Lifting Hook Structural Analysis of An Elbow Exoskeleton System

, N. D. Gedam[1], H. A. Bhimgade[2] , P. R. Walke[3]

Assistant Professor[1,2,3]

[1]Mechanical Engineering Department, Yeshwantrao Chavan College of Engineering, Nagpur, India.
[2]Mechanical Engineering Department, Rajiv Gandhi College of Engineering and Research, Nagpur, India.
[3]Mechanical Engineering Department , Ballarpur Institute of Technology, Ballarpur, India.

ABSTRACT

Traditional physiotherapy rehabilitation systems are evolving into more advanced systems based on exoskeleton systems and Virtual Reality (VR) environments that enhance and improve rehabilitation techniques and physical exercise. In addition, due to current connected systems and paradigms such as the Internet of Things (IoT) or Ambient Intelligent (AmI) systems, it is possible to design and develop advanced, effective, and low-cost medical tools that patients may have in their homes. In this study, the exoskeleton elbow for lifting load has been presented. The elbow is analyzed to obtain the maximum sustainable load which is to be lifted by the elbow hook. This preliminary analysis is required to design the capacity of another power source that operates the exoskeleton elbow. For less power consumption and the weight, suitable material is selected. The 3-D model of the exoskeleton elbow is prepared by using PROE software and computationally analyzed by using ANSYS transient structural tool. The results are simulated for different hook load condition. The safe design condition of the exoskeleton elbow has been determined from the simulated results and the proposed model has been selected for the further advancements.

***KEYWORDS**: exoskeleton elbow; transient structural analysis; ANSYS.*

INTRODUCTION

Exoskeletons are wearable devices that work in tandem with the user. The exoskeleton elbow is an external mechanical structure with joints that correlates to the human limbs as shown in figure 1. The primary purpose of assistive technology is for the user to gain independence and self-esteem. Exoskeletons are placed on the user's body and act as amplifiers that augment, reinforce or restore human performance. This integration helps in the transfer of mechanical power to the biological limbs. The concept is simple – a wearable device that can increase human performance, strength, speed or agility. A lot of people are suffering from different types of muscle sicknesses and muscle weaknesses neither be able to lift everyday things nor move your body as you please, is a struggle for many. Whatever the reason is for suffering from muscle weakness those people would gain a lot from support with lifting objects.

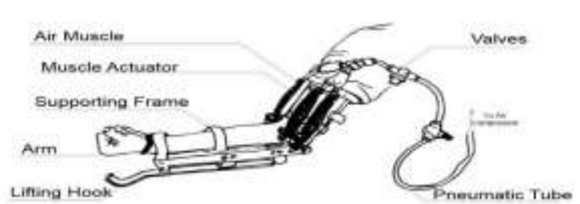

Figure 1: Human limb assisted with the externally powered exoskeleton elbow

1.1. Exoskeleton Elbow:

In this study, efforts are made to build an efficient, lightweight and externally powered limb. Its actuator, or electronic muscle, could provide resistance during therapeutic exercises and can augment strength, allowing user to lift an additional 10 to 15 kilograms approximately with little effort. The main aim of this study is to design such an elbow with lower weight and power consumption which will assist to lift maximum load by human limb. So, primarily an exoskeleton elbow made up of an aluminum alloy with hook, has been studied by using ANSYS software for different load conditions and then**,** for optimum factor of safety the fabrication of the model has been done here.

1.2. Material Data:

In this, the main focus is on reducing the weight to length ratio of the elbow and high strength, so that less external power is required. Hence, exoskeleton elbow of aluminum alloy (general material) which is readily available in the market at reasonable cost is selected for the analysis purpose. The relevant properties of the selected material are shown in the table 1.

Properties	Value	Properties	Value
Density, kg mm^-3	2.77e-006	Tensile Ultimate Strength, MPa	310
Coefficient of Thermal Expansion, C^-1	2.3e-005	Young's Modulus, MPa	71000
Specific Heat, mJ kg^-1 C^-1	8.75e+005	Poisson's Ratio	0.33
Compressive Yield Strength, MPa	280	Bulk Modulus, MPa	69608
Tensile Yield Strength, MPa	280	Shear Modulus, MPa	26692

Table 1: Aluminum Alloy

2. Design Methodology:

The selection of design methodology is a crucial part of any product development which may include many sequential steps that result in a fully functional design. In this study, a computational method has been adopted which is reliable and less expensive than the other conventional methods. The suitable computational model has been generated and analyzed with different load conditions. At the end, the suitable required design model of the exoskeleton elbow has been selected here.

2.1 Methodology:

The process of carrying out the study is depicted in the figure 1 The design and analysis methodology used in this study for the adoption of the best suitable design of exoskeleton elbow.

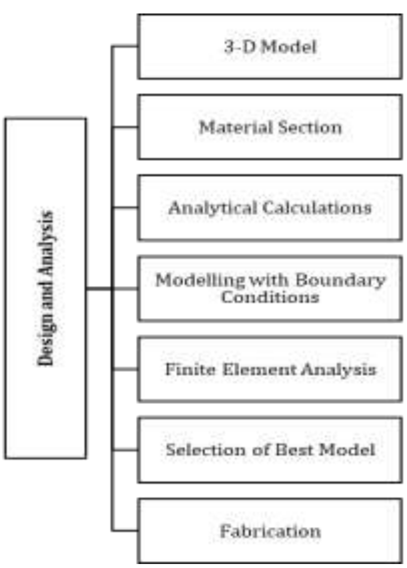

Figure 2: Design Methodology

2.2 Exoskeleton elbow design:

The exoskeleton elbow has been modelled using PROE modelling software with the material thickness of 5 mm, total mass of 0.79085 kg and total volume of 2.8552e+005 mm^3. This model is shown in figure 2.

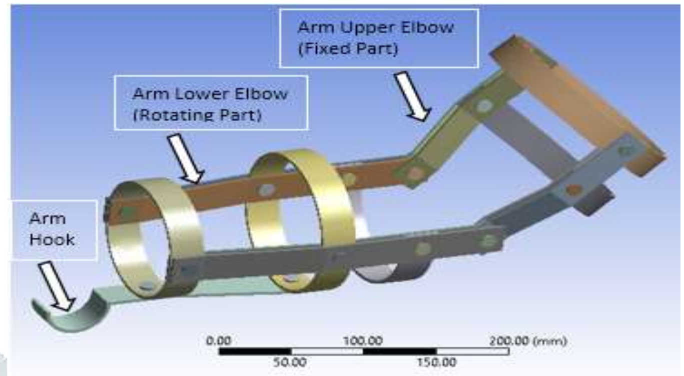

Figure 3: 3-D model of the exoskeleton elbow

2.3 Finite Element Analysis:

Transient dynamic analysis (sometimes called time-history analysis) is a technique used to determine the dynamic response of a structure under the action of any general time-dependent loads. This type of analysis is used to determine the time-varying displacements, strains, stresses, and forces in a structure as it responds to any combination of static, transient, and helbowonic loads. The basic equation of motion solved by a transient dynamic analysis is:

$$[M]\{\ddot{X}\} + [C]\{\dot{X}\} + [K]\{X\} = F(t)$$

Where, [M] = mass matrix; [C] = damping matrix; [K] = stiffness matrix; $\{\ddot{X}\}$ = nodal acceleration vector; $\{\dot{X}\}$= nodal velocity vector; {X} = nodal displacement vector; {F(t)} = load vector.

At any given time, t, these equations can be thought of as a set of "static "equilibrium equations that also take into account inertia forces ([M]) and damping forces ([C]).

The PROE model is analyzed for different hook load conditions using ANSYS v18.0 transient structural analysis for 1 second with proper boundary conditions. The elbow upper elbow is kept fixed and constant force of 100 N is applied in upward direction at elbow lower elbow which is rotating part of the elbow. The table 2 shows the adopted meshing methodology used in the computational analysis.

Object Name	***Mesh***
State	Solved
Display	
Display Style	Body Color
Defaults	
Physics Preference	Mechanical
Solver Preference	Mechanical APDL
Relevance	0
Element Midside Nodes	Program Controlled
Sizing	
Size Function	Adaptive
Relevance Center	Medium
Element Size	3.0 mm
Initial Size Seed	Active Assembly
Transition	Fast
Span Angle Center	Coarse
Automatic Mesh Based Defeaturing	On
Defeature Size	Default
Minimum Edge Length	7.2608e-003 mm
Quality	
Check Mesh Quality	Yes, Errors
Error Limits	Standard Mechanical
Target Quality	Default (0.050000)
Smoothing	Medium
Mesh Metric	None
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	5
Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No
Advanced	
Number of CPUs for Parallel Part Meshing	Program Controlled
Straight Sided Elements	No
Number of Retries	Default (4)
Rigid Body Behavior	Dimensionally Reduced
Mesh Morphing	Disabled
Triangle Surface Mesher	Program Controlled
Topology Checking	No
Pinch Tolerance	Please Define
Generate Pinch on Refresh	No
Statistics	
Nodes	71286
Elements	31419

Table 2: Mesh Statistics

2.3.1 Exoskeleton Elbow Hook Analysis:

The gradual load on the hook is applied and increased from 10 N to 90 N. It is observed that at 90 N, minimum factor of safety (FOS) for the designed model is found out to be 0.84841. So, beyond this value analysis is stopped and for the fabrication purpose minimum FOS is considered at load of 80 N.

Following graphs show the FOS, equivalent maximum stress, equivalent maximum strain and total deformation of the hook against different loading conditions.

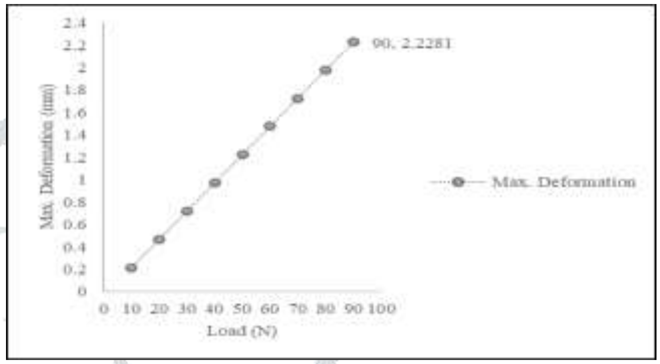

Figure 4: Total Deformation

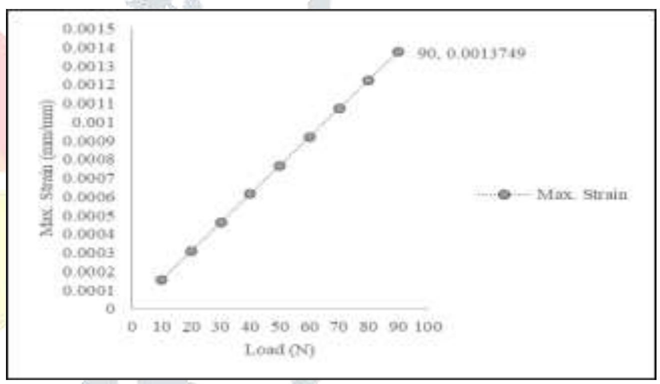

Figure 5: Equivalent (Von-Mises) Strain

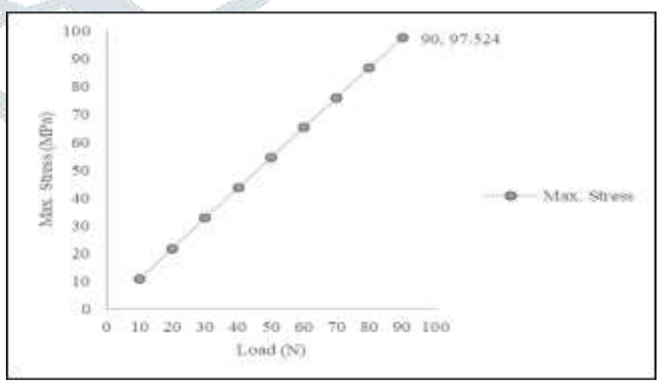

Figure 6: Equivalent (Von-Mises) Stress

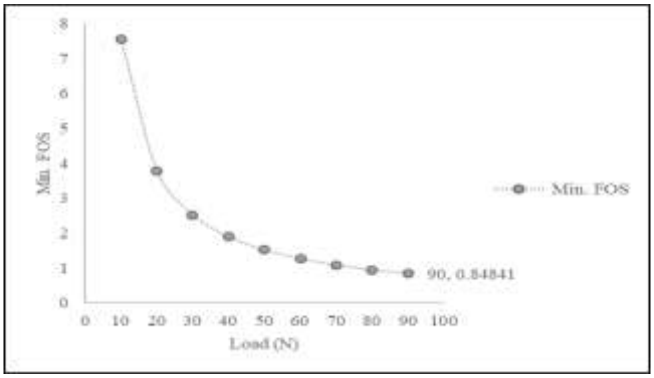

Figure 7: Factor of Safety

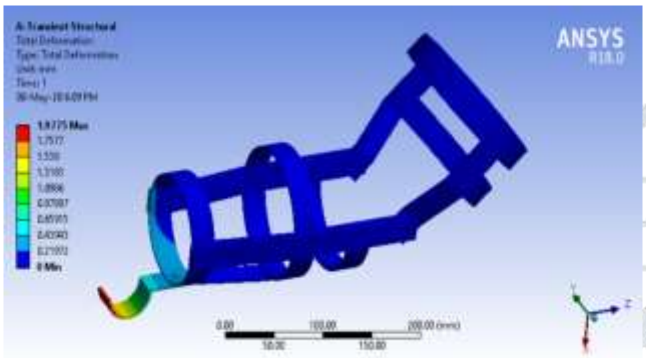

Figure 8: Total Deformation with Load of 80 N

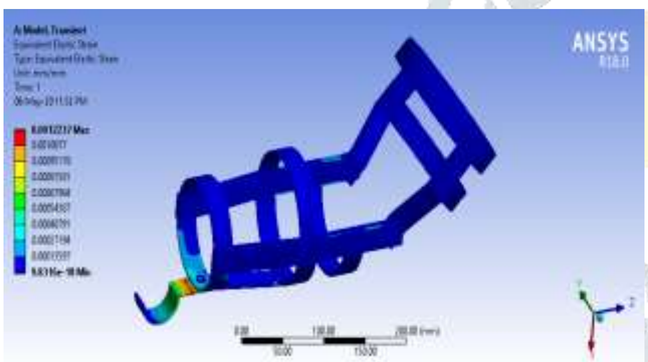

Figure 9: (Von-Mises) Strain with Load of 80 N

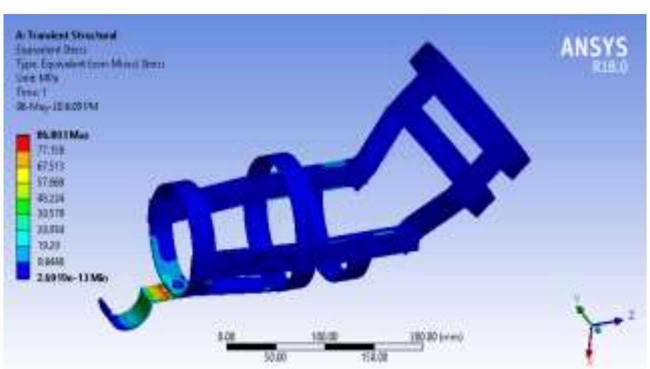

Figure 10: (Von-Mises) Stress with Load of 80 N

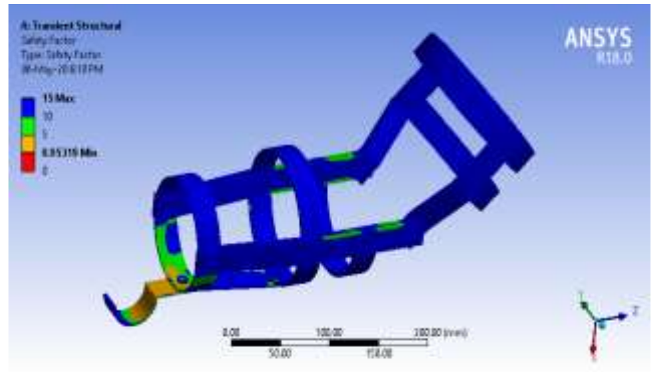

Figure 11: FOS with Load of 80 N

Conclusion

The exoskeleton elbow has been analyzed using transient structural analysis for different load conditions at the hook keeping the upper elbow of an elbow fixed. The analysis is carried out in ANSYS v18.0 software for the time period of 1 second. The load is increased from 10 N to 90 N and the results are obtained for each condition for body deformation or displacement, stress-strain (Von-Mises) and the factor of safety. Thus, it has been observed that at load of 80 N, the results are optimum where minimum factor of safety is found out equivalent to 1. Hence, it can be concluded that the exoskeleton elbow design is safe for the maximum hook load of 80 N or 8.15 kg approximately. It is safe to design other external power source for the required load condition so that it will operate the exoskeleton elbow which may handle or bear approximately 80 percentage of total load for lifting any object which ultimately helps to minimize or reduce the human limb stresses. The design and analysis of the exoskeleton elbow helps to identify the strong and weak parts of the design and hence suitable modification is to be done before final fabrication. Further, in future, the whole body of the exoskeleton elbow can be more realistically optimized using suitable transient dynamic structural models with appropriate boundary conditions.

References

[1] Zhibin Song, Shuxiang Guo, "Development of a New Compliant Exoskeleton Device for Elbow Joint Rehabilitation." Proceedings of the 2011 IEEE/ICME International Conference on Complex Medical Engineering, pp.647-651, 2011.

[2] Shuxiang Guo, Songyuan Zhang, Muye pang and Yuta Nakatsuka, "Preliminary Study on Upper Limb Movement Identification Based on sEMG signal." Proceedings of the 2012 ICME International Conference on Complex Medical Engineering, pp.683-688, 2012.

[3] Shuxiang Guo, Fan Zhang, Wei Wei, "Development of Force Analysis-based Exoskeleton for the Upper Limb Rehabilitation System," Proceedings of 2013 ICME International Conference on Complex Medical Engineering May 25 - 28, Beijing, China

[4] Liai Pan, Chunshan He, Qinghua Li, "Structural Static Characteristic Analysis of Lower Limb Exoskeleton Based on Finite Element Modeling," ICMEIS 2015.

[5] J. C. Perry, J. Rosen and S. Burns, "Upper-Limb Powered Exoskeleton Design," in IEEE/ASME Transactions on Mechatronics, vol. 12, no. 4, pp. 408-417, Aug. 2007, doi: 10.1109/TMECH.2007.901934.

[6] Daniel H. de la Iglesia et all. "Connected Elbow Exoskeleton System for Rehabilitation Training Based on Virtual Reality and Context-Aware", Sensors Volume 20, Issue 3, 10.3390/s20030858.

[7] "Transient Structural Analysis," ANSYS v18.0 manual.