 2. For which it was necessary to determine the inertia of the hand through the use of SolidWorks as shown in Figure 1, and the angular acceleration, based on a person's needs. [6]

Equation 1 . Torque equation depending on inertia and angular acceleration

$$T = I * \alpha$$

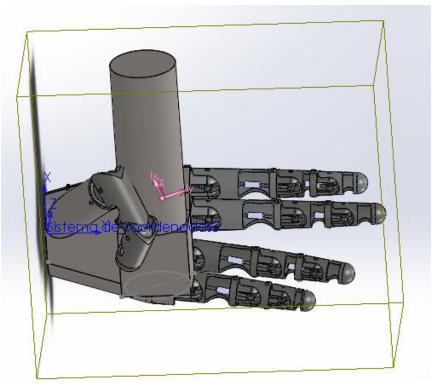

Figure 1. *Hand model. Moment of inertia I1=0.01kgm^2. Angular acceleration* ∝=8.4*rad/s^2*

Determined once the necessary Torque for rotation of the hand selected a servomotor HITC 311 available in the local market.

2.3.2 DC MOTOR SELECTION

For the selection of the actuator was 90 degrees of flexion, since every effort occurs in this position. Establishing the next state of loads for this item as shown in Figure 2.

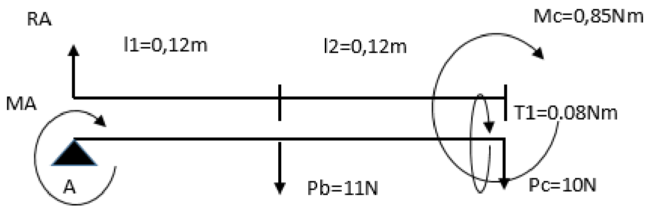

Figure 2. Free body diagram for the forearm.

Where:

Pc is the value of the peso to rise.

PB is the weight of the forearm.

RA is the reaction caused by external forces.

MC is the result of the action of the weight moment to lift Pc.

MA is the time used to determine the value of the actuator.

For which gets the value of MA = 4.5Nm. This was to select the actuator is necessary for this torque. A selected DC motor was 200 rpm and 3Nm. Finally designed a system of transmission using worm and Gear to achieve 4.5 Nm as shown in Figure 3.

2.4 TRANSMISISION SYSTEM SELECTION

They decided to use the mechanism of worm and Gear by able to handle grades reasons of torque in a small space and mainly by property and auto lock.

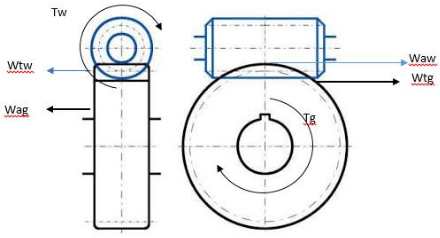

Figure 3. Screw worm wheel.

Selected worm has an advance of 9 degree angle and an angle of θ pressure = 20 degrees. The diameter of the Gear to produce the 4 5Nm is 40 mm. Equation 8 is used to ensure that the mechanism works to the required speed. As a result is obtained that it is necessary for the Gear to have 40 teeth.

Equation 2 Speed gear.

$$Ng = \frac{Nw * a}{zg}$$

$Where$:
$Ng = speed\ of\ the\ gear$
$Nw = speed\ of\ the\ worm$
$a = number\ of\ worm$
$Zg = number\ of\ teeth\ of\ the\ gear$

So:

$$zg = \frac{Nw * a}{Ng}$$
$$zg = \frac{200(2)}{10}$$
$$zg = 40$$

Figure 4. screw worm wheel[10]

2.5 TRANSMISSION SHAFT DESING POWER

The required parameters for the design of this axis are the torque being transmitted to move the elbow joint, and the forces by the use of a helical gear, due to the geometry of the worm. The torque to be transmitted is 4,5Nm previously calculated on the size of the engine. In Figure 5 the axis model is indicated.

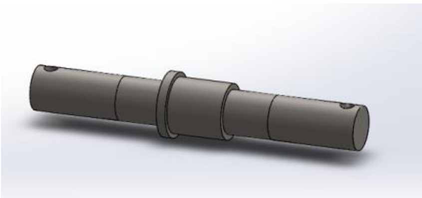

Figure 5. Model axis

Points Ay E shaft is located bars that they will support the forearm, in these places get full power entered the central gear. At points B and D are located for the attachment of the shaft bearings. Point C is in place where is located the central gear, responsible for transmitting all the power from the engine. Figure 6.

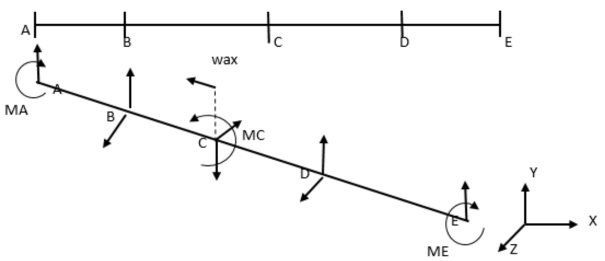

Figure 6 Free body of axis

Performed the analysis determines that you bending moment which the shaft is subjected is MB = 0. 304Nm and MC = 1 76Nmy 4.5 torque Nm.

Diameters to calculate correspond to points B, D place where bearings and C are placed where the gear is placed. Used the theory of failure fatigue through the distortion energy criterion. Equation 9.

- Material ASTM A 36 his = 400MPa, Sy = 248MPa [11]
- Safety factor of N = 3. Suggested in the book of machine design. [11]
- The value of concentration of efforts kt = 3, since it will perform transverse holes on the shaft, to hold the different elements to be placed.[11]

Equation 3 Diameter calculation

$$d = 3\sqrt{\frac{32n}{\pi}\sqrt{\left(\frac{ktM}{Sn'}\right)^2 + \frac{3}{4} * \left(\frac{T}{Sy}\right)^2}}$$

Where
d = diameter to calculate
n = safety factor
kt = concentration of effort
M = bending moment
Sn ^'= real fatigue
T = torque
Sy = yield strength (44MPa)
So:

$$d_B = d_D = 0.007m$$
$$d_C = d_D = 0.01m$$

The points A and E gets diameter 4mm Allen bolts, these will be in charge of holding the forearm support bars. Also used needle roller bearings in brackets. Figure 7. [12]

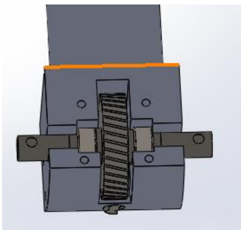

Figure 7 Support, gear, axis and bearing

2.6 FOREARM THICKNESS CALCULATION

The critical elbow joint design element is the forearm, which is subject to different external loads shown in Figure 8, we designed the thickness using the criterion of join by crushing.

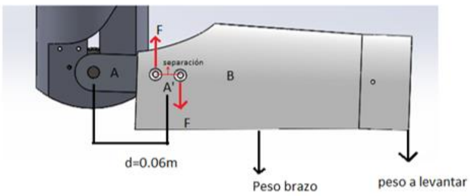

Figure 8. Joint model.

It was determined the force F that the bolted joint using Figure 9-free body diagram is subject.

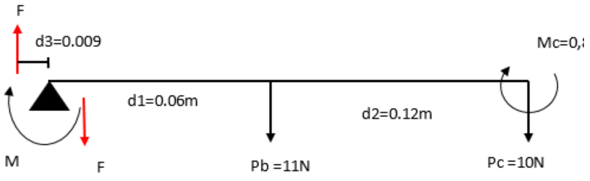

Figure 9. Free diagram of forearm, F=368N

Subsequently determines the area of crushing that can suffer the resin used as source material for the elaboration of the forearm, as shown in Figure 10.

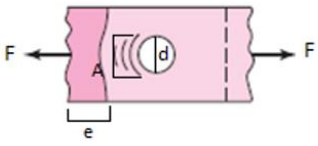

Figure 10. Fasteners and external loads

Equation 4 . Crushing perimeter

$$P = \pi * \frac{d}{2}$$

$$P = \pi * \frac{3{,}9mm}{2} = 6{,}1mm$$

Where:
d = diameter of the hole.
P = semi-perimeter of hole.

3,9mm diameter bolt was considered for analysis, therefore, the equation 7 is used to determine the area of crushing.

Equation 5 crushing area

$$A = P * e$$

To determine this thickness (e) it was necessary to know the resistance to compression of resin and finally used the theory of fault by compression, one gets to a thickness of 2, 4 mm, using equation 10 and 11.

Equation 10 Distortion energy

$$\sigma = \frac{Sy}{fs}$$

Where:

$\sigma =$ Strain

$Sy=$ Creep resistance of the resin

$fs=$ Security factor

Equation 11 drilling strain

$$\frac{F}{nA} = \frac{Sy}{fs}$$

$$e1 = \frac{F * fs}{n * Sy * P}$$

$$e1 = 2.4mm$$

2.7 ANALYSIS MODEL ELBOW JOINT.

To make the analysis of efforts was used SOLIDWORS 2016, allowing to validate the calculations set forth above, by means of a stress analysis by finite elements; so is simulated considering that: the forearm is made of a polyester resin, an ASTM A36 steel drive shaft and stands of nylon actuators.

2.7.1 RESTRICTIONS.

Restricts the movements of the joint placing binding of fixed geometry, loads of the forearm and the load to lift up as shown in Figure 11.

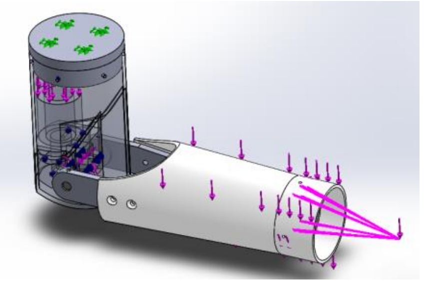

Figure 11. Restrictions for the stress analysis.

2.7.2 STRESS ANALYSIS.

As a result of the analysis of the model on the basis of the failure of Von Mises criterion, was obtained the following distribution of efforts, as shown in Figure 12.

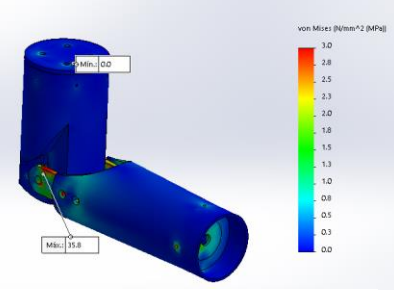

Figure 12 Von Mises Stress

2.1.1. DISPLACEMENT ANALYSIS.

The distribution of displacements is shown in the Figura.13, to determine a maximum displacement of 1.08 mm.

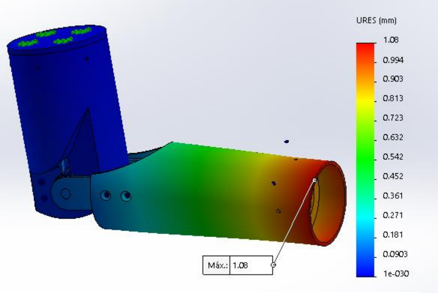

Figure 13 Displacement

2.7.3 ANALYSIS OF SAFETY FACTOR.

Finally, the factor of safety with a value obtained 5.75 minimum is the forearm fasteners as shown in Figure 14.

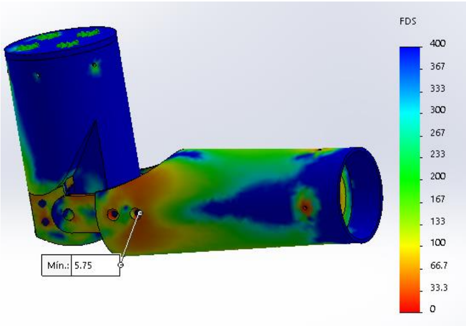

Figure 14 Safety factor

2.2. CONTROL SYSTEM DESING

The control to use in the elbow is a closed loop system as shown in Figure 15.

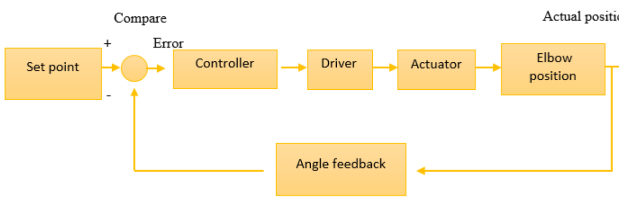

Figure 15. Block diagram of the control system

2.2.1. MATHEMATICAL MODELING CONTROL SYSTEM

The mathematical model is made of the motor assembly - potentiometer, so applying a signal step on the ground is achieved his characterization in equations in the time domain, is transformed to the domain of Laplace, obtaining the transfer function, and thus design the type of control to implement.

The ideal characteristic equation corresponds to a signal ramp in the following way.

$$y \approx mt$$

Applied Laplace's transformed gets the signal in the domain (s)

$$y \approx \frac{m}{s^2}$$

The signal input corresponds to a signal step, with equal amplitude voltage direct current as well:

$$u(t) \approx v$$

$$U(s) \approx \frac{V}{s}$$

The transfer function of the system.

$$G(s) \approx \frac{Y(s)}{U(s)} \approx \frac{m/_{s^2}}{\frac{V}{s}}$$

$$G(s) \approx \frac{m}{\frac{V}{s}}$$

2.2.2. REAL MATHEMATICAL MODELING

The characterization of the mathematical model of the joint it is done by applying different values of voltage to the engine and by measuring the angle of displacement. Figure 16 indicates the behavior of the plant.

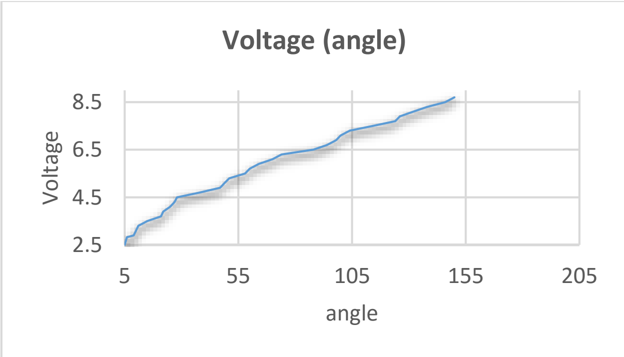

Figure 16. Actual behavior of the system

The data obtained in the figure 17 is processed them in Matlab and using the tool Ident gets the real model with a percentage of the estimate of 94%.

So:

$$G(s) = \frac{24.99}{s + 0.236}$$

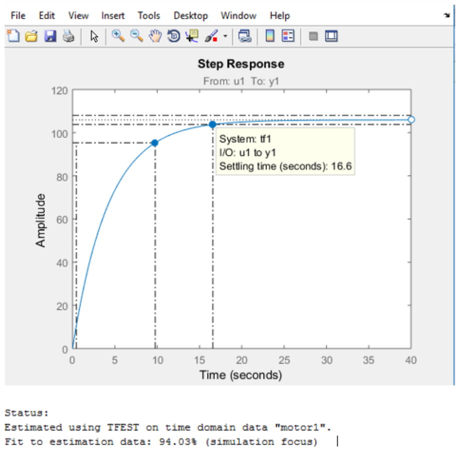

Figure 17. Open loop model

The obtained model corresponds to a first-order control system.

So:

$$G(s) = \frac{K}{\tau s + 1}$$

$$G(s) = \frac{105.8}{4.16s + 1}$$

Being a type 1 system model mathematician contains a term Integrator, therefore it is not necessary to apply the integral part. In addition to only modify the proportional gain can vary the speed of response of the system, hence the derivative part is not necessary.

To implement control system is shown in Figure 18.

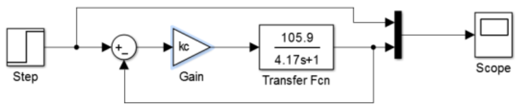

Figure 18. Control system

The error in steady state with a Kc = 2 produces a range of 0.995 and with response time around 70 ms with an error of 0.0046, indicated in Figure 19.

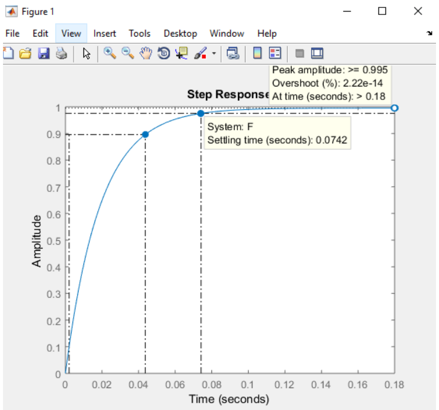

Figure 19. Closed control loop system

In a proportional control output depends directly on the error, which is equal to the difference between the signal of reference or set point with the measured value of the variables to control.

$$e = Sp - V_r$$

Where:

$e = error$

$Sp = set\ point$

$V_r = measured\ value$

Then:

$$Up = kc * e$$

Where:

Up = control signal proporcianal

$Kc = proportional\ gain$

$e = proportional\ error$

Replaced the value of Kc = 2, retrieved previously.

Up = 2 (e)

3. RESULTS

An according to anthropometric measures elbow joint model was obtained and which complies with the specifications of the project.

The prototype of elbow joint makes the movement of flexion - extension between 0 and 120 degrees and the discussed with angles from 0 to 180 degrees. It also supports a load of 0.5 kg without compromising the electrical integrity as physics.

With regard to the mechanical part of the implementation of the screw without end and Gear, was the best option since it allowed to handle big reasons of power and des to energize the power supply, once completed the movement.

The resin material used for the structural part as turned out to be an economical alternative and useful at the time of creating the prototype, however to carry out business models is not suitable because it does not withstand strong impacts and manufactured process takes a long time.

4. CONCLUSIONS.

Bibliographic information collected the important parameters for the design of the elbow joint are the length of the forearm included the measure in hand, in addition to the mass of the forearm and hand.

The mechanism screw without end and Gear is the best option due to the possibility of handling big reasons torque and mainly by the property of auto lock, which allows to leave energize the actuator and that it retain its position unless the driver of a change order, thus saving energy.

Resin as material for prototyping is useful, however to perform business models, is not appropriate since it does not support coups and small thicknesses would break easily.

The design of proportional control allowed position elbow joint, achieving angles with an average error of 2.37 degrees and a response from the system of 74ms.

Carried out the performance tests of elbow joint was observed that the consumption of current and voltage actuators is similar looking with the device without load and with a maximum load of 0.5 kg in the hand.

5. RECOMMENDATION.

Verify that supply voltage is energized the H bridge so it is according to the voltage specified by the manufacturer to avoid damage in the same and the actuator

The power supply for the part of power must be different than the control since when actuators come into operation they adsorb much energy and cause a malfunction of the control elements.

Prevent batteries from downloaded in their entirety since they would lose the possibility to load again and would be useless.

Use another type of sensor that detects the position of the joint, because that used to be a mechanical device is likely to deteriorate, causing failures at the time of controlling the movements.

6. GRATITUDE.

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