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Design of Pneumatic Prosthetic Arm

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Abstract: *The Pneumatic actuated exoskeleton is getting important to humans in many aspects such as power assist, muscle training, pneumatic functioning and rehabilitation. The research and development towards these functions are expected to be combined and integrated with the human intelligent and machine power, eventually becoming another generation of robot which will enhance the machine intelligence and human power. This paper reviews the upper extremity pneumatic exoskeleton with different functions, actuators and degree of freedom (DOF). Among the functions, rehabilitation and power assist have been highlighted while pneumatic actuator, solenoid valve and pneumatic circuit are presented under the categories of components. In addition, the structure of exoskeleton is separated by its DOF in terms of shoulder, elbow, wrist and hand.*

Keywords: *Exoskeleton, Power-assist, Rehabilitation and Upper extremity*

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I. Introduction

The designing of fully functioning pneumatic prosthetic arm with coordinating speed of response and strength is the aim of upper extremity prosthetics research. Unfortunately, current prosthetic arms and collaborating techniques are still a long way from this aim. The current state-of-the-art prosthesis can be considered to be a tool rather than an upper limb replacement. The pneumatic prosthesis as a tool makes no pretense of replacing the lost arm but tries to replace some functions that were lost. The prosthesis is the device which can be worn as per will and can be removed when not wanted. Many efforts in this field are taken to make pneumatic prosthetic as a ideal upper limb replacement, however, current prosthetic arms are limited to be used as tools. The major factors limiting pneumatic prosthesis to tools are practical ones due to the heavy weight, less power, and size of the component as well as the difficulty in finding appropriate control sources to control the number of degrees of freedom. Of these the important drawback is the latter one. As a result, upper-limb prosthetics research is dominated by considerations of appropriate controls for controlling the degrees of freedom. Still, the importance of better pneumatic actuators and better multifunctional mechanisms cannot be ignored.

Current pneumatic prosthetic arm are of single degree of freedom. Generally, vision is the primary source of feedback for the device, the number of functions that are controlled in parallel at one time is two. Otherwise, the mental loading becomes excessive and impossible. Switch, pneumatic actuators, control valves are the primary modes of control for today's upper-limb prosthetic arms.[1] The upper limb prosthetic arms are developed according the tasks they need to perform or according to type of person whom it is wore by. The pneumatic prosthetic exoskeleton used for giving additional strength to normal people in order to make them do extreme work. Therefore pneumatic prosthetic arm has found its applications in military personnel and heavy industry personnel. The exoskeleton also finds its application in physically weak people to regain their power they lost after stroke. [2]

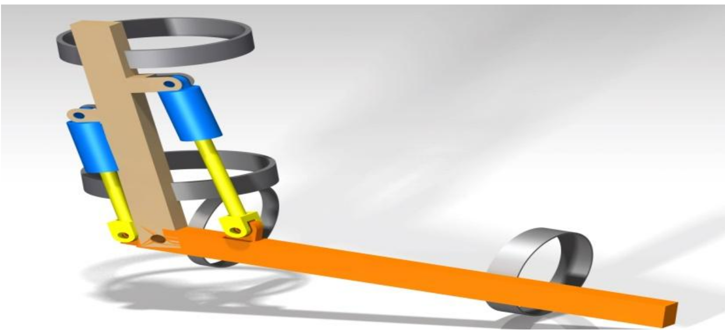

Fig. 1. Pneumatic prosthetic arm

Generally speaking, the shortcomings of the arm prostheses that are now clinically available are the following: The pneumatic prosthetic arm has far fewer degrees of freedom than the normal arm for which they are intended to act as substitute. Thus they perform certain tasks in difficult manner and in some cases only with great difficulty for the amputee. The controls for a given motion are not related to the actions of a normal person which cause the corresponding motion of a normal arm. For example, flexion of the "elbow" of the pneumatic prosthetic arm may result only from movement of the shoulder of the amputee whereas in a normal person elbow and shoulder motions are independent. The result of this is that the amputee must learn an entirely new pattern of activity in order to make the pneumatic prosthetic arm useful to him, and his ultimate performance is often limited because the degree of freedom which is required are few, and the constraints of the control system are so many.[3]

II. Methodology

The methodology adopted to carry out the project is as follows:
1. Problem definition.
2. Available data.
3. Assumptions.
4. Solution.
5. Pneumatic actuator design.
6. Material selection.

2.1Problem Defınıtıon

Designing of mechanical structure with single degree of freedom which can be wear on hand. Structure can sustain with 15 kg mass.

2.2Available Data

Length of fore arm 260 mm and bicep's length 250 mm. Load 15 X 9.81 = 148N . Material: Aluminium.
Ultimate Tensile Strength : 310 MPa.
Tensile Yield Strength : 276 MPa.
Young's modules of elasticity: 69Gpa

2.3Assumptıons

Thickness of links = 3mm, Width of link = 40mm.
Gıven Data
Material is Aluminium and Properties of Aluminium:
Ultimate tensile stress =310MPa
Tensile yield strength =270MPa
Link fore arm length =260mm and
Link bicep length = 250mm
Assume
Width is 40mm. here we select width 40mm because it is optimum for mounting on almost all type of hands.
For first iteration we take 3mm thickness.(b = 3mm.)
Load for lifting = 15 Kg.
Structure is under elastic limit.
Factor of safety =1.8

2.4 Solutıon
Free body diagram:

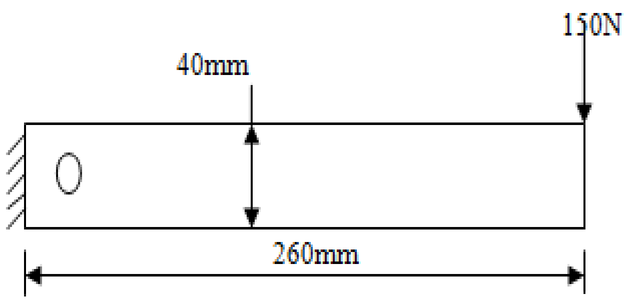

Fig. 2. Lower Lınk Dımensıons

Loading condition for lower link :
Force=15kg*9.81N=147.15N
Take force=150N.
Bending Moment: Bending moment = 150 X 260 = 39000 Nmm
Bending moment diagram:
a. Now we take thickness 4mm.(b = 4mm.)
Bending Stress:
σ_b = M*y / I
y = distance from neutral axis to extreme edge of lower link.(mm)
$=\frac{40}{2}$ =20mm
I = moment of inertia about the axis (mm^4).
$= \frac{bh^3}{12}$
$=\frac{3*40^3}{12}$
=16000 mm^4
$\sigma_b = \frac{39000*20}{16000}$
σ_b = 48.75 N/mm^2.
i. Ultimate bending stress with factor of safety (1.8): 310*0.5 = 155N/mm^2.
ii. Standard bending stress:
$\sigma_{std} = \frac{155*0.5}{1.8}$ = 43.055N/mm^2 .
Therefore,
$\sigma_b > \sigma_{std}$
Hence assumed thickness(3 mm) is not safe for given load condition.

b. Now we take thickness 4mm.(b = 4mm.)
i. Bending Stress:
σ_b = M*y / I
y = distance from neutral axis to extreme edge of member (mm)=$\frac{40}{2}$=20mm.
I = moment of inertia about the axis (mm4).
$= \frac{bh^3}{12}$
$=\frac{4*40^3}{12}$
= 21333.33 mm^4.
$\sigma_b = \frac{39000*20}{21333.33}$
σ_b = 36.56 N/mm^2.
ii. Ultimate bending stress with factor of safety (1.8):$\frac{310}{0.5}$=155 N/mm^2.
iii. Standard bending stress:
$\sigma_{std} = \frac{155*0.5}{211.8333.33}$ = 43.055N/mm^2

Therefore,
$\sigma_b < \sigma_{std}$

Hence thickness(4 mm) is safe for the given load condition.

2.5 Pneumatic Actuator Design

The Pneumatic circuit consists of 2 double acting cylinders connected in circuit. The cylinders are controlled by 5/2 control valves each connected to the cylinder.

Pneumatic Actuator Dimensions:
Assume force (20Kg)
Force =20 x9.81 = 196.2N ≈ 200N.
Pressure = force/area
Standard sizes available = 10, 12, 14, 16.
a) 10mm bore:

Pressure = 200/(3.14 *10^2/4)
Pressure = 2.35 N/mm^2

b) 16 mm bore
Pressure = 200/3.14*16^2/4)
Pressure = 0.995 N/mm^2

Hence according to minimum pressure requirement we select 16 mm bore diameter cylinder.
In 16 mm there are three types:

a. 50mm stroke
b. 75mm stroke
c. 120 mm stroke

For optimum design and cost reduction we select 75mm stroke.
Cylinder operating pressure:
Dimensions of cylinder:

i. Diameter = 16mm.
ii. Stroke length =75mm and 100mm.
iii. Area = 200.96 mm^2.
iv. Force=150N.

Pressure = force/area.
Pressure = 150/200.96
Pressure = 0.7464 N/mm^2 ≈ .75N/mm^2.
Hence cylinders having operating pressure more than .75Mpa. are taken.

2.6 Materıals Selectıon

2.6.1Upper Link

Upper link is made of Aluminium. Length of upper link is that of bicep length and that is 250mm. The width of the link is 40mm and the thickness is 4mm. As shown in above figure Velcro straps are put for wearing it in the arm. Upper link is connected at one end to the lower link.

2.6.2Lower Link

Lower link is made of Aluminium. The length of lower link is 260mm. The thickness of the link is 4mm and the width is 40mm. Two Velcro straps are attached to the link as shown in the figure.

2.6.3Pneumatic Actuator

Pneumatic actuator is made of Aeroflex Company. It is 16mm bore and 75mm stroke. The pressure range is 0.1 to 1.1 MPa. Two actuators are used in the prosthetic arm. It is linked between upper link and lower link.

2.6.4 Solenoid Control Valve

Solenoid valve is used as the control valve in the pneumatic circuit. It is a 5/2 direct control valve which is solenoid actuated. The two positions of one end are connected to the two pneumatic actuators. At the other end middle position is connected to the air storage tank. Other two ends act as exhaust for the air coming out from the actuators.

2.6.5 Air Reservoir

Air reservoir is used for storage of air under pressure. It is made of mild steel. The pressure inside the cylinder is 3 to 5 N/mm^2. It supplies air to the pneumatic actuators through control valve.

Working Of Pneumatic Circuit

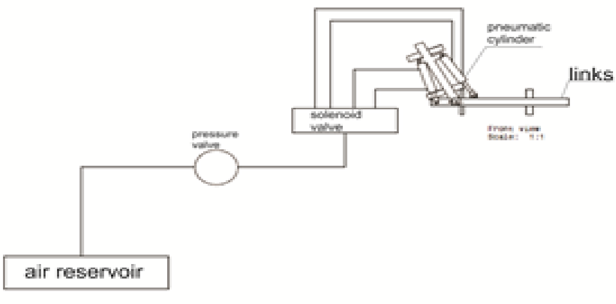

Fig.3 Pnuematıc Cırcuıt

Working- When link turns through some angle, angle sensor detected the motion. Sensor sends this data to controller and solenoid valve activate. Compressed air in reservoir passes through valve and enters in pneumatic actuator. According to its position cylinder move the links. One link turns its full range angle the another solenoid valve open and pneumatic actuator moves in reverse direction.

III. Result And Discussion

The pneumatic prosthetic arm is designed in CATIA. The designed arm is used to lift 15 kg load. Therefore the lower link thickness is mathematically calculated and taken as 4mm. The static structural analysis in ANSYS proves that thickness 4mm is safe and the design is safe from failure.

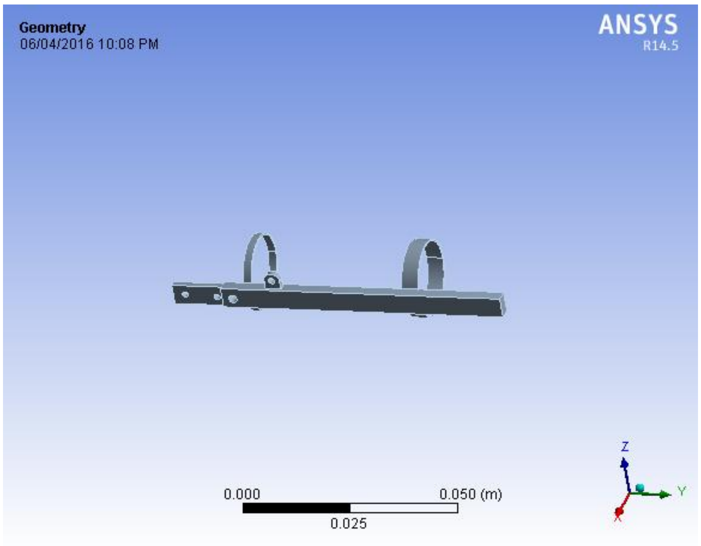

Fig.4 Lower Link

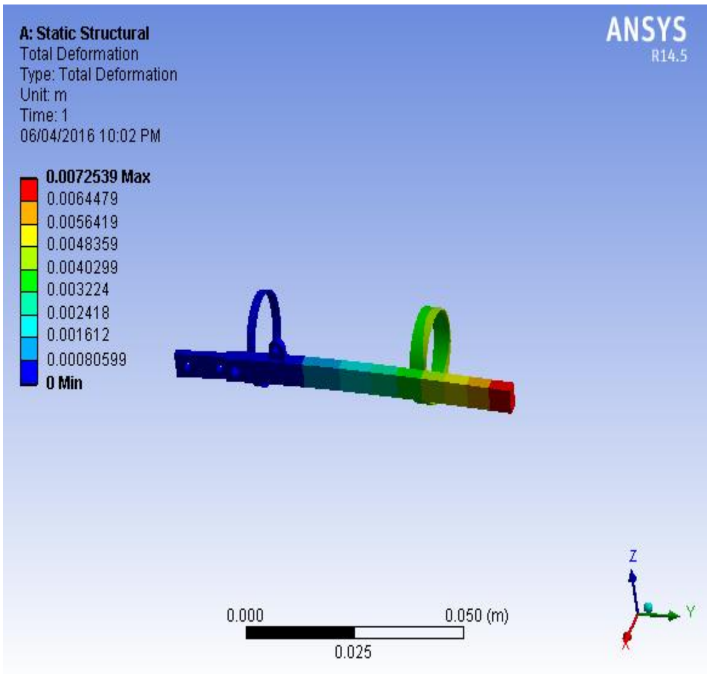

Fig.5 Total Deformatıon Of Lower Lınk

The lower link is subjected to downward force of 150N acting at the end and at the other end where pin is situated which connects the upper link to lower link ,that end acts as the fixed support. Accordingly static analysis is done and the results are displayed in form of total deformation, maximum principal stress and maximum principal strain.

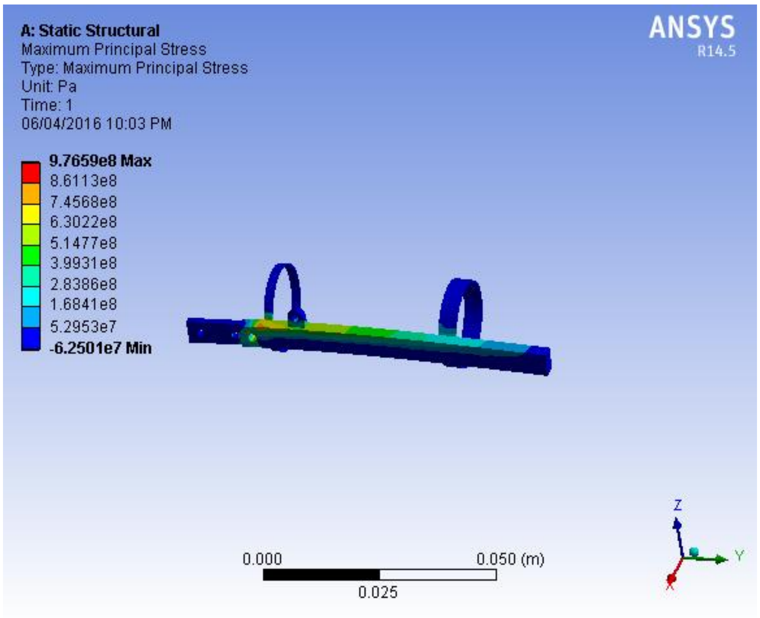

Fig.6 Maximum Principal Stress of Lower Link

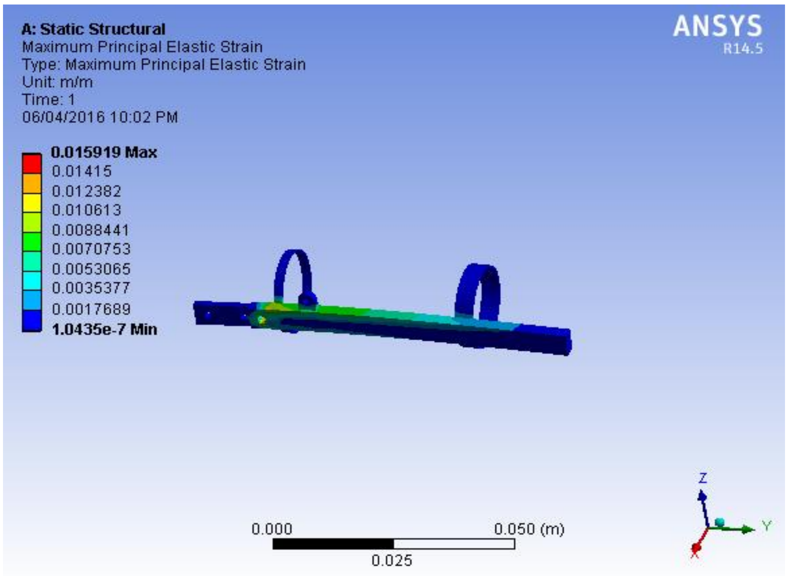

Fig.7 Maximum Principal Strain of Lower Link

Total deformation, maximum principal stress and maximum principal strain analysis prove that the design is safe and the materials used are safe from failure.

IV. Conclusion

It can be seen from the survey that most of the advanced work in this field has been done in recent decades and many of the outcomes have been demonstrated in wired environments. Because not all of the technical components are well developed enough or packaged for use in daily life and in outdoors applications, a combined amount of cooperative work and use of resources from medical technology, biomechanics, engineering, and product development are required. Power source technologies and reliable wireless technologies so that it is comfortable for outdoor chores must be resolved. Ensuring the portability of the pneumatic hand exoskeleton system is possibly the most challenging part of the development. In the review, it is found that the focus is on a single DOF at a single joint while a look at the system design of whole upper extremity and even carry out a whole body suit exoskeleton is needed. No matter how many DOFs are included in the exoskeleton, the exoskeleton is benefiting the human. Further review is needed on exoskeleton control system so that it might help to understand more about the exoskeleton.

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