International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 05 Issue: 05 | May-2018 www.irjet.net p-ISSN: 2395-0072

DESIGN AND FABRICATION OF ASSISTIVE EXOSKELETON

Abhay S Roy[1], Ashish Gejo[2], Aswath MK[3], Mithun S[4], Prof. Ernest Markose Mathew[5]

[1,2,3,4] B. Tech Student, Dept. of Mechanical Engineering, Mar Athanasius College of Engineering, Kerala, India
[5]Professor, Dept. of Mechanical Engineering, Mar Athanasius College of Engineering, Kerala, India

***

Abstract - *An exoskeleton is structure consists of joints and links similar to those of the human body. Exoskeleton robotic system is a feasible solution that can help people with locomotion difficulties walk again. This system equipped around the human body can support the load and a part of the body weight, enlarging the load bearing capacity and endurance of the biological system. The exoskeleton system basic needs are continuous power supply, simple kinetic energy transmission, degree of freedom of motions. The exoskeleton component design is based on the movement of human body. While loading exoskeleton it transfer 80% of the load to the ground. Exoskeleton helps to reduce the stress on back and shoulder while loading. They are oriented into different usages - both industrial and medical purposes. The product of this project is the basis of future powered exoskeleton, where it can make a huge impact on industry and research field. By studying the present technology and designs we fabricated portable, lightweight and easy to wear assistive exoskeletons*

Key Words: Exoskeleton, industrial purposes, lightweight, portable

1. INTRODUCTION

Early concepts of exoskeletons have been developed in the late 20th century from many novels of man-machine systems. The developments achieved by exoskeleton gave new energy to mechanical and electronic engineering, material science automation technology and biological science. In industrial area, exoskeleton assists a worker to lift and carries heavier loads. It helps a soldier to fight better with protected armor and well equipped with more weapons and more strength than a normal people have. The idea for exoskeleton was derived from fictions and movies. In this paper, our focus is more on industrial side for helping the workers to lift the tool by the help of assistive exoskeletons.

1.1 Literature Review

From the middle of 18th century onwards ideas regarding basic model of exoskeleton was studied. But they were all confined to paper works. Never actually build or tested. Earliest device similar to exoskeleton was found in 1890. It as a simple design of bow spring working parallel to our legs. This then lead to full body powered exoskeleton prototype. That exoskeleton was hydraulically powered. It helps to amplify the strength of arm.

The device can bring drastic changes in the industrial field. Most of the machine we use are heavy to lift. The workers have to work for long hours carrying this load. This may lead to muscle cramps etc. It reduces the efficiency of their work and can affect productivity. By supporting the tool by using exoskeleton they can transfer the weight of the tool to the ground. This helps to work more effectively.

Ackreman et al (2015) we find the most effective way to minimize the natural frequency by using metal coil spring. The spring can be used to adjust the mass that we can lift. The device helps to load and position a tool at a particular height during different activities

Atenburger et al (2016) a passive parallelogram arm mechanism is introduced. The additional mechanism has two favorable feature. It exhibit iso-elasticity behavior where by the lifting force is a constant for a wide range. By adjusting the supporting joints the value of supporting force can be varied.

MJ French et al (2000) spring and lever balancing mechanism was studied. Perfect balancing can be achieved by the use of closed coil spring. Its free length is affectively zero.

J Ponsed et al, (2008) the resultant motion on operating a mechanism is determine by the kinematic joints connecting members of the mechanism.

1.2 Problem Statement

Exoskeleton can readily be found in certain fields and their development to date has been mainly driven by industrial, military and medical applications. However such models are inadequate for industrial purposes due to excessive weight or lack of functionality, such as being unable to provide the lifting and maintaining handling support essential to the industrial settings. Therefore, developing an exoskeleton specially destined for use in industrial environment is crucial.

2. METHODOLOGY

Design phase:

- Selection of spring
- Design of arm
- Optimisation

Analysis:

- CFD Analysis

Fabrication:

- Procurement of components
- Fabrication and field testing

3. DESIGN

3.1 SELECTION OF SPRING

An arm mechanism should have a low mechanical impedance. To isolate vibration and reject disturbances, a stabilizing arm mechanism should have a low natural frequency. Both of these objectives can be obtained in one system by achieving a low effective stiffness.

In a linear spring–mass–damper system, the natural frequency is

$$\omega_n = \sqrt{\frac{k}{m}}$$

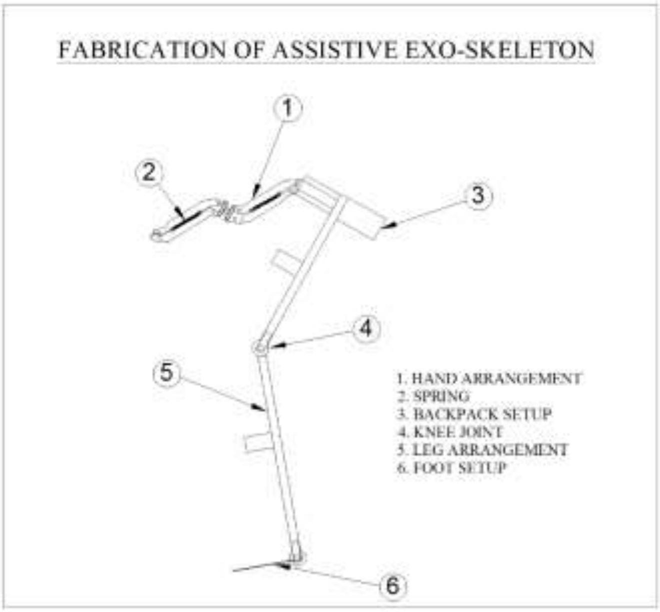
Statically, the load weight must be equal to the linear spring force

$$F_0 = mg = k\Delta x$$

The static spring deflection can then be related to the natural frequency

$$\Delta x = \frac{g}{\omega^2}$$

Minimizing the natural frequency significantly increases the effective static spring deflection. Metal coil springs are well-understood, offer predictable performance, have low damping, and are cost effective. So spring made of mild steel are used.



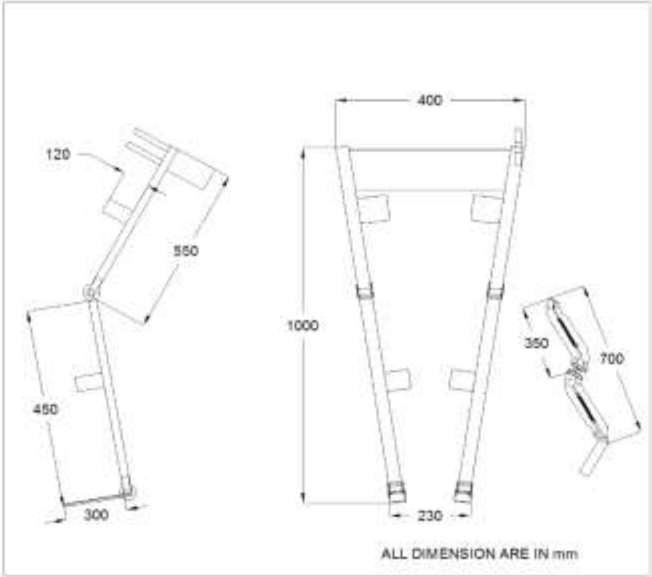


Fig-1:2D drawing

Longer linkage lengths will increase the overall range of motion of the load mass. This may be an important consideration for certain applications, such as positioning a camera, a tool, or an arm about its vertical static equilibrium position. Longer linkage lengths also increase the physical envelope of the device and reduce the range of acceptable load masses. If the linkage length cannot be made longer to increase the range of motion, then multiple shorter stabilizing arm segments can be attached in series.

Parameter	Measured value from exoskeleton arm
Net mechanism mass	4.5kg
Arm lift adjustment, r	0.005-0.045m
Linkage length, L	0.28m
Other mechanism lengths, L_1, L_2, L_3	0.18m, 0.13m, 0.06m
Vertical linkage shaft height, H	0.045m
Wire diameter, d	0.005m
Outer diameter, D	0.035m
Number of coils, n	18
Nominal spring length, l_o	0.2m
Wire modulus of elasticity, E	193×10^9 pa
wire modulus of rigidity, G	80×10^9 pa
Spring stiffness, k	11,733N/m
Spring damping, b	100N s/m

Table-1: Measured parameter of the exoskeleton arm

From the table-1

Spring stiffness, $k = \frac{d^4G}{8D^3n} = 11733N/m$

The simulation data was processed using MATLAB. The damped natural frequency of the stabilizing arm was calculated using the logarithmic decrement method. The natural frequency was approximately equal to the damped natural frequency because the damping ratio for all simulations was less than ~0.05.

3.2 DESIGN OF ARM

The design of arm of the assistive exoskeleton targets the arm of the exoskeleton. For this exoskeleton sensors and powered actuators are not used. The force need to lift the tool is obtained by the spring forces only. The minimum supporting force loaded by the spring is 40N ie; the weight of the arm. This arm range should cover ±45◦ from a horizontal position.

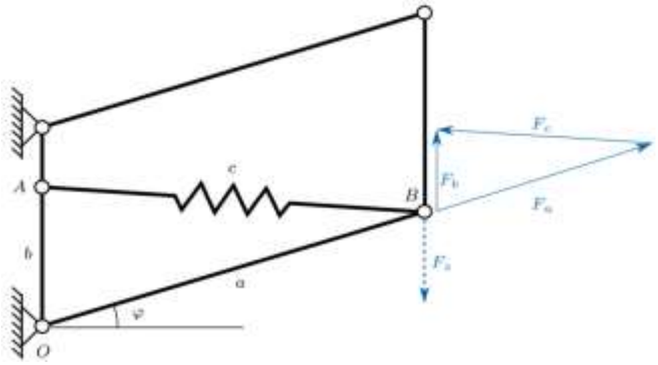


Fig.2: Standard parallelogram layout with metal spring

A load F acts in the z-direction on the right bar. The resulting forces calculated in the lengths a, b, c using vector addition is

$$\frac{F_a}{a} = \frac{F_b}{b} = \frac{F_c}{c}$$

In equilibrium, the force F_b will equal to load force, hence

$$F_b = -F$$

and the force in F_c is the restoring force generated by the spring. By assuming the spring is an ideal spring, the force is

$$F_c = F_{spring} = k \times c$$

where k is the spring constant. Considering the above assumption, the lifting force F_b is

$$F_b = \frac{b}{c}F_{spring} = \frac{b}{c}kc = kb = const.$$

Since F_b is a constant so no force or torque is required to balance the weight within its workforce for load F. This property is called iso-elasticity.

Actually the ideal springs are very difficult to produce so a tension spring is required to produce the ideal spring characteristics of load F_0. The restoring force needs are

$$F'_{spring} = k(c - l_0) + F_0$$

The lifting force F_b ,

$$F_b = \frac{b}{c}F'_{spring} = \frac{b}{c}[k(c - l_0) + F_0]$$

$$= \frac{b}{c}(F_0 - kl_0) + kb$$

Where c is,

$$c = \sqrt{a^2 + b^2 - 2ab\sin(\varphi)}$$

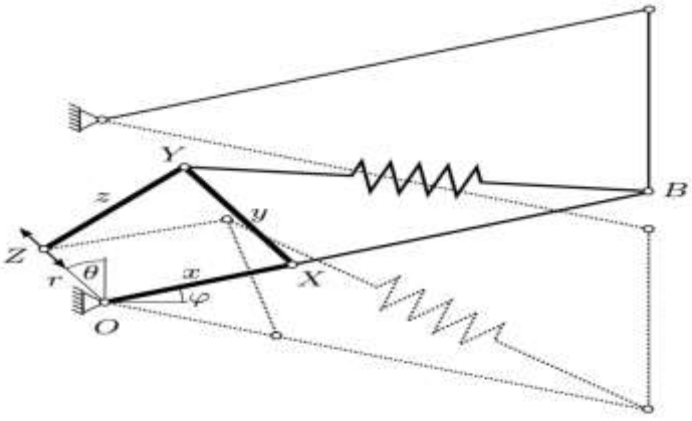


Fig-3: Parallelogram with 4-link mechanism

If we consider the standard parallelogram behavior with real values of the spring, the spring force are too low for small extension and too high for large extension. This problem is solved by the addition of 4-link mechanism in which y, z and r are the additional bars which is given to the standard parallelogram. In the 4-link mechanism, the length r can be adjusted while length x, y, z are constant

Fig-4 defined the angles and lengths. Taking the sum of moments around the origin O, the resultant force F is:

$$F a \cos(\varphi) + F_y x \sin(\alpha) - F_c x \sin(\beta) = 0$$

$$F = \frac{F_c a \sin(\beta) - F_y x \sin(\alpha)}{a \cos(\varphi)}$$

where F_c and F_y are the spring force and the force in bar y, respectively. Using the Fig-4, the force F_y is:

$$F_y = \frac{F_c \sin(\gamma + \alpha - \beta)}{\sin(\gamma)}$$

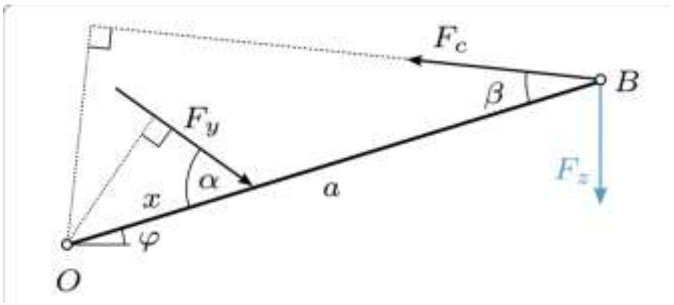


Fig-4 the forces acting around the origin O

By substituting F_y , the final resultant force as a function of spring force F_c and internal angles is:

$$F = \left(\frac{\sin(\beta)}{\cos(\varphi)} - \frac{x \sin(\gamma + \alpha - \beta) \sin(\alpha)}{a \sin(\gamma) \cos(\varphi)} \right)$$

3.3 OPTIMISATION

A design optimization problem is formulated. For practical reasons, it was decided to move point Z on a straight line starting at origin O to vary the supporting force F_z. The pitch angle θ is introduced as an additional parameter to be optimized. The length r should vary from 5 mm (40 N support) to approximately 45 mm (120 N support). The working range of the parallelogram is between φ = −45◦ ... + 45◦.

The optimization is done using Matlab .The optimized geometrical parameters are x = 58.2 mm, y = 72.9 mm, z = 94.3 mm and θ = 51.4◦. Then find the counter force required to lift the tool by keeping the F_c at constant value (F_c=5 kg) and by varying r= 5mm to 45 mm at different positions of the φ and by keeping r = 5mm by varying load F_c (2, 5, 7, 9 kg) at different positions of φ.

4. ANALYSIS

The analysis of arm of exoskeleton is done with the help of ANSYS 16.2 Fluent software. The result obtained is clearly says that it can withstand at given loads.

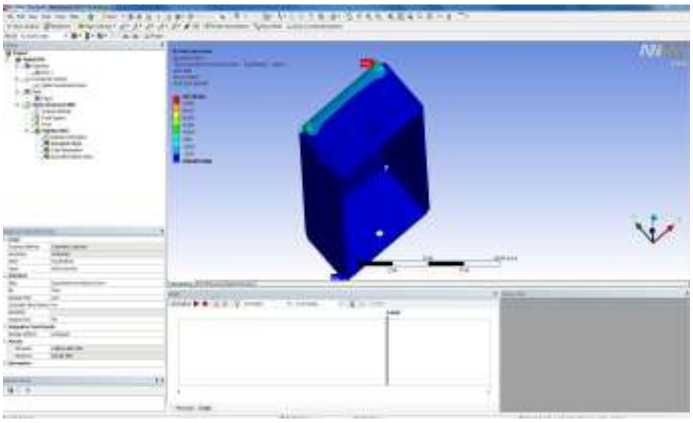


Fig-6: Total shear stress analysis

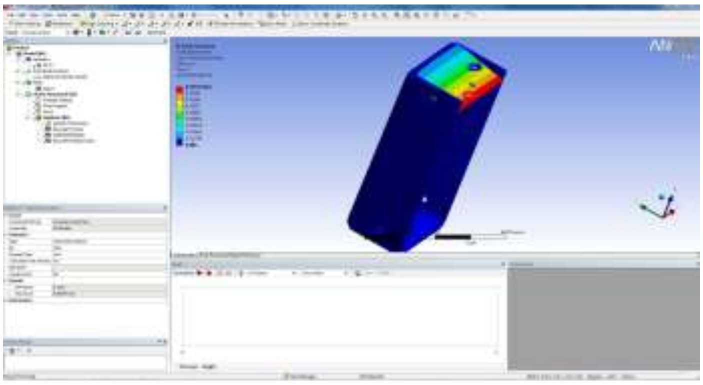


Fig-7: Deformation analysis

5. FABRICATION

The design was analyzed and approved, then we started the fabrication part. The fabrication includes the fabrication of arm and body part.

5.1 MATERIALS USED

Sl No.	Parts	Qty	Material
1	Frame	-	MS
2	Bearing	2	Steel
3	Arm	1	Steel
4	Links	-	Steel
5	Leg support	2	Steel

Table-2: Material chart

5.2 FABRICATED MODEL

This is the fabricated model of assistive exo-skeleton. Here arm is properly designed such it can take the given loads.

Fig-6: Fabricated model

6. RESULTS AND CONCLUSION

6.1 EXPERIMENTAL DETAILS

Experiment were carried out to verify the behavior of the developed system. Using different weights and a spring balance, the effective lifting force at 7 different angles φ were measured. The force was applied with a hand held spring scale. The spring characteristics was validated on a tensile testing machine. The values of the spring characteristics in the optimization was taken from the datasheet and was: length l_0 = 0.2m, preload force: F_0 = 115 N, spring constant: c = 11733N/m.

6.1.1 By keeping r at constant value (r=5mm)

The moving distance r kept at constant value of 5mm then different weights are 20, 50, 70, 90 N are given as load. The supporting force tends to higher values at larger angles φ.

6.1.2 By keeping F_c at constant value (F_c = 5kg)

The resulting force values at the end effector for different angles φ and at constant F_c = 5kg by varying distance r from 5 ... 45 mm.Nearly perfect iso-elastic behavior can be reached by applying small lifting forces. The maximum force at 120 N shows a variation of ±3.2 N for positions φ =−45◦ ...45◦.

6.2 RESULT AND OBSERVATIONS

6.2.1 When r=5mm

F_c=2kg		F_c=5kg		F_c=7kg		F_c=9kg	
Φ(deg)	F(N)	Φ(deg)	F(N)	Φ(deg)	F(N)	Φ(deg)	F(N)
-45	30	-45	62	-45	84	-45	100
-30	28	-30	58	-30	78	-30	98
-15	27	-15	56	-15	76	-15	96
0	27	0	54	0	74	0	96
15	28	15	56	15	76	15	98
30	29	30	58	30	78	30	98
45	30	45	60	45	80	45	100

Table-3: Lifting/Supporting force required at different position angle φ at r=5mm

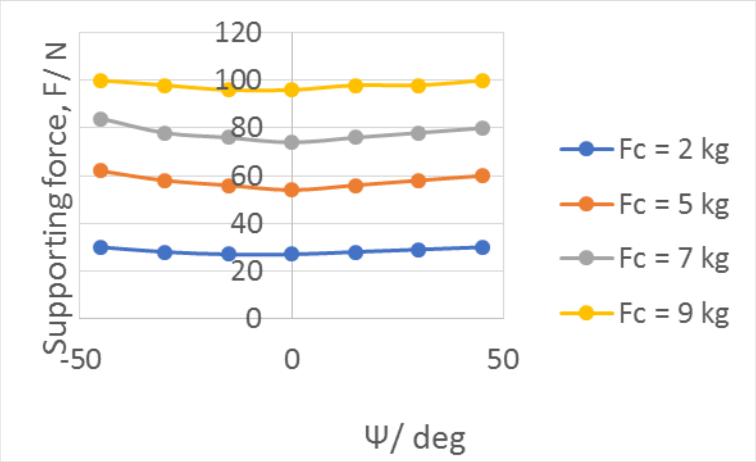


Fig-7: Position angle, φ vs Supporting Force, F

6.2.2 When F_c=5kg

r = 5mm		r=15mm		r=25mm		r = 35mm		r = 45mm	
Φ(deg)	F(N)	Φ(deg)	F(N)	Φ(deg)	F(N)	Φ(deg)	F(N)	Φ(deg)	F(N)
-45	18	-45	55	-45	81	-45	102	-45	116
-30	18	-30	54	-30	78	-30	97	-30	115
-15	18	-15	52	-15	76	-15	97	-15	116
0	18	0	50	0	74	0	98	0	118
15	18	15	52	15	76	15	99	15	120
30	19	30	54	30	78	30	100	30	119
45	20	45	57	45	80	45	99	45	110

Table-4: Lifting/Supporting force required at different position angles at F_c=5kg

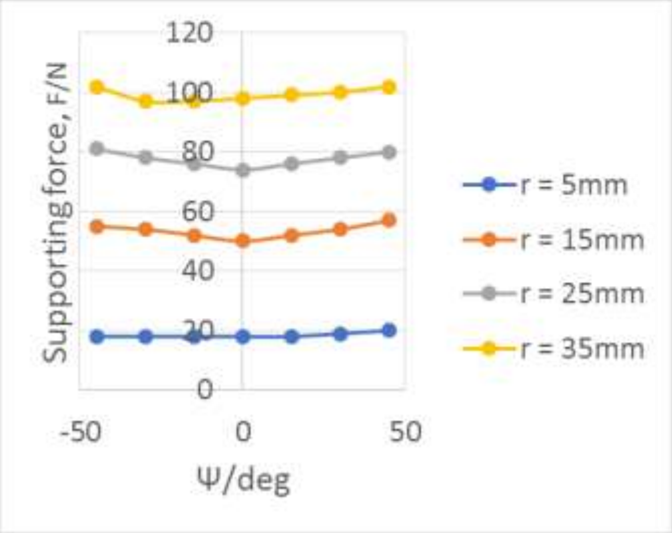


Fig-8: Position angle, φ vs Supporting Force, F

6.3 CONCLUSIONS

The arrived design shows close to iso-elastic behavior over a wide operating range . It is also adjustable for loads in the range of 40–120 N. This makes the mechanism a lightweight exoskeleton arm, which is fully passive but still is powerful to support significant weight. The same mechanism can be used to balance an object such as tools. The design is ideal for supporting the user's posture and for lower load weights. The design optimization approach provided an efficient framework for selecting the best parameters. Future developments lies in further reducing the weight and designing multiple forms of the exoskeleton arm which is to be more suitable for specific tasks.

This project work has provided us an excellent opportunity and experience, to use our limited knowledge. We achieved a lot of practical knowledge on planning, assembling and machining while completing this project.

We are proud that we have completed the work with the time successfully. The "DESIGN AND FABRICATION OF ASSISTIVE EXO-SKELETON" is working with satisfactory conditions. We are able to understand the difficulties in maintaining the tolerances and also the quality.

REFERENCES

[1] French MJ, "The spring-and-lever balancing mechanism, george carwardine and the anglepoise lamp. Proc Inst Mech Eng", 2000, Elsevier

[2] Carwardine G, "Improvements of elastic force mechanisms. UK Patent Specification", 2016, Elsevier

[3] Lu Q, "Passive gravity compensation mechanisms: technologies and applications", 2011, Elsevier

[4] Ackerman, "Design of stabilizing arm mechanisms for carrying and positioning loads", 2015, Elsevier