International Journal of Latest Research in Engineering and Technology (IJLRET)
ISSN: 2454-5031
www.ijlret.com || Volume 09 - Issue 06 || June 2023 || PP. 11-20

Linkage Driven Robotic Hand Modelling and Analysis for Dexterous Grasping and Manipulation of Industrial Objects

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Abstract: In humanoid robotics, imparting dexterity and autonomous competence to a robotic system is a substantial burden, especially in the sectors of industrial manufacturing, prosthetics, orthopedic rehabilitation, and so on. Operating a humanoid hand requires a very inventive actuator and gearbox system. Under-actuated principles are proven to be an effective way of generating particularly dexterous robotic hands without requiring a diversified mechanical design. The fundamental characteristics of an under-actuated robotic hand are that it requires fewer actuators to function than degrees of freedom. The under-actuated equivalent hand is much more affordable than the fully-actuated equivalent hand and considerably reduces the control system's complexity. The existing work dealt with the design and analysis of a three fingered underactuated robotic hand for grasping variety of objects with dexterity. The hand is underactuated one which is used for grasping of objects with less number of actuators and the degrees of freedom is more than the number of actuators. The design and analysis is performed by ADAMS software.

Keywords: Dexterous, Grasping, Linkage driven, Manipulation, Underactuation

Introduction

The human hand is an exceptionally complex and diversified exterior end of the human body, the result of thousands of years of creativity[1].The hand of a human being can be utilised for a wide variety of tasks. In contrast to the human hand, robotic hands are designed to do a wide range of tasks in a variety of fields where the human hand has limitations. During the design phase of a robotic hand, both fully actuated and under actuated concepts can be applied.[2]. The hand of a human being can be utilized for a wide variety of tasks. In contrast to the human hand, robotic hands are designed to do a wide range of tasks in a variety of fields where the human hand has restrictions. Throughout the design phase of a robotic hand, both fully actuated and under actuated concepts can be utilized.[3].Under-actuation in the robotic hand minimizes complexity greatly. Under-actuation techniques in the robotic hand are more effective in terms of proper gripping, a better index of dexterity, and easier to expose control than a fully-actuated hand, according to technological advancements in sensing and other related domains.[4]. It has been investigated how to provide suitable grasping and dexterity activities for the rigid robotic hand with the fewest degrees of freedom and no sliding and rolling contact pairings. [5]. A tendon-driven hand with three fingers and both active and passive tendons has been constructed to concentrate on the hand's control mechanism. Kinematic and mathematical modelling The analysis of a tendon-driven robotic hand is suggested.[6].The design of a tendon-driven finger for a five-fingered robotic hand has been proposed, and its analysis, which includes processes that mirror the properties of the human finger, has been provided. [7]. The modelling and finite element based analysis of a five fingered underactuated robotic hand grasping a cuboidal shaped object is described[8].An humanoid hand with tendons guiding the phalanges has been thoroughly investigated in terms of contact with the object to be gripped. [9]. A robotic hand has been made with two actuators and seventeen joints in total, which may be utilised to reorganise synergies between the hand's first two postures. [10].A novel type of compliant and underactuated robotic hand for dexterous grasping is propose by the author [11].B.Heet al., 2021 proposed Underactuated robotics a review is proposed [12].This article reviews the state of the art on underactuated robotics. On the basis of previous studies, this article takes the non-holonomic constraint equation as the entry point to classify and summarize underactuated robot and their common mechanisms. The controllability of underactuated robot is further discussed. Evolution of Industrial Robotic Grippers-A Review is proposed by D. Arulkirubakaran [13].K. Du Frene in 2022 gives a Comparison between Actuation and Underactuation of Robotic Hands[14].Linkage Driven Mechanism Based Underactuated Robotic Finger Modelling and Analysis for Dexterous Grasping and

Manipulation is presented by R.Devaraja et al.,2021 [15].U.Scarcia et al., 2017 proposed modeling, design, and experimental evaluation of rotational elastic joints for underactuated robotic fingers[16]. D.Wang et al., is presented Design, analysis and experiment of a passively adaptive underactuated robotic hand with linkage-slider and rack-pinion mechanisms [17]. X.Ha et al., 2016 proposed a general contact force analysis of an under-actuated finger in robot hand grasping[18].A low-cost linkage-spring-tendon-integrated compliant anthropomorphic robotic hand: MCR-Hand III is presented by H.Yang et. al., 2021.[19]. S.Kashef et al., 2020 proposed Robotic hand: A review on linkage-driven finger mechanisms of prosthetic hands and evaluation of the performance criteria[20].H.Yang et al., 2021 proposed the design and development of a linkage-tendon hybrid driven anthropomorphic robotic hand[21].Design and Evaluation of Anthropomorphic Robotic Hand for Object Grasping and Shape Recognition is presented by [22]. An anthropomorphic underactuated robotic hand is examined employing modelling and finite element analyses.[23].An anthropomorphic Under actuated robotic hand with 5 fingers,15 degrees of freedom (DOF) and a single actuator has been debated[24].The S-type kinematic humanoid hand, which has five fingers, has been proposed. This hand can demonstrate hand forms, a master-slave system employing the five-finger bilateral process technique, and dexterous gripping. There were discussed theoretical studies on the kinematic modelling of a multi-finger robot hand. A hand-arm system with hemispherical fingers and a non-holonomic rolling constraint formulation between individual fingertips and the object's surface were used to suggest a dynamic gripping approach for an arbitrary polyhedral body.[12].Development of anthropomorphic robotic hand with underactuated mechanism is offered[25]. M.Sarac et al., 2017 proposed Design and kinematic optimization of a novel underactuated robotic hand exoskeleton.This study presents the design and the kinematic optimization of a novel, underactuated, linkage-based robotic hand exoskeleton to assist users performing grasping tasks. The device has been designed to apply only normal forces to the finger phalanges during flexion/extension of the fingers, while providing automatic adaptability for different finger sizes[26]. Plan of a Partially Compliant, Three-Phalanx Underactuated Prosthetic Finger is presented [27]. Finite element analysis of a three-fingered robot hand design is described [28]. Design and Analysis of a Synergy-Inspired Three-Fingered Hand[29]. Integrated linkage-driven dexterous anthropomorphic robotic hand is described in[30].Even if numerous projects were approved, there are still few that deserve special attention. In light of this, the current effort focuses on the modelling of anthropomorphic underactuated robotic hands utilising modelling tools, followed by analysis for grasping. Deformation, stress, and strain analysis are all included in the analysis. The suggested hand model has 6 actuators, 12 degrees of freedom, and 9 joints. In the current analysis, the distal interphalangeal (DIP), metacarpophalangeal (MCP), and proximal interphalangeal (PIP) joints of all four fingers have been assumed to be underactuated.

1.0 MATERIAL AND METHOD

The material used for the analysis of the proposed hand model is, Aluminium Alloy, stainless steel. The properties of the material are mentioned in the table.1. The software used for the modelling of the hand is Solid work 2015. The kinematic analysis of the underactuated fingers are analyzed in ADAMS Software. To analyze the mechanical properties Ansys 2021 software is used.

Table I.: Properties of the material

Mechanical properties	Stainless steel	Aluminium Alloy
Young's modulus	1.93e+05 MPa	71000 MPa
Poisson's ratio	0.31	0.33
Shear modulus	73664MPa	26692MPa
density	7.75e-06 kg/mm³	2.77e-06Kg/mm3

2.0 DESIGN OF THE PROPOSED HAND

Three similar fingers constitute the robotic hand that is being projected. The three phalanges that make up each finger. PIP, DIP, and MCP joints are the three joints that make up each finger. There are 4 degrees of freedom in each finger. Figure 1 shows the schematic diagram of the hand model with all of its joints, phalanges, and degrees of freedom.

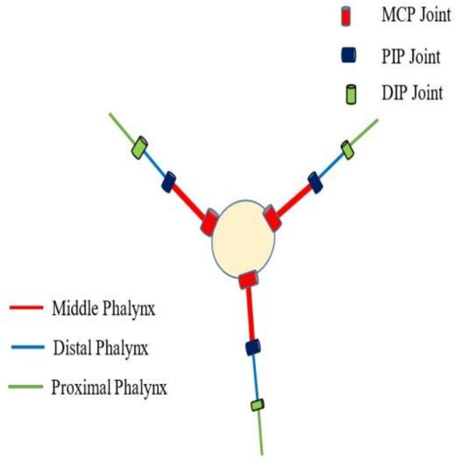

Figure 1: Model of a Three Fingered Robotic hand with the number of joints and Degrees of freedom

The dimension of all the phalanges and other links which are used for underactuation of the proposed hand are stated in table 2.The planned hand has a palm, three fingers. The fingers are linked to the palm's base. Each finger is made up of three phalanges. All of the phalanges on a single finger are joined together by revolute joints.

Table II.: Dimension of proposed hand model

Name	Dimension (l x w x t in cm)
Distal Phalynx	3.5 x 1.5 x 0.5
Middle Phalynx	3.8 x 1.5 x 0.5
Proximal Phalynx	5.8 x 1.5 x 0.5
1st Driving bar	3.2 x 0.5 x 0.5
2nd Driving bar	2.2 x 0.25 x 0.25
3rd Driving bar	1.1 x 1.5 x 0.5
1st Underactuated bar	5.4 x 0.5 x0.5
2nd Underactuated bar	3.8 x 0.25 x0.25
3rd Underactuated bar	3.8 x 0.4 x 0.2

The three fingered robotic hand is modelled by using the solid work platform. The three fingers are identical and are present at the periphery of the palm to grasp the object perfectly.

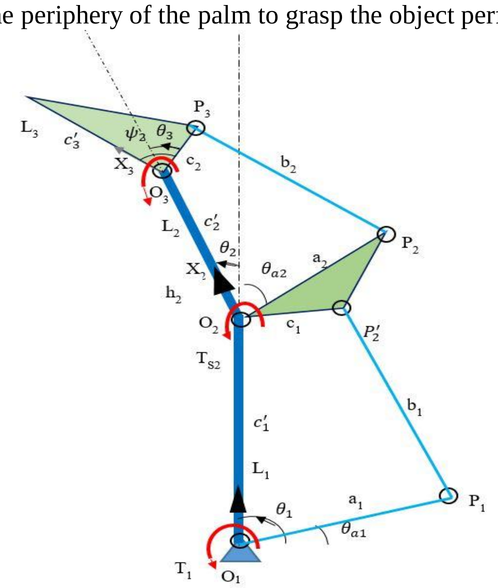

Figure 2: Linkage driven Robotic hand

Figure 2 depicts the skeleton layout of the single linkage driven underactuated finger. .The human hand's primary functions include grasping and manipulating. Gripping is the collection of skills and movements that must be recognised in a robotic hand in order to grip an object in the hand. Finding a design for the dexterous robotic hand capable of performing a strong hold is one of the challenges. The hand makes a power grip motion when employing a power grip. The fingers and palm envelop the thing and make several touches to it. The object is grasped strongly between the fingers and palm. The hand grips the thing so tightly that no relative motion exists between the hand and the object. The object is gripped using only the tips of the fingers in precision grasp. There are no more touch points at the fingers, nor is there a palm connection to the object. Although precision grasp has a high level of manipulability, it does not have a high level of load resistance. As a result, the solid grasp is not obtained in this type of grasp.

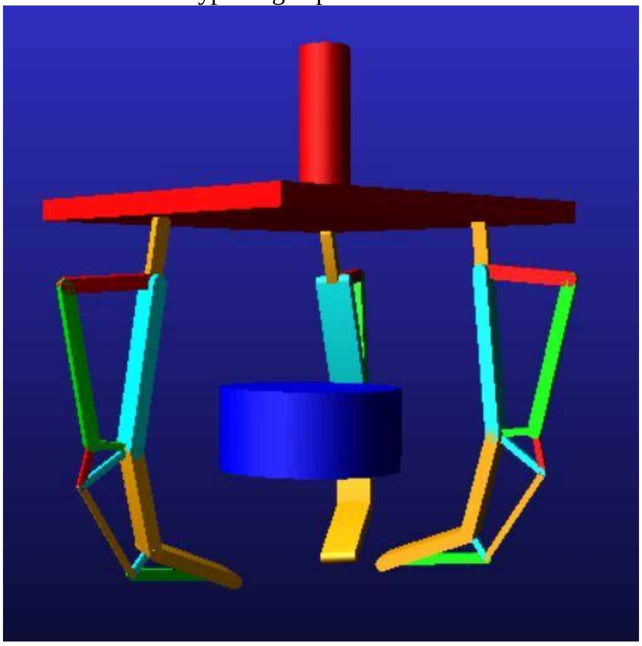

Figure 3: Three fingered robotic hand approaching to hold the job

The three fingers of the hand is present the periphery of the palm for proper grasping of the object to be manipulate. The three fingers without manipulating a job is presented. The three fingers approaching to hold a cylindrical job is presented in fig.3. All the three phalanges are approaching to manipulate the job. While in contact with the object all three distal phalangeal tip.

3.0 ANALYSIS OF THE HAND

The three fingered robotic hand is used for the appropriate grasping and manipulation of the variety types of items. Since to hold the object properly it is needed to move the finger in a correct way to manipulate the object therefore the kinematic analysis of the phalanges are essential for the proper grasping. The analysis is carried out in ADAMS software. The contact force produced at the point of contact between the tip of the distal finger-1 and the cylindrical object is presented in fig.4. The time duration of the analysis is 0.2 sec. The maximum contact force of the distal link tip is nearly 8.0E-05 N. The analysis shows that the average value of the contact force is 3.0E-05 N. It is viewed from the analysis that the contact force first increases from zero to 8.0E-05 Nmaximum and when the distal phalanges are in contact with the cylindrical object the contact force of the distal tip of the finger decreases suddenly and then increases. It is viewed that the distal phalanges are in contact with the object during the period 0.025 sec to 0.15 sec.

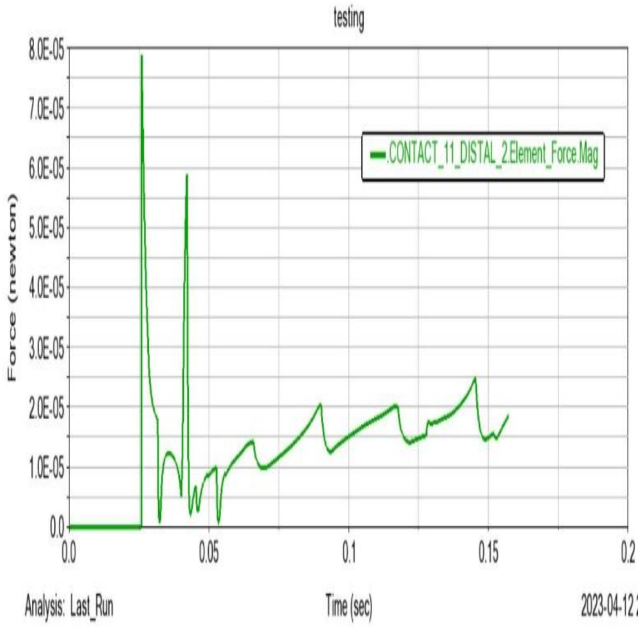

Figure 4: Contact force-1 of Distal Phalynx tip of finger-1

The Contact force-2 of Distal Phalynx tip of finger-2 of distal link tip is presented in fig.5. It is viewed from the analysis that the contact force-2 of the distal link tip increases first and then decreases. The maximum value of the angular velocity is 7.0E-05N.From the analysis it is found that the cylindrical body get in contact with the four distal phalanges from 0.025 sec to 0.16 sec.

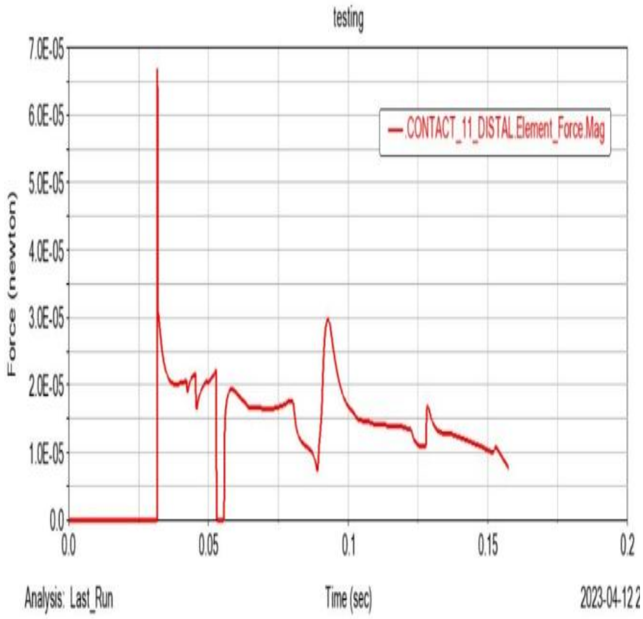

Figure 5: Contact force-2 of Distal Phalynx tip of finger-2

Fig. 6 represents the contact force produced at the point of contact between the tip of the distal finger-3 and the cylindrical object. The time duration of the analysis is 0.2 sec. The maximum contact force of the distal link tip is nearly 5.5E-05 N. The analysis shows that the average value of the contact force is 2.0E-05 N. It is viewed from the analysis that the contact force first increases from zero to 5.5E-05 N maximum and when the distal phalanges are in contact with the cylindrical object the contact force of the distal tip of the finger decreases suddenly and then increases. It is viewed that the distal phalanges are in contact with the object during the period 0.030 sec to 0.16 sec.

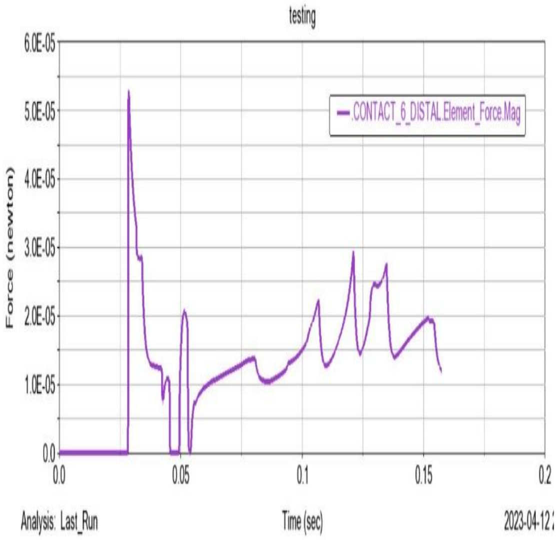

Figure 6: Contact force-3 of Distal Phalynx tip of finger-3

A solid work environment is used to model the suggested three fingered robotic hand. To stop the movement of an object of cylindrical shape, a hand with three fingers is modelled. The goal of the current work is to model and investigate a three fingered robotic hand using finite element analysis for grasping. The hand is used to hold a cylindrical-shaped object and has three underactuated fingers and a palm. The investigation of the modelled hand is defined in the current article. In the analysis part the hand material is steel and the cylinder is made up of Aluminum. The force is Applied which varies on the fingers of the hand while these are used to stop the movement of an object. Various mechanical parameters were analyzed in Ansys-2021 environment. The mechanical properties analyzed are Maximum principal stress, Maximum shear stress, Total deformation, Equivalent elastic strain. The Modelling is done by solid work 2015 and the Analysis is done in ansys-2021 platform. The robotic hand is analyzed in the Ansys environment to find out the various mechanical parameters. Meshing details includes that the palm and fingers as triangular and the cuboid as square. Standard earth gravity g=9.81m/sec2 is taken. Total nodes are 25027 and total elements are 11280. The Ultimate values of stress, strain and deformation of each finger due to application of different loads are presented. Force is applied on the surface of the distal phalanges with intensity of 100N. All the mechanical parameters are presented as follows i.e. Maximum principal stress, maximum shear stress, total deformation and strain. The analysis is done in static structural mode.The analysis of maximum principal stress and maximum shear stress are presented in fig.7 and fig.8. The analysis plot of total deformation and equivalent elastic strain is presented in fig.9 and fig.10 Target body taken in Ansys analysis is three touching distal phalanges total body of the fingers. The analysis of the maximum principal stress is presented in fig.7 where the maximum and the minimum value is presented. It is observed that the maximum stress is induced at the joints.

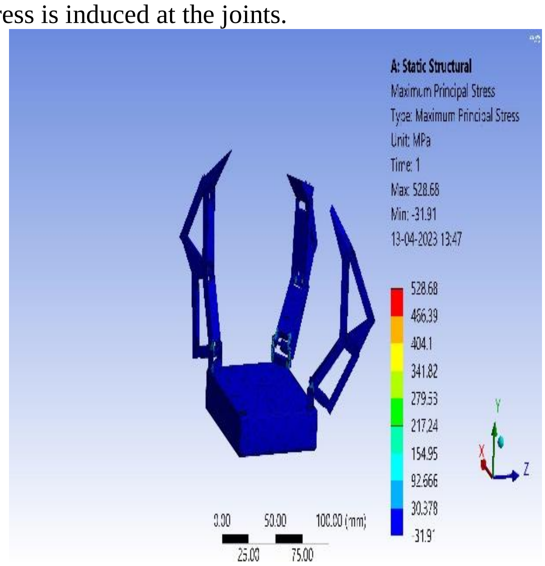

Figure 7: Maximum principal stress

The analysis of the maximum shear stress is presented in fig.8. The maximum and the minimum values of the shear stress is presented in red mark and blue mark.

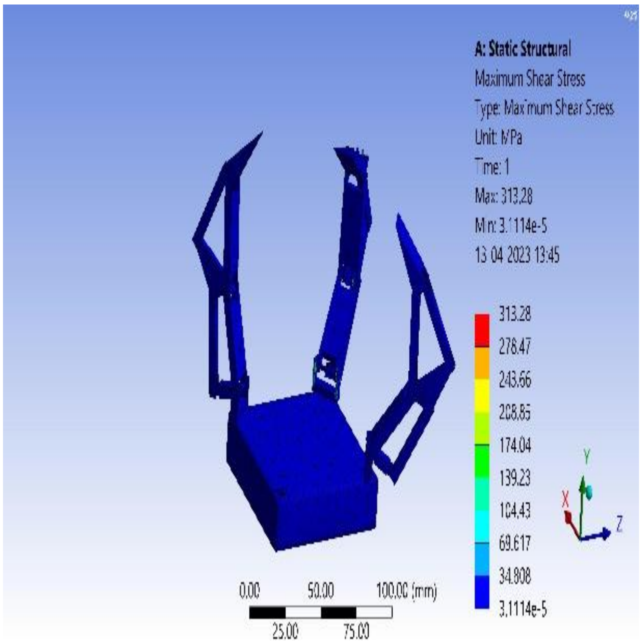

Figure 8: Maximum shear stress

The analysis for the total deformation is presented in fig.9.It is found that the maximum value of the deformation is observed in the tip of one of the distal Phalynx tip.

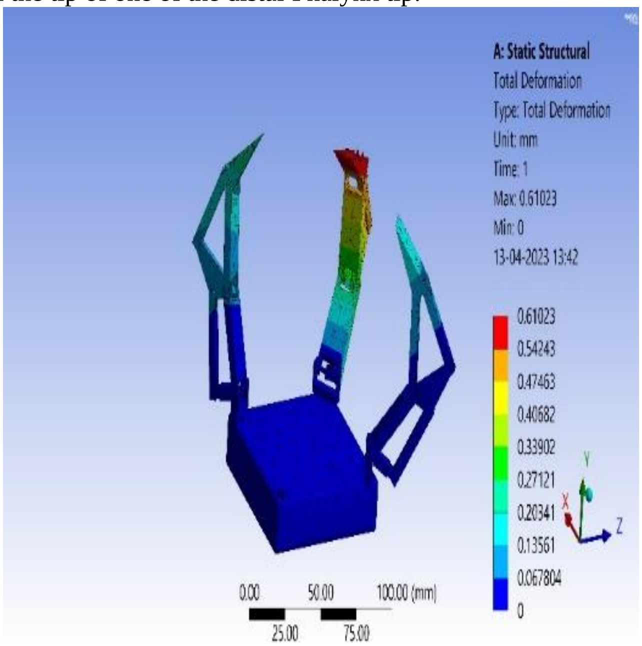

Figure 9: Total deformation

The analysis for the equivalent elastic strain is presented in fig.10. The maximum and the minimum value of the strain is presented in table. It is observed that the maximum equivalent elastic strain is at the joints of the two phalanges. The maximum value is presented in red colour and the lowest value of the elastic strain is presented in blue colour.

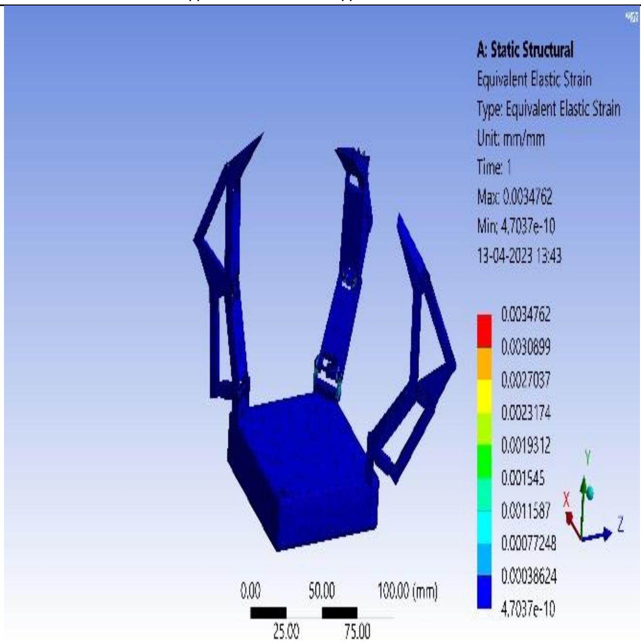

Figure 10: Equivalent elastic strain

4.0 RESULT AND DISCUSSION

Table 3 shows the analysis of deformation, maximum principal stress, and maximum principal elastic strain for the modelled hand for Aluminium Alloy, as well as the maximum and minimum values derived in the analysis.The designed robotic four fingered hand is utilized for the application in the industries as well as in the precision medical applications for holding various types of jobs.

Table III.: Analysis of the Mechanical Parameters

Mechanical Parameters	Maximum value	Minimum value
Maximum Principal stress (MPa)	528.66	-31.91
Maximum shear stress (MPa)	313.28	0.000031114
Total deflection (mm)	0.61023	0.0
Equivalent elastic strain (mm/mm)	0.0034762	4.7037e-10

5.0 CONCLUSION

The present Project work deals with the modelling and analysis of a three fingered linkage driven underactuated robotic hand. The modelling has been carried out in modelling software. For the robotic finger Stainless steel is used and Aluminum is taken for the cylindrical shaped object. The orientation of the traces has been validated with the existing works. The analysis has been carried out for the proposed hand model during the grasping of the cylindrical shaped object. This paper presents the modelling of an under actuation robotic hand and the hand comprises of three fingers which are present peripherally around the palm. The under actuation is accomplished by linkage driven mechanism. The robotic hand is used to grasp the variety of objects. The Present work focuses on the grasping of a cylindrical object while its in motion. All the distal phalanges are used by the process of under actuation to stop the movement of the moving cylinder. The kinematic analysis is analyzed in ADAMS environment. The deformation stress, strain and other mechanical properties have analyzed in the Ansys environment with variation of application of load at the surface of the cuboid on the top. From the analysis it has been observed that due to variation of the load the values of the mechanical properties also increases.

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