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Design and Development of Upper Limb Exoskeleton Arm

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Abstract
Our team is designing and developing the Upper Limb Exoskeleton Arm which will be fitting on the right hand. Our model is based on Mechatronics Domain. Though this system exist in the market, the model present in the market is bulky, expensive and more complex to use. The main challenge in front of our team is to build an arm which will be fully automated, light in weight and economical. We are planning to develop an arm which will be mainly focusing on the Indian market. The arm will be used by common workers in industries, handicapped people and also the doctor in medical field. We will be designing and fabricating pneumatically powered exoskeleton arm to assist the physically weak individuals. We will be applying the concepts of engineering which we have learnt in our undergraduate program to make this model. In the present work a comprehensive design and fabrication of hand exoskeleton technologies for rehabilitation and assistive engineering were made from the basic hand biomechanics to actuator technology with the involvement of mechanical power. This project aims to accelerate the upper limb rehabilitation speed for hemiplegia and disability caused by stroke and other diseases and designs an arm-assisted rehabilitation exoskeleton robot.
Key Words: *Exoskeleton, rehabilitation,upper limb.*

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I. INTRODUCTION

An exoskeleton arm, such as Excelsior's exoskeleton suit, is an external mechanical structure that is worn by a person to enhance their physical abilities. It typically consists of an outer framework and a powered system of pneumatic artificial muscles or fluidic muscles. The exoskeleton suit is designed to transfer mechanical power from the exoskeleton structure to the human arm, helping and augmenting the user's strength, endurance, and durability. Exoskeleton suits have various applications, including military use to help soldiers carry heavy loads, both in combat situations and during training. In civilian areas, exoskeleton technology can assist firefighters and rescue workers in navigating dangerous environments by providing additional strength and protection. The medical field also benefits from exoskeletons, as they can be used for enhanced precision during surgical procedures or to aid nurses in moving heavy patients. To ensure safety and environmental concerns, exoskeleton suits like Excelsior's are designed using recyclable, lightweight, and durable materials. These considerations help minimize the impact on the environment while ensuring the longevity and reliability of the exoskeleton system. Overall, exoskeleton technology has the potential to revolutionize various fields by enhancing human capabilities and improving productivity and safety in physically demanding tasks. Upper limb exoskeleton arm is innovative field focuses on creating external mechanical structures that enhance the capabilities of the human arm, helping and augmenting strength, endurance, and functionality. Upper limb exoskeleton arms have promising applications in rehabilitation, assistive engineering, and various industries where physically demanding tasks are common.

The inherent complexity and mobility of the human shoulder joint make it particularly prone to injuries. As a result, there is a growing need for exoskeleton technologies that can aid in the recovery and rehabilitation of individuals with upper limb impairments. Moreover, advancements in robotics and materials science have paved the way for the development of exoskeleton arms that can assist individuals in their daily activities, improve their quality of life, and restore independence. One of the key challenges in designing upper limb exoskeleton arms lies in replicating the intricate movements and dexterity of the human arm. The exoskeleton must provide a wide range of motion and precision control, allowing the wearer to perform tasks with ease and accuracy. Additionally, the exoskeleton arm should be lightweight, comfortable to wear, and capable of integrating seamlessly with the user's body to facilitate natural and intuitive movements. Safety is of paramount importance in the design and development of upper limb exoskeleton arms. These devices closely interact with the wearer, necessitating meticulous attention to detail to minimize the risk of malfunctions or unintended movements that could cause harm. Robust mechanical designs, reliable control systems, and fail-safe mechanisms are crucial to ensure the well-being and safety of the users.

Z. Li et.al[1] fdescribes in order to achieve minimal potential energy variation and accurate motion control of the upper-limb exoskeleton, we propose a novel motion planning strategy with minimal potential energy modulation. **M. A. Gull et.al[2]** provides a general classification, comparisons, and overview of the mechatronic designs of upper-limb exoskeletons. In addition, a brief overview of the control modalities for upper-limb exoskeletons is also presented in this paper. A discussion on the future directions of research is included. **Rhyan Andrad et.al**[3] has developed an exoskeleton controller for a prototype robotic arm, which is stand-alone, portable, programmable, and easy to maintain and use. The product of this project can become a basis for future exoskeleton controller designs. **Duha Qais Abdul-Amir et.al[4]** studies a smart arm exoskeleton robotic device that designed to perform the physical therapy for disabled patients in order to rehabilitate the affected limb. The basic principle of this exoskeleton is its dependence on electromyography signal myoware sensor was used to measure surface electromyography signal. **Rahul R. et al[5]** studied that a single robot arm has four actuators which lead to increase in the complexity and heaviness of the entire system. Soft exoskeletons combine the use of fabrics and a Bowden cable-driven actuation for motion transmission to directly induce or apply torques at the joints level. **Kwok-Hong Chay et.al[6]** proposes the exoskeleton structural mechanism for applications in rehabilitation medicine and virtual reality simulation, which offers benefits for both disabled and healthy populations. **S. Alabdulkarim et.al[7]** they compared different passive exoskeletal designs in terms of physical demands (maximum acceptable frequency = MAF, perceived discomfort, and muscular loading) and quality in a simulated overhead drilling task, and the moderating influence of tool mass (∼2 and ∼5 kg). **Caraiman. S et.al.[8]** describes a perceptual displacement device for the sight handicapped based on computer vision. Its primary goal is to provide users with a three dimensional depiction of the surroundings around them, which is delivered through the audible and tactile senses. **P. Maurice, et al.[9]**Work-related musculoskeletal disorders (WMSDs) are the first cause of occupational diseases in developed countries and represent a major health issue and an important cost for companies (Parent Thirion et al. 2012). WMSDs develop when biomechanical demands at work repeatedly exceed the worker's physical capacity (e.g., extreme postures, high efforts). **Surachai Panich et.al[10]** describes The kinematic exoskeleton suit for human arms is simulated by MATLAB software. The exoskeleton suit of human arm consists of one link length, three link twists, two link offsets and three joint angles. This project is used to increase the strength of human that can lift heavy load or help handicapped patients, who cannot use their arm. **E.A. Lomonova et.al[11]** The main objective of this paper to analyze the actuation principles in these systems. This actuated arm support systems are classified according to their user environment, namely: ambulatory, rehabilitation and industrial. Arm support systems provide support throughout daily tasks, training or in an industrial environment.

Designs of exoskeleton arm

Model

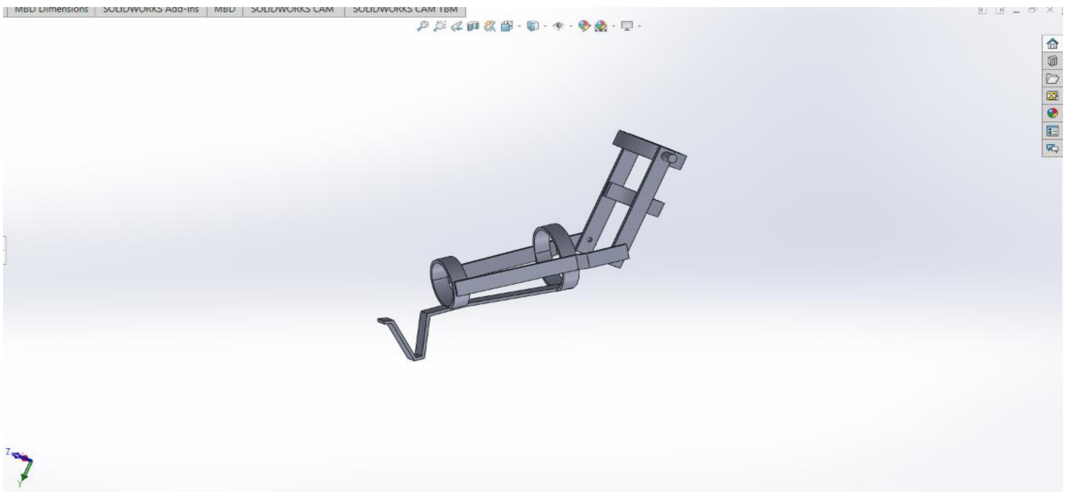

Fig no 1: Geometry of model

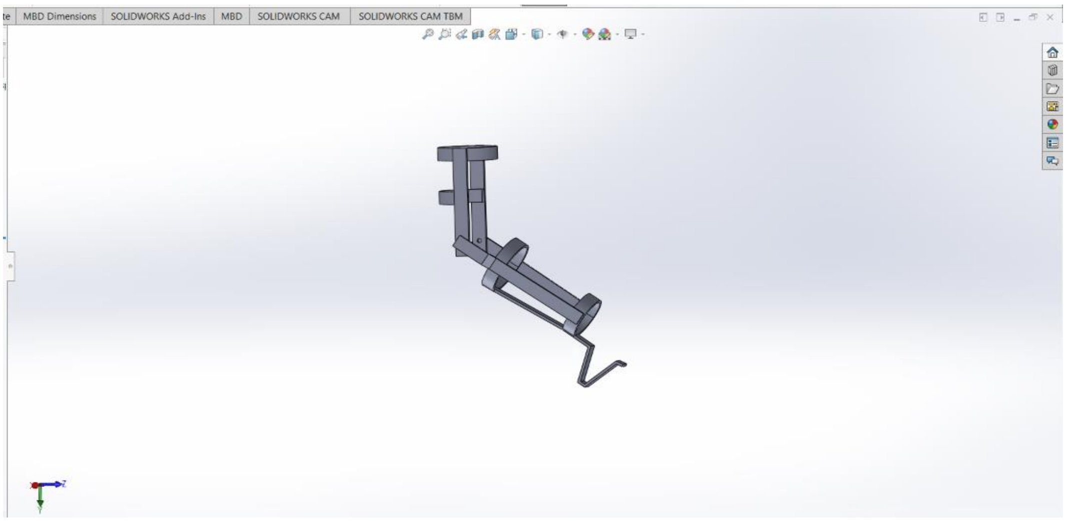

Fig no 2: Geometry of model

As per fig 1.The design is the final design made in CAD software Solidworks. show different views of the design. The design is made by keeping all the objectives stated above in mind. A hook is also designed and attached to the exoskeleton in the software. For the model firstly we select the aluminium as a material because of the it is light in weight and its cost is less as compared to other. The hook is attached the wrist side of the model so that the weight is lifted from front side after selecting strip for fitting drilling is done it. After that the nuts and bolts space are fitted on it. This is to make the exoskeleton sized accordingly.

Calculations:
Force exerted on the arm at the front side and at the back side of the elbow joint.

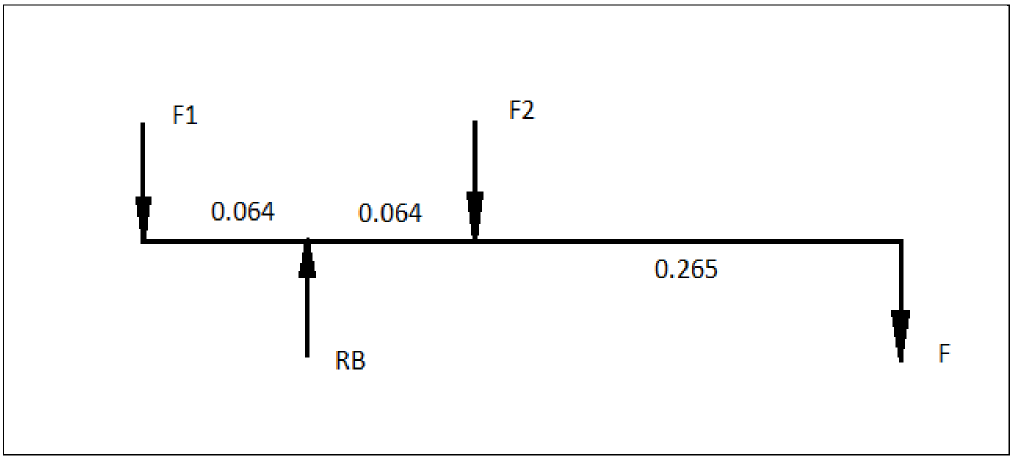

Fig No. 3: Stresses on arm

TAKING MOMENT ABOUT B

ΣMB=0

F×0.265–F2×0.064-F3×0.064=0

SINCE F2=F1 AND F=40×9.81=392.40 NEWTONS

392.40 ×0.265=2× F2 ×0.064

F1=F2=812.39 NEWTON

ΣFY=0

– F1+F2+RB–F=0

– 812.39+812.39 +RB –392.40 =0

RB=392.40 NEWTONS.

Arm material selection
Cantilever Beams are members that are supported from a single point only; typically with a Fixed Support. In order to ensure the structure is static, the support must be fixed; meaning it is able to support forces and moments in all directions.
Sample Cantilever Beam equations can be calculated from the following formulae, where:

Bending stress formula

$$\sigma = \frac{My}{I}$$

Where, σ = bending stress
M = bending moment (which is calculated by multiplying a force by the distance between the point of interest and the force),
y= The distance from the neutral axis
I= Moment of inertia

1.Cantilever Beams at square section

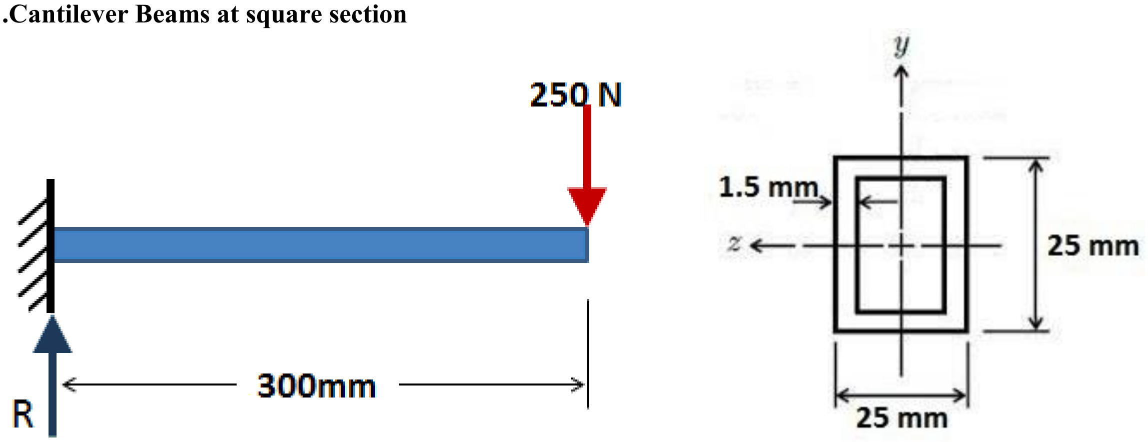

Fig No. 4 :- for cantilever beam at square section
Fig. Cantilever Beams at square section
- Load(W) = 250N
- Member Length(L) =300 mm
- Thickness(T) = 1.5 mm
- The distance from the neutral axis (y) =12.5 mm
- Width (B) = 25 mm
- Depth (D) = 25 mm

For Circular hollow section

$$I = \frac{BD^3}{12} - \frac{bd^3}{12}$$

$$y_{max} = \left(\frac{D}{2}\right)$$

$$Z = \frac{1}{6D}\left[BD^3 - bd^3\right]$$

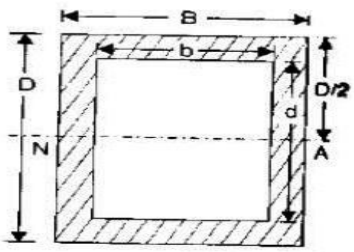

Fig No. 5 : hollow section

$$I = \frac{25 * 25^3}{12} - \frac{22.5 * 22.5^3}{12}$$

$$I = 390625 - 256289.0625$$

I=11419.6614
Y=12.5 mm
M_A -250*300 =0
M_A= 75000 N.mm

$$\sigma = \frac{My}{I}$$

$$\sigma = \frac{75000 * 12.5}{11419.6614}$$

σ = 82.09 N/mm^2

2. Simple Cantilever Beams

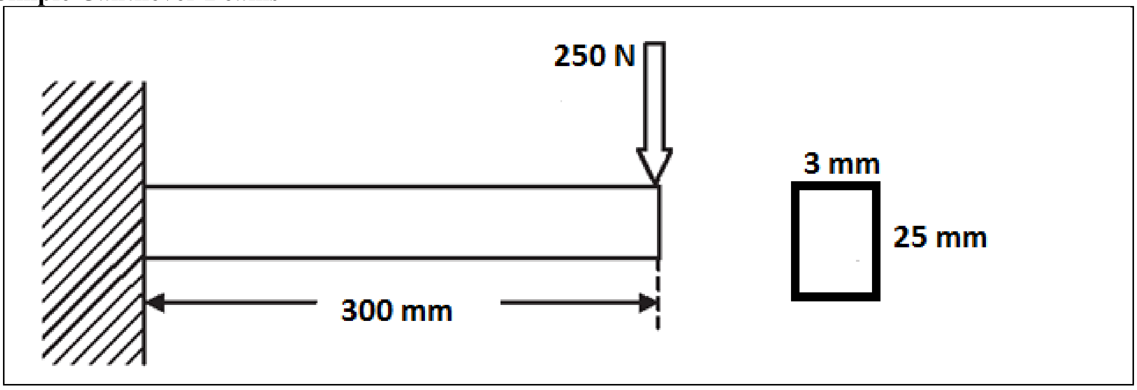

Fig No. 5:- for flat plate section

For flat plate section

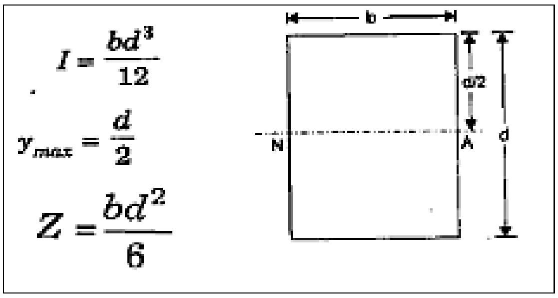

Fig No. 6: for flat plate

Bending stress $\sigma = \frac{My}{I}$

$$I = \frac{3 * 25^3}{12}$$

I=18.75 mm^4
Y=1.5 mm
M_A -250*300 =0
M_A= 75000 N.mm
$\sigma = \frac{75000*1.5}{3906.25}$
σ = 28.8 N/mm^2

3. Cantilever Beams at hollow tube

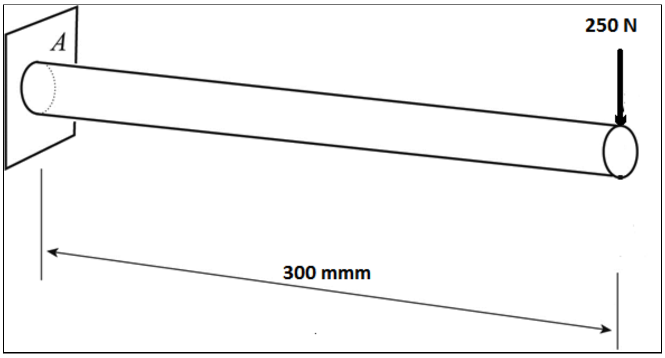

Fig No. 7:- for hollow tube

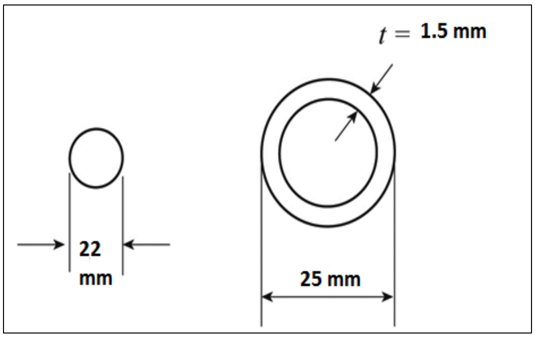

Fig NO. 8:- For circular hollow section

For Circular hollow section

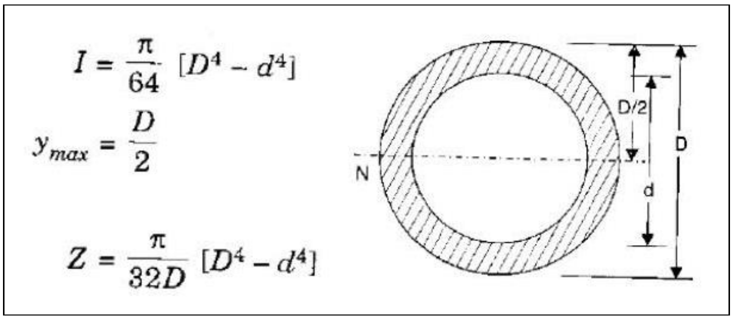

Fig No. 9:- For circular hollow section

$$I = \frac{\pi}{64}(25^4 - 22^4)$$

I= 7671.85mm^4
Y=12.5 mm
$\sigma = \frac{75000*12.5}{7671.85}$
$\sigma = 122.19$ N/mm^2

Discussion:
From the above-mentioned table, the bending stress of the simple Cantilever Beam (For the Flat Plate) is minimum as compared to Cantilever beam at square section and Cantilever beam at hollow tube, so We select the Simple Cantilever Beam (Flat Plate) for our project.

II. STRUCTURAL ANALYSIS

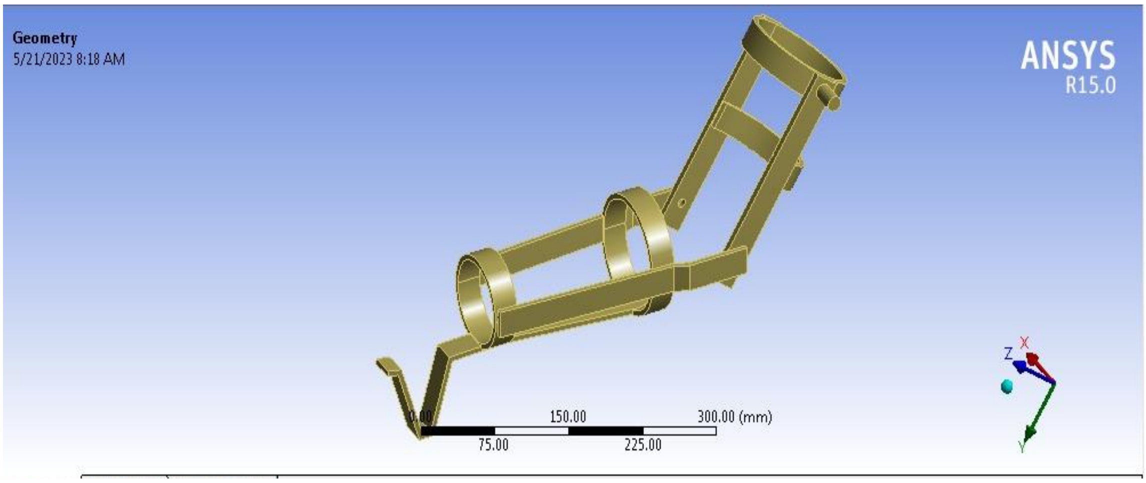

Fig No 10: Geometry in Ansys

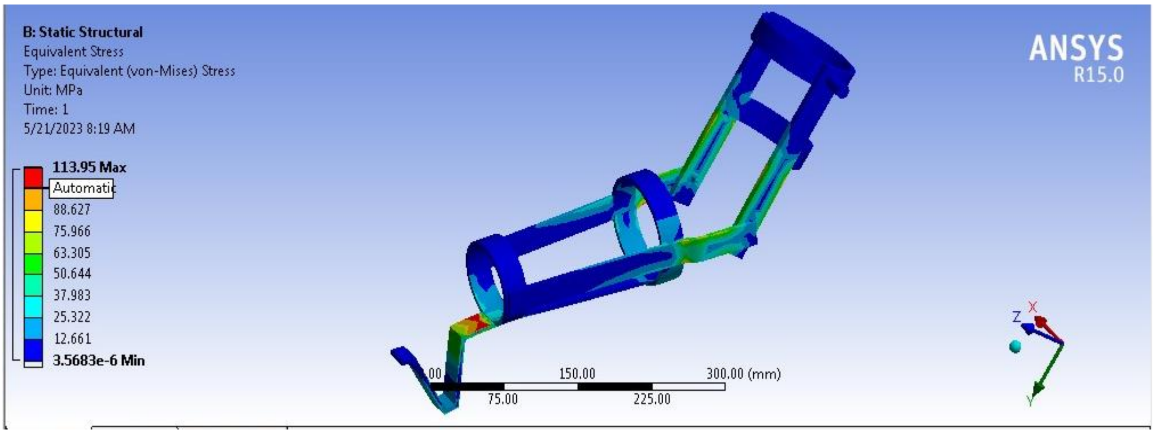

Fig No. 11: Final Result of model

For the analysis of the process first we import the geometry from the Solidworks software. After the importing the geometry, for the analysis of parts we do meshing of the model. It can significantly impact the accuracy of the simulation and the resources required to perform the simulation. After the meshing of the model for analysis the we apply the boundary conditions on the it. Apply the at point A fixed support, at point B force 200N is applied, at point is b is load is apply so point C has same load as Point b, at point D means at wrist position there is also fixed support apply. After applying boundary conditions, the we analyse model.

III. BLOCK DIAGRAM

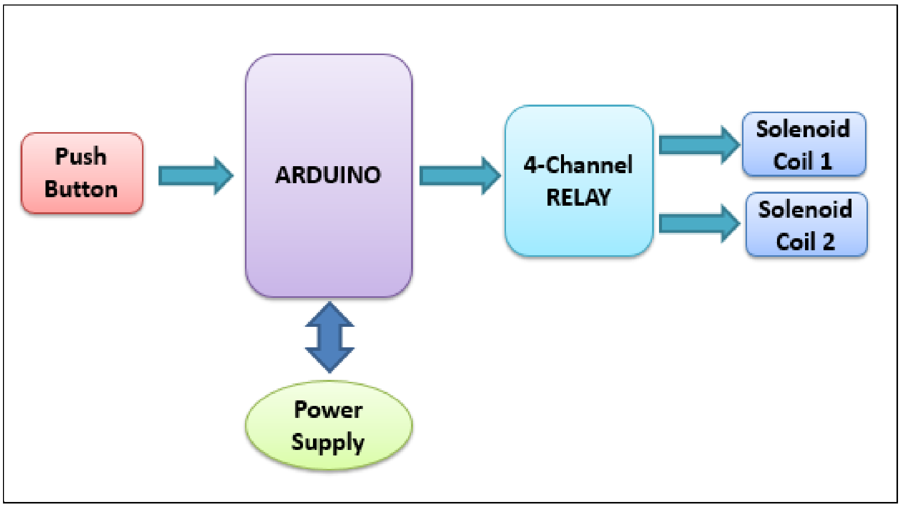

Fig no. 12: Block diagram

Working:- In this project, block diagram consists of Arduino, Push Button, 4-Channel Relay, 1 Solenoid Coils and Power Supply. Here, Arduino is the heart of the system.

1. Firstly, we will push the switch button. There is switch for relay.
2. The switch will give signals to Arduino board. The Arduino will process in signals and check the conditions.
3. After that Arduino will gives signals to Relays. There is relays for solenoid coils.
4. Each relay works with separate pneumatic cylinder. Then relays will give signal to Solenoid coils which is connected to pneumatic cylinder through pipes for air pressure.
5. The solenoid coils are activated by compressor for air pressure.
6. After those weights is lifting by exoskeleton arm.
7. Rehabilitation robots have become important tools in stroke rehabilitation.
8. Compared to manual arm training, robot-supported training can be more intensive, of longer duration and more repetitive.
9. The Exoskeleton is a robotic arm that assists muscle movement.
10. It is an outer framework that can be worn on a biological arm.
11. It uses a Non-invasive method to acquire muscles to control the framework, that can be worn on a biological arm.
12. It is Powered by a high torque servo motor.
13. It Can aid or increase the strength of the biological arm, depending on the torque of the servo motor.

IV. Result

Below table made from consider following paramerter-

- Load(W) = 250N
- Member Length(L) =300 mm
- Thickness(T) = 1.5 mm
- The distance from the neutral axis (y) =12.5 mm
- Width (B) = 25 mm
- Depth (D) = 25 mm

Table No. 1:- Calculations of all section of cantilever beam.

Sr.No.	Sections	Moment of Inertia (I) in MM^4	The distance from the neutral axis (Y) in MM	Bending Moments (Ma) in N/MM	Bending stress in N/MM^2
1	Cantilever Beam at square section	11419.6614	12.5	75000	82.09
2	Simple Cantilever beam(for flat plate)	18.75	1.55	75000	28.8
3	Cantilever Beams at hollow tube	7671.85	12.5	750000	122.19

V. Conclusions

1. The idea behind this project is to develop an inexpensive and user-friendly system. This project shows that it is simple in construction, design and cheaper.
2. It gives quick response and flexible compared to hydraulic and electrical type exoskeleton. This can be achieved while maintaining simplicity, ease of use, implementation, and maintenance.
3. Our project is not only used to lifts weights but also is applicable in rescue operations, military, industries. It makes physically disabled people to carry weights in their daily life because the maximum load is carried by this pneumatic system.
4. The exoskeleton robot can be mainly used in hospital to assist the patient to accomplish rehabilitation trainings.

References

[1]. Nef T., Mihelj M., Kiefer G., Perndl C., Muller R., Riener R. ARMin—Exoskeleton for Arm Therapy in Stroke Patients; Proceedings of the 2007 IEEE 10th International Conference on Rehabilitation Robotics; Noordwijk, The Netherlands. 13–15 June 2007; pp. 68–74.[**Google Scholar**] [**CrossRef**]

[2]. Zhang L., Guo S., Sun Q. Development and Assist-As-Needed Control of an End-Effector Upper Limb Rehabilitation Robot. Appl. Sci. 2020;10:6684. doi: 10.3390/app10196684. [**Google Scholar**] [**CrossRef**]

[3]. Lee S.H., Park G., Cho D.Y., Kim H.Y., Lee J.-Y., Kim S., Park S.-B., Shin J.-H. Comparisons between end-effector and exoskeleton rehabilitation robots regarding upper extremity function among chronic stroke patients with moderate-to-severe upper limb impairment. Sci. Rep. 2020;10:1806–1808. doi: 10.1038/s41598-020-58630-2. [**Google Scholar**] [**CrossRef**]

[4]. Sutapun A., Sangveraphunsiri V. A 4-DOF Upper Limb Exoskeleton for Stroke Rehabilitation: Kinematics Mechanics and Control. Int. J. Mech. Eng. Robot. Res. 2015;4:269–272. doi: 10.18178/ijmerr.4.3.269-272 [**Google Scholar**] [**CrossRef**].

[5]. Islam M., Spiewak C., Rahman M., Fareh R. A Brief Review on Robotic Exoskeletons for Upper Extremity Rehabilitation to Find the Gap between Research Porotype and Commercial Type. Adv. Robot. Autom. 2017;6:2. doi: 10.4172/2168-9695.1000177. [**Google Scholar**] [**CrossRef**]

[6]. Gull, M. A., Bai, S., and Bak, T. (2020). A review on design of upper limb exoskeletons. Robotics 9, 16. doi: 10.3390/robotics9010016. [**Google Scholar**] [**CrossRef**]

[7]. Wang, W., Qin, L., Yuan, X., Ming, X., Sun, T., and Liu, Y. (2019). Bionic control of exoskeleton robot based on motion intention for rehabilitation training. Adv. Robot. 33, 590–601. doi: 10.1080/01691864.2019.1621774 [**Google Scholar**] [**CrossRef**]

[8]. Jarrassé, N.; Proietti, T.; Crocher, V.; Robertson, J.; Sahbani, A.; Morel, G.; Roby-Brami, A. Robotic exoskeletons: A perspective for the rehabilitation of arm coordination in stroke patients. Front. Hum. Neurosci. **2014**, 8, 947. [**Google Scholar**] [**CrossRef**] [**PubMed**]

[9]. Engín, A. On the biomechanics of the shoulder complex. J. Biomech. **1980**, 13, 575–590. [**Google Scholar**] [**CrossRef**]

[10]. J. C. Perry, J. Rosen, and S. Burns, "Upper-limb powered exoskeleton design," IEEE/ASME Transactions on Mechatronics, vol. 12, no. 4, pp. 408–417, 2007. . [**Google Scholar**] [**CrossRef**]

[11]. S. Sridar, Z. Qiao, A. Rascon et al., "Evaluating immediate benefits of assisting knee extension with a soft inflatable exosuit," IEEE Transactions on Medical Robotics and Bionics, vol. 2, no. 2, pp. 216–225, 2020. . [**Google Scholar**] [**CrossRef**].