Design and Fabrication of a Flexible Robotic Gripper for Material Handling

PROJECT REPORT

submitted by

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to

the APJ Abdul Kalam Technological University
in partial fulfillment of the requirements for the award of Master of Technology in Mechanical Engineering with specialization in Computer Integrated Manufacturing.

Department of Mechanical Engineering

T K M College of Engineering, Kollam

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DEPARTMENT OF MECHANICAL ENGINEERING
T.K.M COLLEGE OF ENGINEERING, KOLLAM

CERTIFICATE

Certified that this report entitled **‘Design and Fabrication of a Flexible Robotic Gripper for Material Handling**’ presented by **ABHINAND C.S, TKM22MECI01** during **2022-2024** in partial fulfillment of the requirements for the award of the Degree of Master of Technology in Mechanical Engineering with specialization in Computer Integrated Manufacturing of the APJ Abdul Kalam Technological University

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DECLARATION

I, Abhinand C.S. hereby declare that, this project report entitled " **Design and Fabrication of a Flexible Robotic Gripper for Material Handling** " is the bonafide work of mine carried out under the supervision of, **Dr. MUBARAK ALI M.** I declare that, to the best of my knowledge, the work reported herein does not form part of any other project report or dissertation on the basis of which a degree or award was conferred on anearlier occasion to any other candidate. The content of this report is not being presented by any other student to this or any other University for the award of a degree.

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I take this opportunity to express my deep sense of gratitude and sincere thanks to all who helped me to complete the project successfully. I am indebted to the **GOD ALMIGHTY** for giving me an opportunity to excel in my efforts to complete this mini project on time.

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Finally I thank my parents and friends near and dear ones who directly and indirectly contributed to the successful completion of my project.

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ABSTRACT

Robotic grippers are integral components in modern automation. Recent technological advances enable gripper-equipped robots to perform many task traditionally associated with the human hand, allowing the use of grippers in a wide range of applications. In order to handle different components or materials , different end effectors are used , once the end effector is attached to the manipulator, it will only be capable to handle an object that is compatible with the end effector. Deploying multiple robotic manipulators for handling different materials can incur significant costs not only in terms of the robotic manipulators themselves but also in infrastructure, maintenance, and training. Switching between different tasks often requires changing the end-effectors or tools attached to the robotic manipulator. This tool changeover process can be time-consuming and may result in downtime, affecting overall productivity. This project focuses on the design and fabrication of a robotic gripper prototype with the capability to handle both fragile and non-fragile materials. The design incorporates integration of jaw gripping along with vacuum gripping

Keywords: Robotic gripper, End Effector, End of Arm Tooling (E.O.A.T) .Manipulator

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LIST OF FIGURES

ABBREVIATIONS

FMS	Flexible Manufacturing System
TPE	Thermoplastic Elastomer
DOF	Degrees of freedom
EOAT	End of Arm Tooling
CAM	Computer Aided Manufacturing
CAD	Computer Aided Design

CHAPTER 1

INTRODUCTION

Over the past few years, the manufacturing sector has experienced a significant transformation through the incorporation of robotics. Robotics has become a pivotal force in boosting efficiency, precision, and overall productivity within manufacturing industries. This technological transition signifies a paradigmatic shift, fundamentally altering conventional production methods and establishing novel benchmarks for innovation. Manufacturing sectors are progressively embracing robotics for a variety of reasons. To begin with, robots provide unmatched precision and uniformity in task execution, leading to a substantial decrease in errors and ensuring the delivery of high-quality results. This dependability is especially critical in industries where precision and repeatability take precedence, such as in automotive, electronics, and aerospace manufacturing. Automating routine and repetitive tasks with robotics has not just accelerated production rates but has also minimized the potential for human error, resulting in enhanced product quality. Robots are particularly adept at handling tasks that pose risks or are monotonous, thereby creating a safer work environment for human employees. This, in turn, enables them to concentrate on more intricate and value-added facets of the production process. A robotic manipulator and its end effector are crucial components of a robotic system, working together to enable the robot to perform various tasks. The manipulator provides the robot with the ability to move and reach different positions within its workspace. The number and types of joints in the manipulator determine the robot's degrees of freedom and, consequently, its flexibility in movement. A well-designed robotic manipulator allows for precise control of movement, which is essential for tasks that require accuracy and repeatability. This is particularly important in manufacturing processes and other applications where precision is critical. The manipulator's versatility allows it to be employed in a wide range of applications, from simple pick-and-place tasks to complex assembly operations. It can adapt to different environments and tasks with appropriate programming. The end effector is the tool or device attached to the end of the robotic manipulator that interacts directly with the environment or objects. It determines the robot's capability to perform specific tasks. Different end effectors can be attached to the same robotic manipulator, allowing the robot to adapt to various tasks. For example, grippers, welding tools, or sensors can be interchanged based on the requirements of the application.

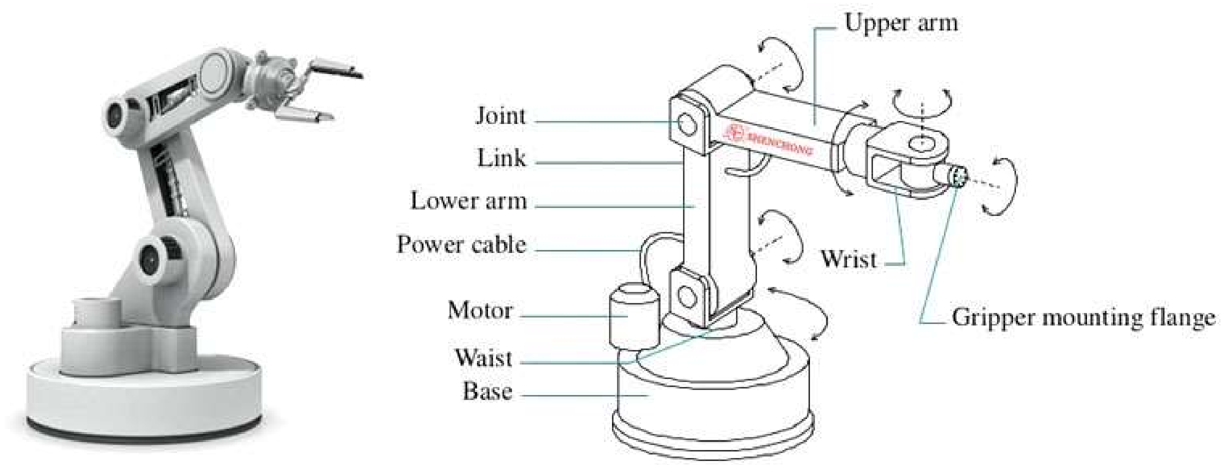

Fig 1. Components of a robotic manipulator

In applications where the robot needs to handle objects, the end effector, such as a gripper, is crucial for grasping, lifting, and manipulating items of different shapes, sizes, and weights. Some end effectors incorporate sensors to provide feedback to the robot about the environment or the success of a task. This enhances the robot's ability to adapt to changes in its surroundings. Depending on the industry and application, end effectors can be specialized for tasks such as welding, painting, cutting, or even performing delicate tasks in fields like healthcare or electronics assembly. Many industrial robots are equipped with sensors and vision systems to perceive and respond to their environment. These sensors can include cameras, proximity sensors, force/torque sensors, and more, enabling robots to interact with the surrounding environment and make decisions based on feedback. A robotic gripper is a mechanical device or end effector attached to the manipulator that is designed to grasp and hold objects. It is a crucial component of robotic systems used in various applications, including manufacturing, assembly, packaging, and material handling. In order to handle different components or materials, different end effectors are used , once the end effector is attached to the manipulator, it will only be capable to handle an object that is compatible with the end effector in most cases. Consider a robot centered FMS layout system where a single robot placed at the center is used to do operations within in the different workstations.

So if the parts to be handled within the layout is of same type a single end effector is enough but if the components or parts to be handled varies (such as fragile goods), there is a need to change the end effector.

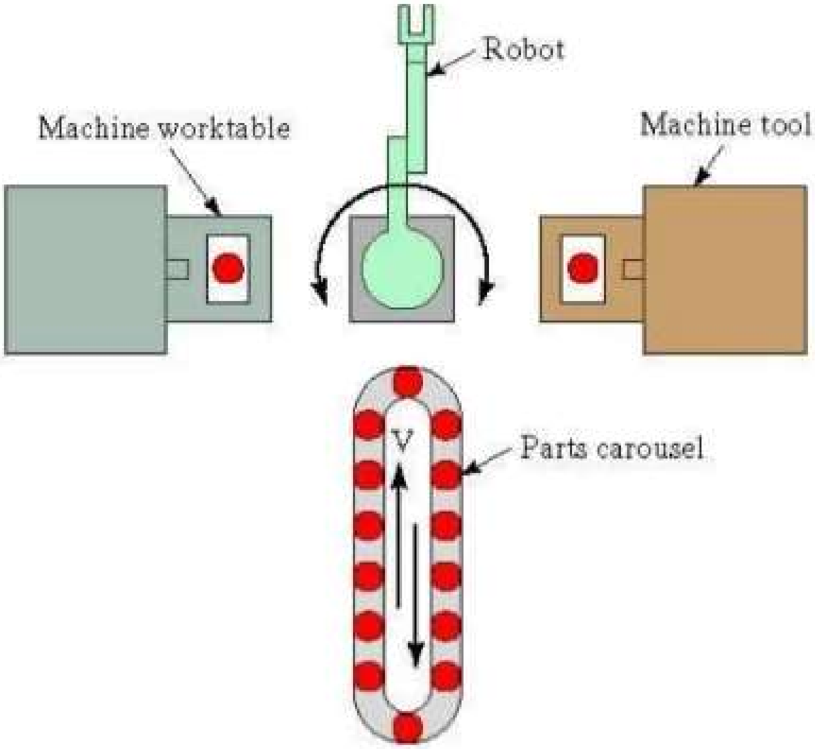

Fig .2. Robot Centered FMS layout

Image source : student Mechanica.blogspot.com/ FMS systems

The material properties of the components influence the choice of end effector. Fragile or delicate items may require a soft gripper or a vacuum system to avoid damage during handling. Conversely, rigid or heavy items may require a more robust gripping mechanism to ensure a secure hold. Changing the end effector allows the system to optimize its performance for each specific task. Deploying multiple robotic manipulators and end effectors can incur significant costs not only in terms of the robotic manipulators themselves but also in infrastructure, maintenance, and training. Switching between different tasks often requires changing the end-effectors or tools attached to the robotic manipulator. This tool changeover process can be time-consuming and may result in downtime, which is considered as a waste affecting overall productivity. So the manipulator may use a suction cup for picking up smooth, flat items and switch to a mechanical gripper for handling irregularly shaped components. Thus the project involves design of robotic end effector that is capable of performing grasping operation on both fragile (such as glass panels, porcelain, electronics) and Non-fragile Objects and the fabrication of a prototype of the same.

Fig.3. Mechanical 2 jaw Gripper

Fig.4. Vacuum Gripper

CHAPTER 2

LITERATURE REVIEW

Daniel Cardin-Catalan, et.al [1] focuses on the design and construction of gripper prototypes for delicate edible products, using a soft and variable-stiffness approach. The grippers consist of fingers with rigid and soft parts, allowing for modification of stiffness using the jamming principle. The gripper properties were evaluated using NIST benchmarks and a new benchmark called the edible grasping benchmark. The final gripper prototype demonstrated the ability to grasp fruits and vegetables without causing damage, overcoming problems observed in fruit and vegetable picking systems. The gripper prototypes were designed and constructed, with fingers composed of rigid and soft parts that can be modified in stiffness using the jamming principle. The gripper properties were experimentally evaluated using a subset of NIST benchmarks, leading to improved gripper designs. A new benchmark, the edible grasping benchmark, was proposed and used to measure the performance of the grippers in grasping fruits and vegetables

Aswin K Ramasubramanian. et.al [2] proposes a novel approach for the design and validation of robotic gripper fingers, aiming to reduce the time and cost required for physical validation. It combines a Computer-Aided Design (CAD) software platform and a physics-based simulation framework to automatically generate and validate new iterations of the gripper finger design. The approach employs a parametric design strategy to determine the characteristics of the gripper fingers, allowing for iterative modifications based on feedback from tests carried out in a physics-based simulation environment .The paper highlights the promising results of rapid prototyping methods, including parametric modeling, geometrical analysis, and grasp planning and analysis, in designing robotic gripper fingers. The proposed approach is validated in a real robotic case scenario, performing a series of pick and place tasks, and shows a close correlation between simulation and physical experiments in terms of success rates.

Maxwell Samuels et al [3] presents three-and four-DOF linkage mechanisms for designing robot grippers that can conduct two-finger twisting and rolling, providing additional manipulation ability beyond open-and-close. The kinematics of the linkage mechanisms is studied, and tendon drives are designed to enable the use of the grippers on tubular robots. A folding mechanism is proposed to help the gripper navigate small entrances and narrow passages, and measures for miniaturization are discussed, particularly in the context of minimally invasive surgeries. The paper also explores advanced design concepts to enhance the potential of the robot grippers. The grippers can be tendon-driven and used on tubular robots, making them suitable for applications such as minimally invasive surgeries.

Fontanelli, G.A, et al [4] presented a re-configurable gripper for robotic autonomous depalletizing for supermarket logistics. The gripper is reconfigurable with five actuated degrees of freedom, automatically controlled using embedded sensors to adapt grasping to different shapes and weights. The gripper's lightweight design and use of aluminum alloys for main parts contribute to its compactness and easy integration into preexisting logistic systems The Gripper has its ability to grasp boxes from the top and side, as well as boxes placed over other boxes. It can handle boxes with a maximum weight of about 15 Kg. The effectiveness of the proposed gripper design was evaluated in a real depalletization scenario, successfully picking 19 different products, including standard boxes, boxes with a fast opening structure, and boxes of bottles .The results demonstrate the gripper's capability to grasp various types of boxes, including those with complex shapes, indicating its adaptability and versatility for depalletizing tasks.

Gualtiero Fantonia. et.al [5] defines a set of parameters that will be the input of the method.A compatibility matrix between component characteristics and grasping-releasing principles has been proposed and developed. Parameters are defined and selected with the purpose to consider all the phases in which the gripper is involved : grasping, handling and releasing. The robot which manipulates the gripper influences gripper capabilities and therefore its proper choice.

Liu, C.H.; Chung. et.al [6] discusses a compliant mechanism is a flexible mechanism that transmits force and motion through elastic deformations. Compliant mechanisms have a reduced number of moving parts which makes them light. The finger mechanism was fabricated with a thermoplastic elastomer (TPE). The gripper mechanism has only one linear actuator to actuate the three fingers simultaneously, which generates the same displacement on each finger.

A. K. Jaiswal1 et.al [7] In this paper, vacuum gripper in industrial robot applications has been discussed exclusively with gripping of different variety of materials/parts comparing with other various types of vacuum grippers. The theoretical holding suction force for universal suction cups, flat suction cups with bars, suction cups with bellow and depth suction cups is obtained.

Holding force is proportional to the pressure difference and the suction area. The greater the difference between ambient pressure and pressure in the suction cup or the larger the effective suction area, the greater the holding force.

Jaime Hernandez et.al [8] The paper provides a review of the majority of robotic grippers from the last four years, classifying them based on the number of degrees of freedom (DOF), actuation system, design approach, and shape of the grasping objects. The authors compare the advantages and disadvantages of different gripper designs, aiming to identify the design with broader capabilities. Flexible grippers, although lacking in strength, can adapt to various shapes and are suitable for holding fragile objects.

Ramish et.al [9] design and fabrication of a stepper motor controlled robotic gripper for handling small objects in industries .Kinematic analysis were done to accurately predict design parameters for proper selection of motor and linear actuator. Guidelines for gripper design, including minimizing gripper weight to favor robot acceleration and ensuring secure grasping of objects to allow for higher robot speeds and reduced cycle time.

Mikell P. Groover [10] ***Industrial Robotics technology, programming and applications (Book)***

- Fundamentals of robotics.
- Control systems and components.
- Analysis and control
- Robot Programming and languages.
- Applications in manufacturing

CHAPTER 3

THEORY

An industrial robot's joint system's grasping organs or tools serve as the end of the kinematic chain and enable interaction with the surrounding work environment. Wide clamping range universal grippers can be used for a variety of item shapes, although they frequently need to be modified to fit the precise shape of the workpiece. Grippers are handling mechanism subsystems that establish momentary contact with the thing to be grabbed. When carrying and mating the object to the handling apparatus, they guarantee its position and orientation. Prehension is attained through form-matching and force-producing components. The term "gripper" is sometimes used to describe situations in which keeping an object such as in vacuum suction, where the retention force may work on a point, line, or surface instead of physical grasping is involved.

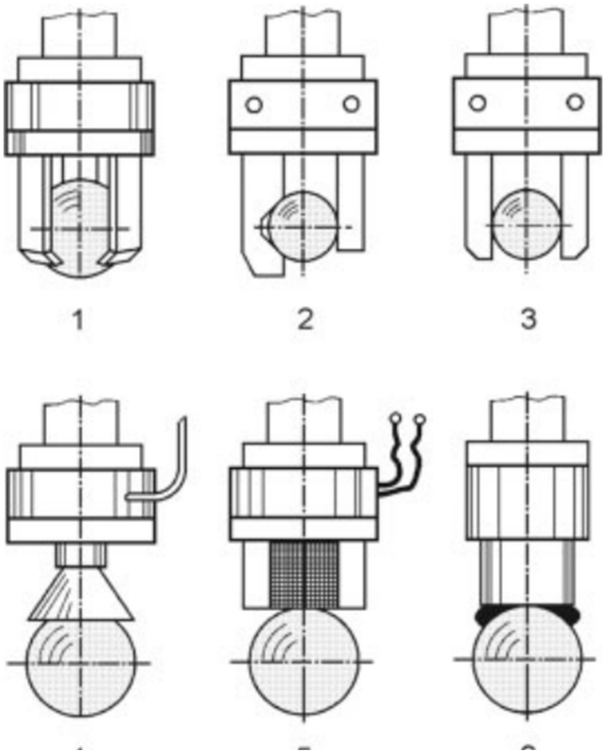

Fig.5. Possibilities for prehension of a spherical object

1. Pure enclosing without clamping.
2. Partial form fit combined with clamping force.
3. Pure force closure.
4. Holding with vacuum air (pneumatic force closure).
5. Retention using magnetic field (force field).
6. Retention using adhesive media.

3.1 Type of Prehension in Grippers.

Astrictive gripper: An astrictive field is one that produces binding forces. This field can be caused by magnetism, electrostatic charge displacement, or air movement (vacuum suction)**.**

Basic jaw (universal jaw): The moving portion of an impactive gripper is called the basic jaw, or universal jaw. The fundamental jaw, which is an essential component of the gripper mechanics, is typically not interchangeable. On the other hand, extra fingers may be added to the basic jaws to meet certain needs.

Chemoadhesion: Contigutive prehension force by chemical actions is known as chemoadhesion. Typically in the form of a single-use or permanent adhesive.

Contigutive gripper: Touching is contigutive. Contigutive grippers are those whose surface has to come into direct touch with the object's surface in order to cause prehension. Thermal and chemical adhesion are two examples.

Electroadhesion: Prehension force by means of an electrostatic field.

Magnetoadhesion: Prehension force by means of a magnetic field (permanent or electrically generated).

Thermoadhesion: Contigutive prehension force by means of thermal effects. Usually in the form of freezing or melting.

3.2 Type of Mechanisms

Based on the mobility of the robotic grippers, exists three main categories that classify the design of the grippers:

Completely constrained, underconstrained, and deformable. Inside those categories, there are various subdivisions based on the actuation mechanisms.

3.2.1 Completely Constrained Gripper Mechanism

A Completely constrained finger mechanisms are devices with a DOF equivalent to their number of actuators, which allows the trajectory of the tip of the finger to follow a predefined path. Note that the number of DOF is computed using the Gruebler-Kutzbach

equation presented below:

$$M = 3L - 2J$$

where M is the total DOF

L is the number of links, and

J is the number of joints.

3.2.2 Compliant Mechanism

A compliant mechanism is pliable and uses elastic deformations to transfer force and motion. Compliant mechanisms are lightweight because they contain fewer moving parts. Because compliant mechanisms require fewer assembly parts than rigid connections, they are more affected by friction. On compliant mechanisms, the fewer assembly parts mean less noise and unwanted nonlinear effects like backlash. The majority of compliant mechanisms are made of 3D printed materials, which lowers the cost of production. The flexible links have a lower output torque capability than stiff links because they are significantly weaker.

3.2.3 Rigid Links

Rigid linkages, in contrast to compliant mechanisms, are able to provide a high output torque without sacrificing their rigidity. Force sensors are necessary for this gripper mechanism to prevent damage to the things it is manipulating. The purpose of these grippers is to give the workpieces a secure and solid hold. Rigid grippers have a set, unchangeable structure in contrast to compliant or flexible grippers, which can conform to the shape of the object. Sturdy grippers provide stability while grabbing, guaranteeing that the object being grasped stays firmly in place without undue distortion. Rigid grippers' mechanical designs can have parallel jaws or various arrangements that best fit the demands of the particular use case. Rigid grippers are nonetheless flexible and capable of handling a variety of objects with regular shapes, even though they might not be as adaptive to changing object shapes as certain other gripper kinds.

3.2.4 Underconstrained Gripper mechanisms

When compared to fully constrained Gripper mechanisms, underconstrained ones enable a wider range of motion. Because the DOF is greater than the number of actuators, there is more flexibility to handle objects with irregular shapes, which accounts for the higher motion. Typically, springs are used to passively actuate the extra DOF in order to sustain the structure. Compared to underconstrained compliant mechanisms, underconstrained rigid gripper mechanisms can support a higher load capacity. When compared to fully constrained gripper mechanisms with rigid linkages, their load capacity is still rather modest. As a result, their mean output load capacity is achievable. Rigid links have the drawback of requiring more rigid links than fully restricted mechanisms. Therefore, bulkiness may be an issue for some gripper mechanisms.

3.3 Vacuum Gripping force estimation

The basic formula F=PxA is used to calculate the force of the suction cup with:

F is force

P is pressure.

A is the contact area (the size of the suction cup surface)

This is derived from the definition of pressure, which is P = F / A.

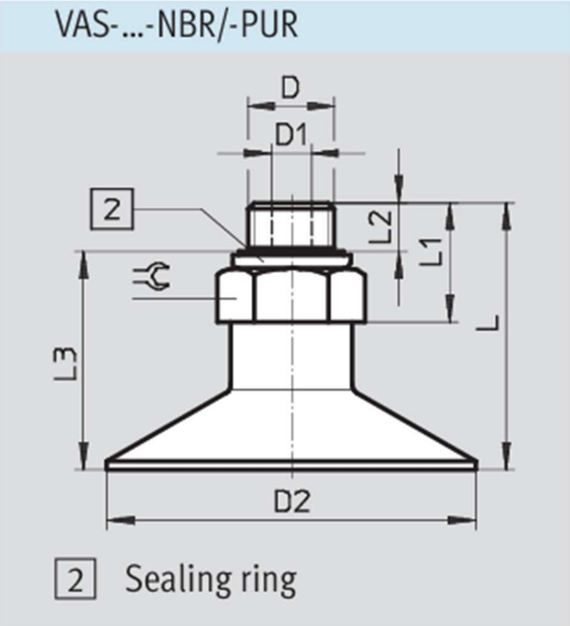

Fig. Schematic Diagram of Suction cup

Technical Data

Type	D	D1	D2	L	L1	L2	L3	🔧
VAS-55-1/4-PUR	G 1/4	4	55	32.5	19	5.8	26.7	17

CHAPTER 4

METHODOLOGY

4.1 Design Phase

CATIA V5 R20

CAD software Used.

- Design Workbenches.
    - Mechanical Part Design.
    - Assembly Design.
- Mechanism Creation & Dressup
    - DMU Kinematics.
    - Delmia Device Building.

CATIA (Computer-Aided Three-Dimensional Interactive Application) is a powerful and comprehensive software suite for computer-aided design (CAD), computer-aided engineering (CAE), and computer-aided manufacturing (CAM). Within CATIA, mechanical part design is a significant module that focuses on creating and designing 3D models of individual components or parts. The created parts are then assembled to create the product in Assembly design workbench. The DMU Kinematics module specifically focuses on the simulation and analysis of mechanical motion in the virtual environment. DMU Kinematics allows to simulate the motion of mechanical systems and analyse the behaviour of moving parts. This includes the study of joint movements, constraints, and the overall motion of assemblies. Users can create and simulate mechanisms within CATIA. This involves defining joints, constraints, and connections between components to accurately represent the physical behaviour of a mechanical system. The module supports various types of joints, such as revolute joints (rotational), prismatic joints (linear), cylindrical joints, and more. Users can define these joints to model the connections between different parts and specify their degrees of freedom. DMU Kinematics includes features for detecting and analysing collisions between moving parts. This helps in identifying potential interferences and ensuring that the designed mechanism operates smoothly without interference.

The design concept of the end effector were sketched and later converted to drawings and 3D models in to the CATIA software. Design iterations were performed to select the best feasible design for fabrication of the prototype. The first design included the concept sketching with the integration of mechanical jaw gripping and vacuum gripping. The design was inspired from grippers in the shape of octopus tentacles used in soft robotic applications.

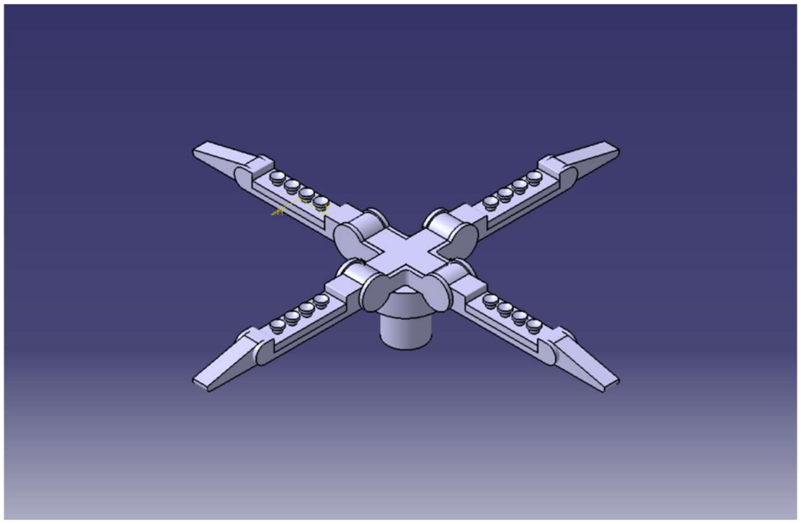

Fig.6. Design 1 (open position)

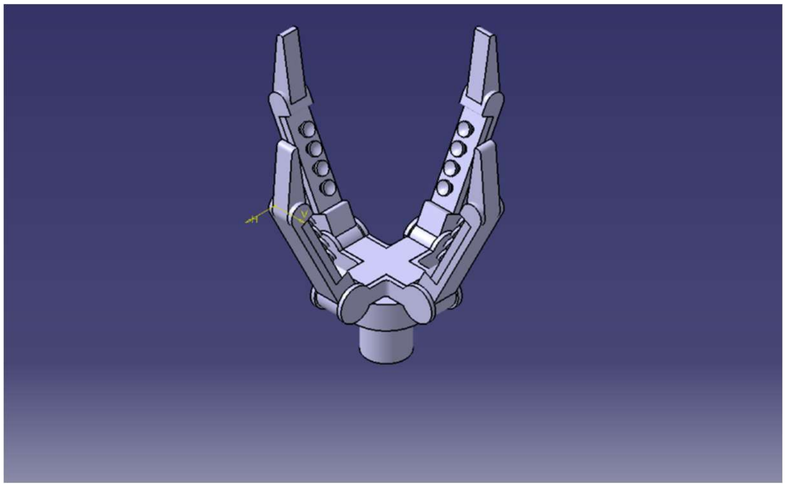

Fig7. Design 1 (close position)

This design had challenges associated such as :

- Each arm should be operated with rotary actuators / Servos.
- It can lead to increased weight of the End Effector.
- High Power Requirements.
- Complexity in Design & Fabrication due to increased number of parts

In order to overcome this issue another design were made which used the basic screw mechanism for jaw actuation. A rotating lead screw with a nut connecting the four arms (jaws) through links were created along with a prismatic movement for the vacuum cup in each arm. A lead screw mechanism, also known as a power screw or translation screw, is a mechanical device that converts rotational motion into linear motion. It typically consists of a threaded screw (helical or spiral groove) and a nut, where the screw is turned, causing the nut to move along its length. This mechanism is commonly used in various applications, including linear actuators, positioning systems, and lifting devices.

The designed model has five Parts including:

1. Main Frame
2. Jaws
3. Nut
4. Links
5. Vacuum Cups

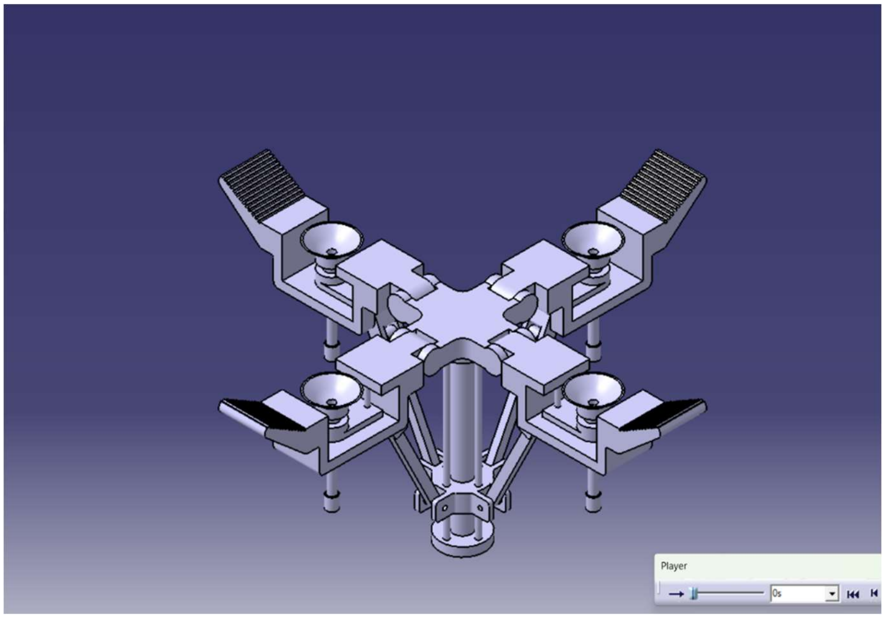

Fig.8. Four Jaw gripper Design (friction gripping)

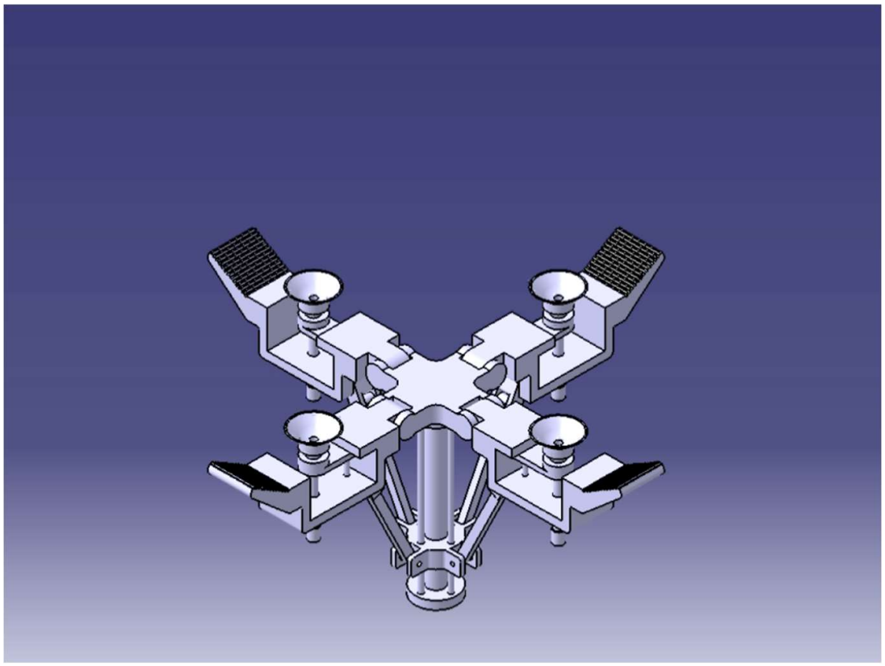

Fig 9. Four Jaw gripper Design (vacuum gripping)

With all four jaws actuating from a single source, there may be limitations in achieving independent control of each jaw. This limitation can affect the gripper's ability to adapt to irregularly shaped objects or handle tasks that require different levels of force on individual jaws. The lack of independent control may limit the gripper's adaptability to handle a diverse range of objects. Gripping mechanisms that cannot adjust independently to the shape of each object may struggle with irregularly shaped or fragile items. All industrial standard grippers such as designs with Four jaw , Three jaw and two jaws where created.

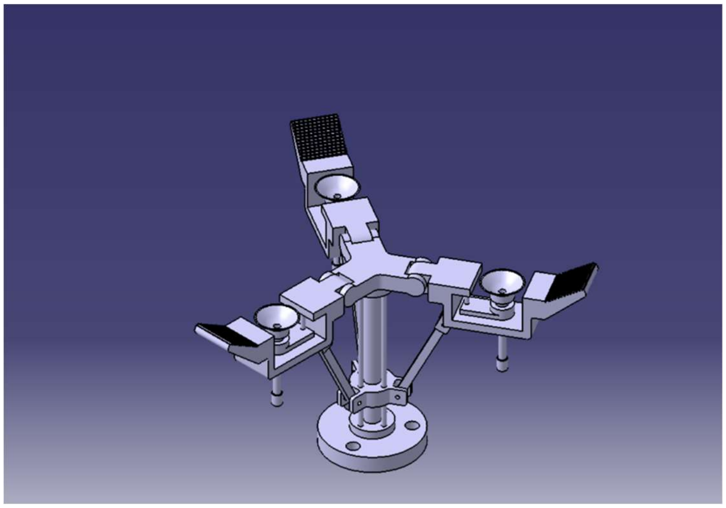

Fig 10. Three Jaw gripper Design

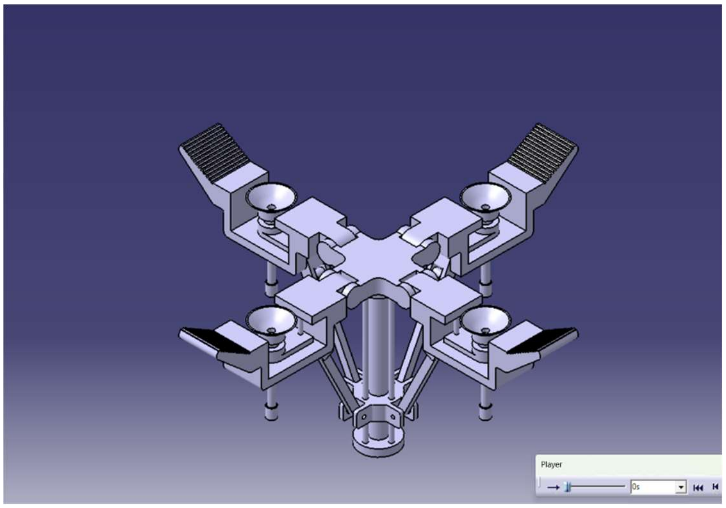

Fig 11. Four Jaw gripper Design

The two jaw design stands better in the design iteration stage because the two-jaw grippers are often simple in design, making them reliable and easy to use and their straightforward mechanics contribute to fewer points of failure, enhancing overall reliability in operations. These grippers have two opposing jaws that come together to secure an object. Two-jaw grippers can achieve fast grasping and release actions due to their simple mechanical design. They can adapt to a wide range of object shapes and sizes. This adaptability makes two-jaw grippers suitable for applications where the gripper needs to handle diverse items. They can be adapted for handling objects of varying geometries, providing flexibility in applications. Considering the integration of vacuum gripping on the end effector, on an opposing two jaw gripper only two suction points can be provided which is not sufficient to hold the objects. The design were modified to a four jaw gripper with a pair of jaws on either side of the central main frame opposing each other. This could reduce the Slip of grasped object during robotic motion and they can be scaled up or down to accommodate different load capacities. This scalability makes them suitable for a variety of applications, from small electronic components to larger industrial objects. Four Vacuum points can be provided in this design which could improve the vacuum gripping capability of the gripper.

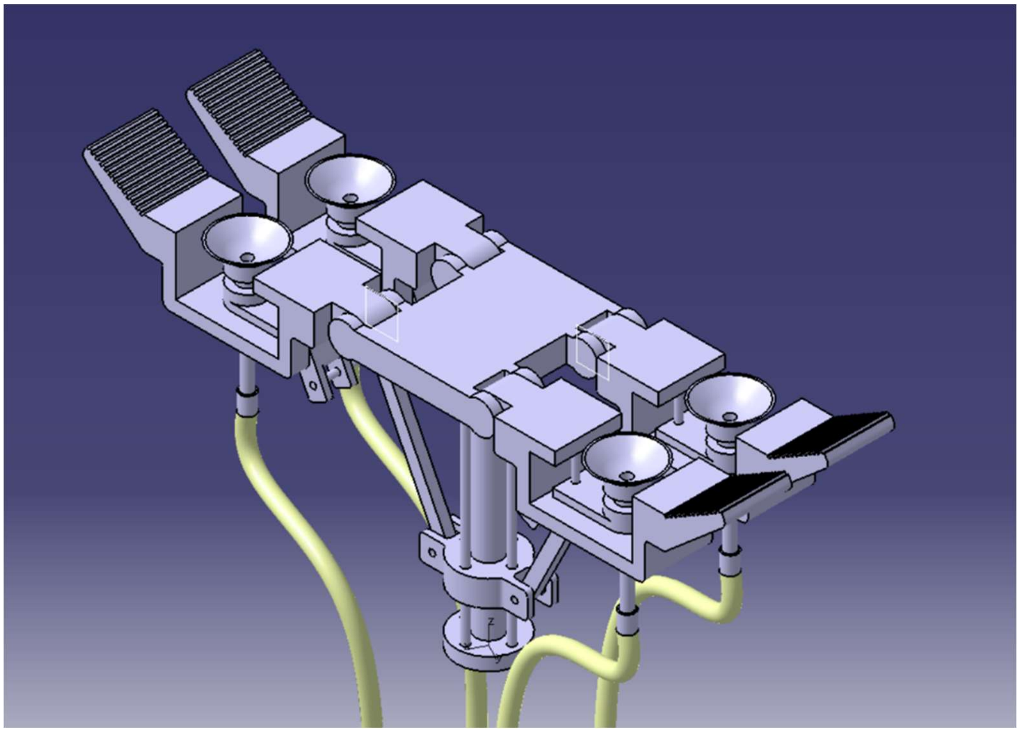

Fig 12. Four Jaw gripper Design with opposed jaws

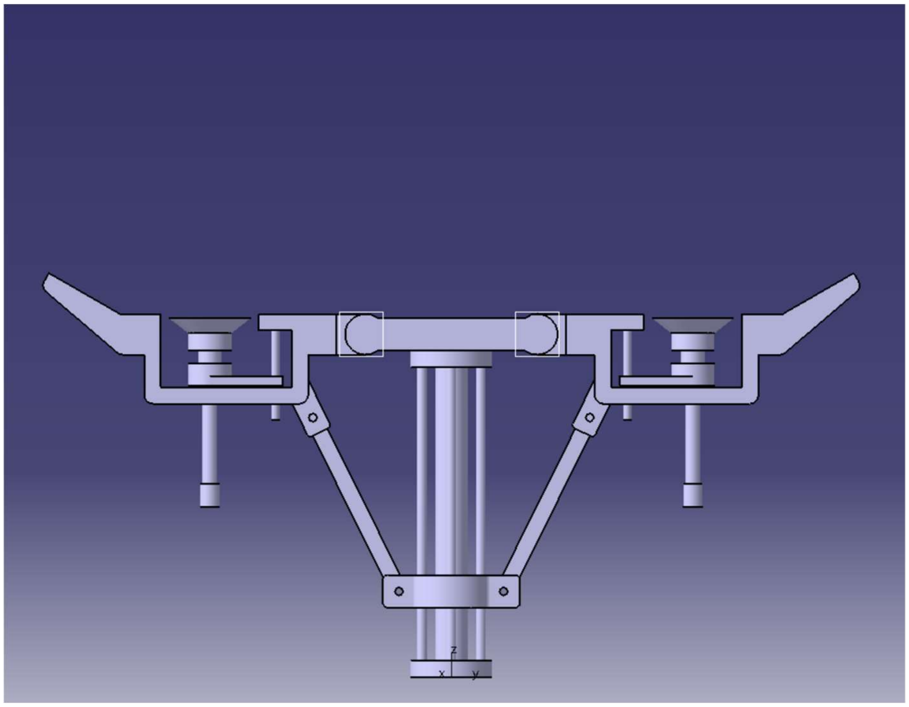

Fig 13. Vacuum Gripping Mechanism in opposed jaw gripper

Side view (OFF)

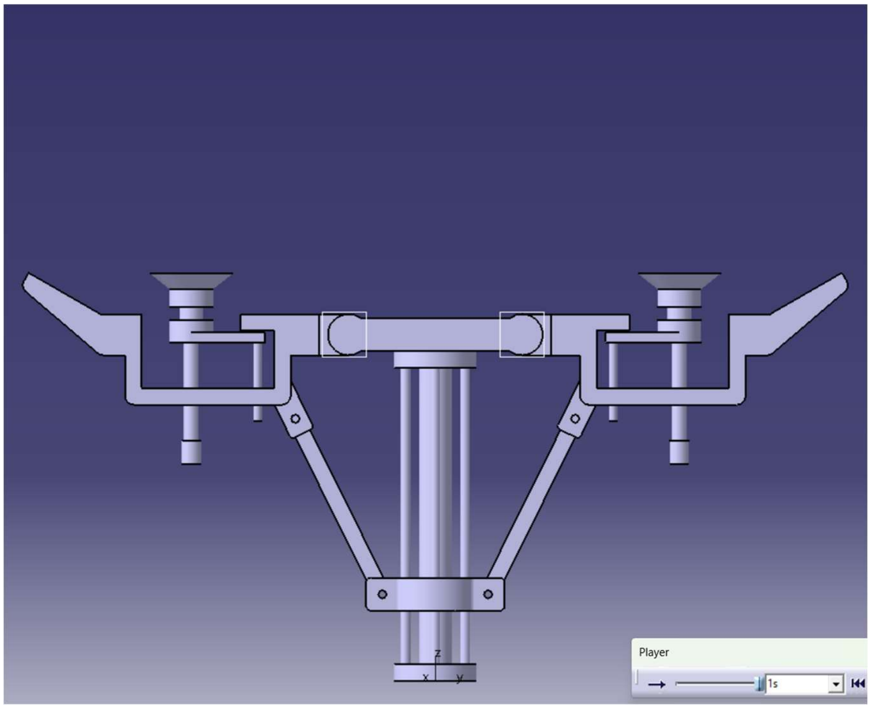

Fig 14. Vacuum Gripping Mechanism in opposed jaw gripper

Side view (ON)

CHAPTER 4

SIMULATION

4.1 Virtual Simulation

DELMIA, which stands for Digital Enterprise Lean Manufacturing Interactive Application, is a set of applications within the larger CATIA platform focused on digital manufacturing and production planning. DELMIA V5 provides a range of digital manufacturing solutions, allowing users to simulate and optimize manufacturing processes in a virtual environment. The software enables users to plan and optimize production processes, including resource allocation, scheduling, and layout design. A robot centered Flexible Manufacturing System layout were created using delmia v5 software with a conveyer system and a workstation. A central robot manufactured by fanuc were used to perform the simulation. The robot end effector trajectory were planned using the jog mechanism considering the cell layout.

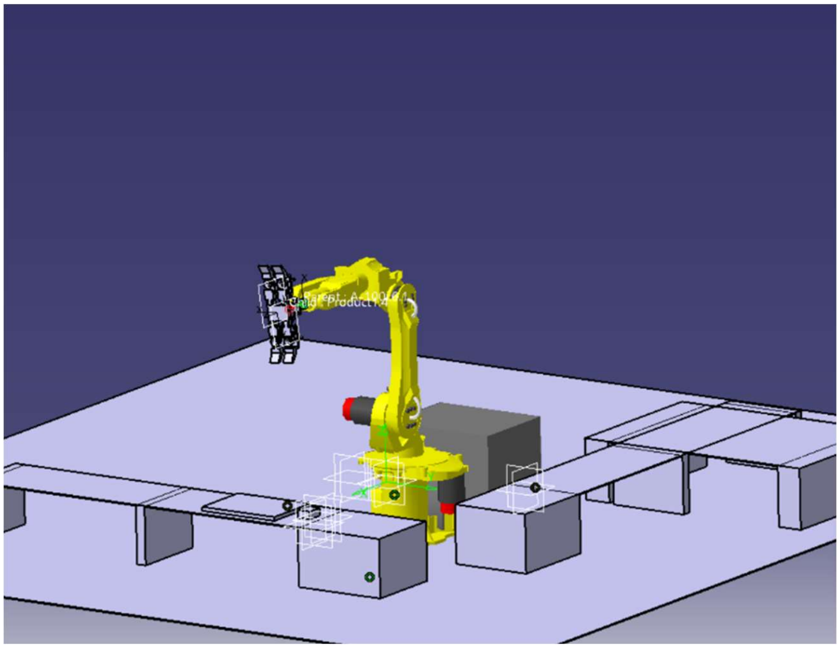

Fig 15. Process simulation with robotic manipulator and E.O.A.T

- A spherical work volume is obtained along with the End of arm tooling (E.O.A.T).This is helpful in designing the cell layout and the workspace with maximum reach.
- The time taken to complete the pick and place operation using the end effector in the workcell is obtained as 13.414 seconds

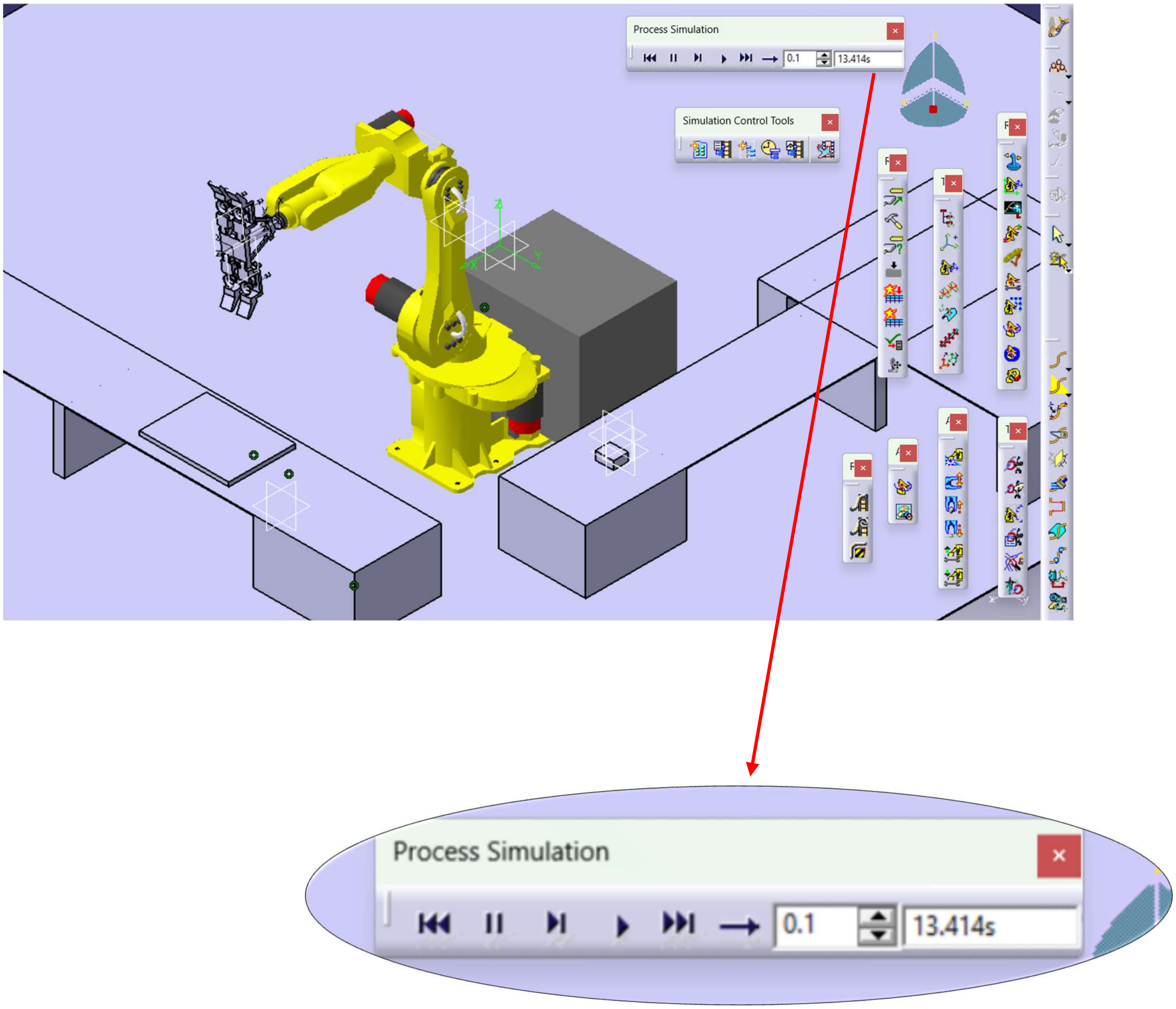

Fig 16. Process simulation result

CHAPTER 5

FABRICATION OF PROTOTYPE

The Design is finalized for fabrication with linear actuator mechanism. The parts for assembly of the prototype is fabricated by using 3d printing by using ABS and PLA as materials. The Fabricated Parts include Arm, Central post, Nut and Links .The Motor Holder is fabricated using Forex sheet with 8mm thickness. Slicing software used for 3d printing is flash print by flash forge. The Fabricated parts are then assembled according to the final rendered assembly of the prototype

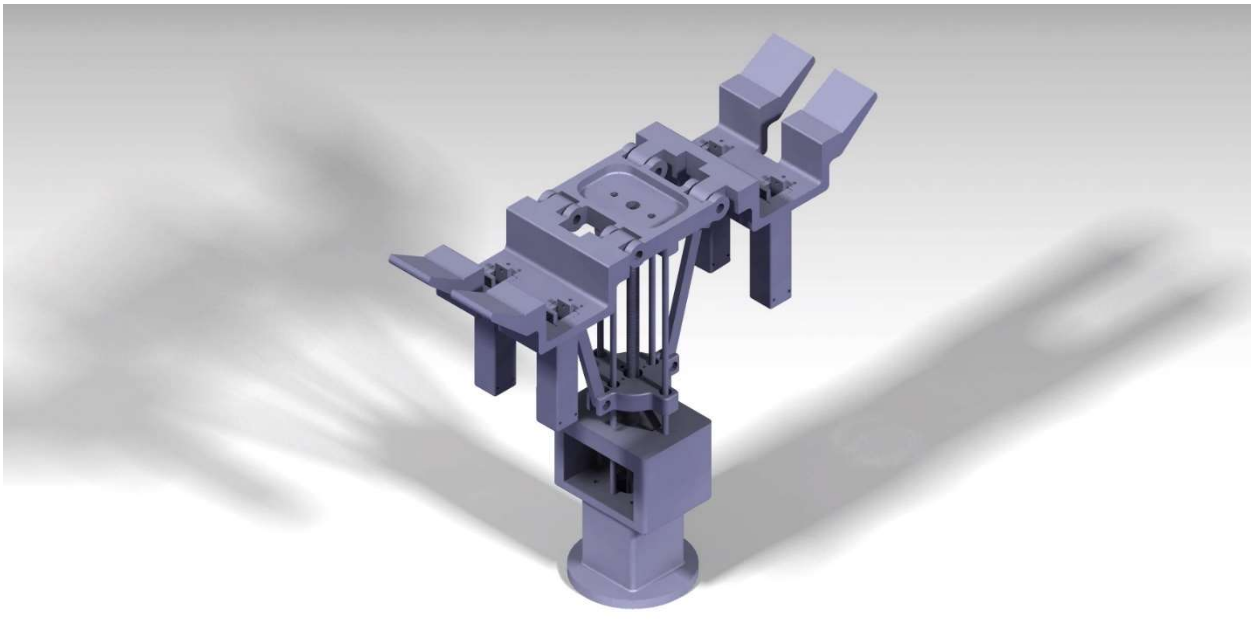

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Fig 17. Rendered Isometric view of Gripper Assembly

Other parts for assembly include Stepper Motor NEMA 23,N20 -12V- 60rpm - DC motor for linear actuation. Ball Bearings (3mm x 10mm x 4mm) 623Zz. Pillow Block Flange Bearing (KFL00). Linear Motion Bearing (LM6UU 6mm). Stepper Motor Driver TB6600 4A, 9-42V. Pneumatic Connectors, Solenoid valve, Hoses and Fittings. Suction Cup for vacuum gripping.

5.1 Fabricated Components for Assembly.

5.1.1 Arm

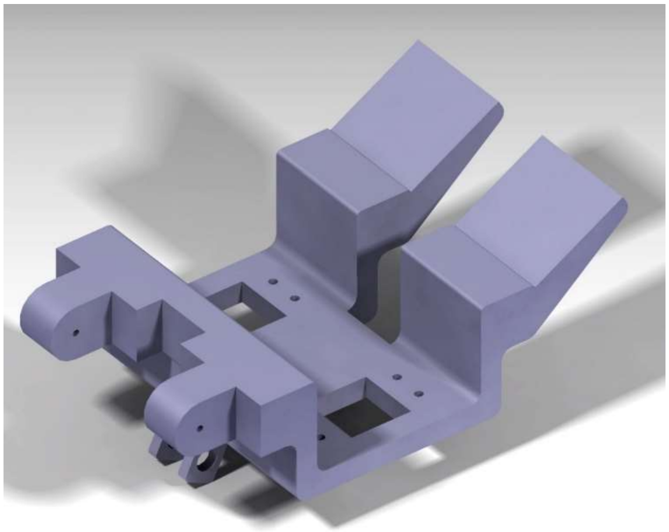

Fig 18. 3D model of Arm

Fig 19. 3D printed Arm

The jaw or arm of the end effector is responsible for gripping and manipulating objects. This fundamental task underpins a wide array of industrial applications, from assembly lines to warehouse logistics. The Jaw is pivoted to the central post and is moved with the help of links connected between the arm and the central nut. The Design of jaws are in such a way that it have slots to attach linear actuators to move the vacuum cups up and down.

5.1.2 Central Post

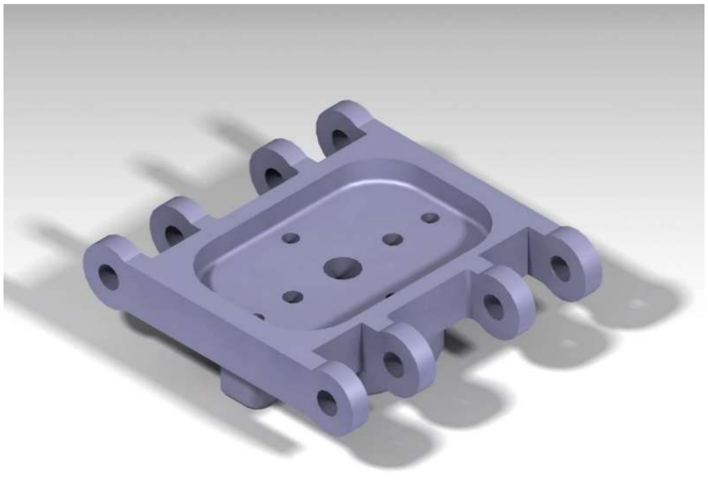

Fig 20. 3D model of Central Post

Fig 21. 3D printed central post

The central post holds the two jaws of the end effector. One end of the lead screw is inserted into the pillow flange bearing placed inside the central post and other end to the stepper motor through a motor shaft coupler. Slots are provided on the central post for inserting the 8mm Stainless steel rods that holds the central post and the motor holder through which the nut slides.

5.1.3 Nut

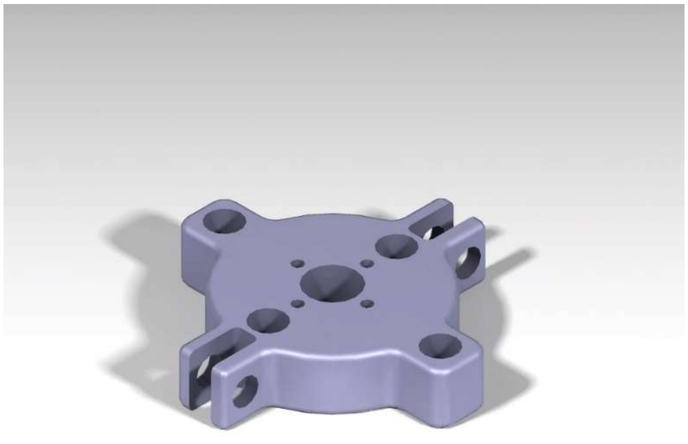

Fig 22. 3D model of Nut

Fig 23. 3D printed Nut with bearings and brass thread insert

The Nut is fabricated using ABS material. A brass nut is inserted on the centre of the Nut which is in mesh with the central threaded rod. The Threaded rod is rotated with the help of a stepper motor , as the threaded rod is rotated and the nut is held stationary(not rotating) the nut will slide along the screw. This creates a linear movement of the Nut which helps in the opening and closing of the jaws. Slots are provided in the nut for linear bearings which helps in smooth sliding of the nut through the S.S rods. Link rods are connected to the larger ends of the nut which moves the jaws up and down respective to the motor rotation.

5.1.4 Motor Holder

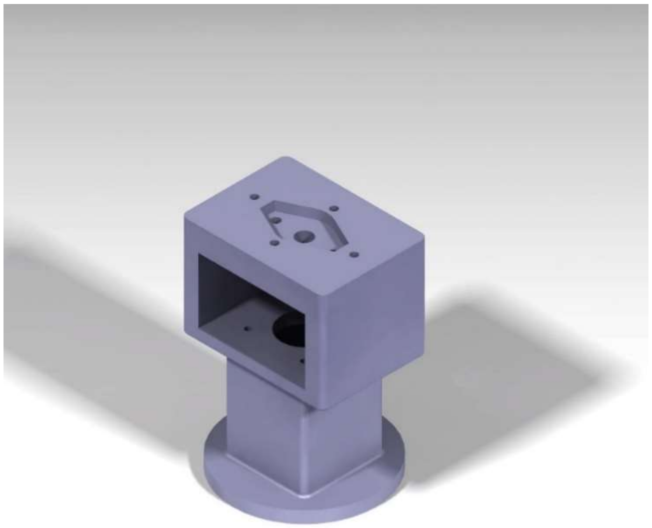

Fig 24. 3D model of Motor Holder

Fig 25. Fabricated model of Motor Holder

The Motor holder is the base of the end effector assembly which provides a provision for placing of the stepper motor. Pillow flange bearings are provided on the top of the motor holder where the lead screw fits in and the end of the lead screw is connected to the stepper motor with the help of a shaft coupler.

5.1.5 Links

Fig 26. 3D model of Connector link

Fig 27. 3D printed Connector link

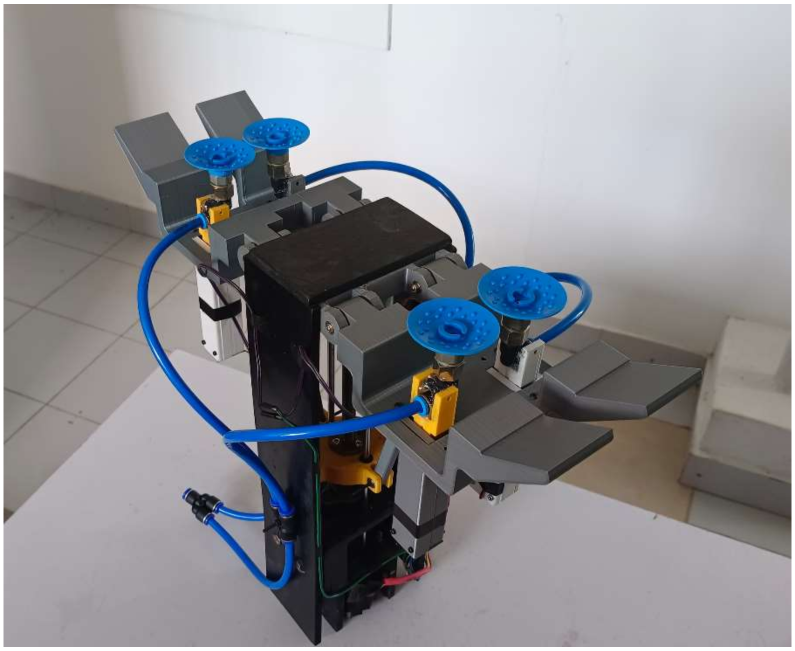

Fig 28. Finalized assembly of the end effector prototype.

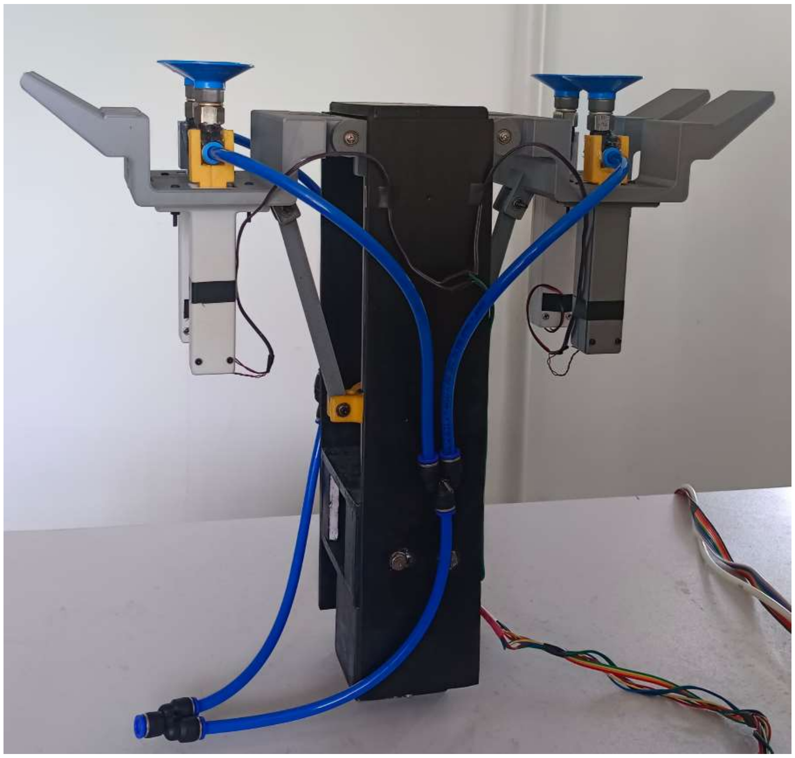

Fig 29. Finalized assembly of the end effector prototype (side view).

Limit switches are installed at the two extreme ends of the end effector so that any further movement of the jaw is restricted beyond the maximum and minimum points. When the nut comes in contact with the limit switch the motor rotation is stopped restricting the jaw movement.

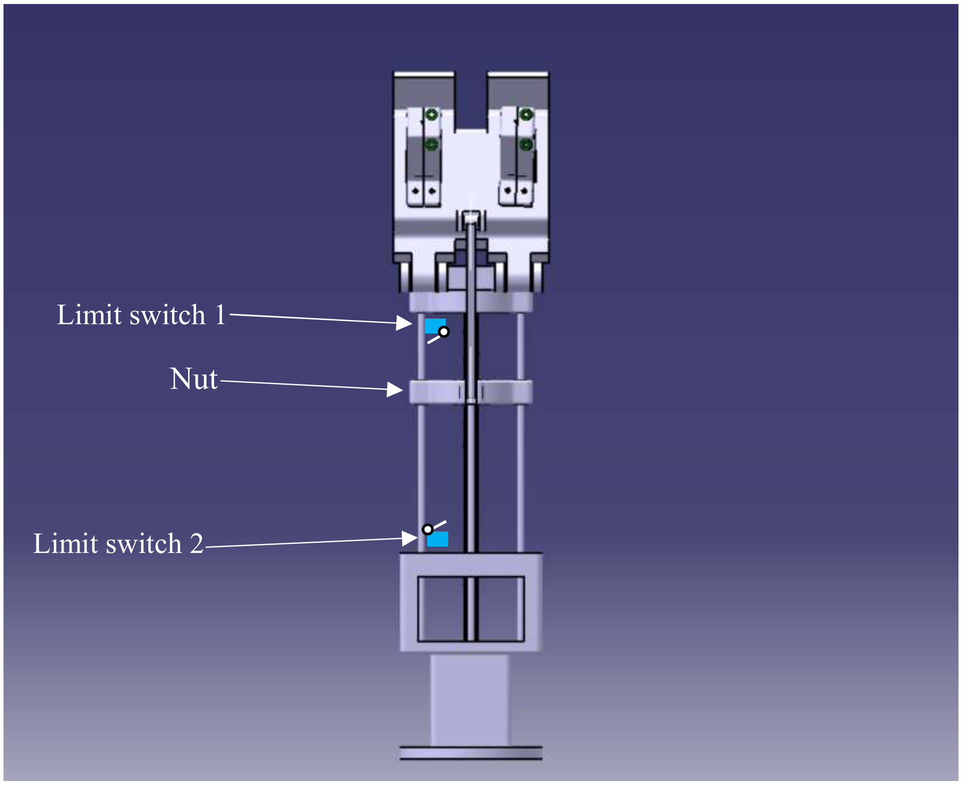

Fig 30. Limit switch integration on end effector.

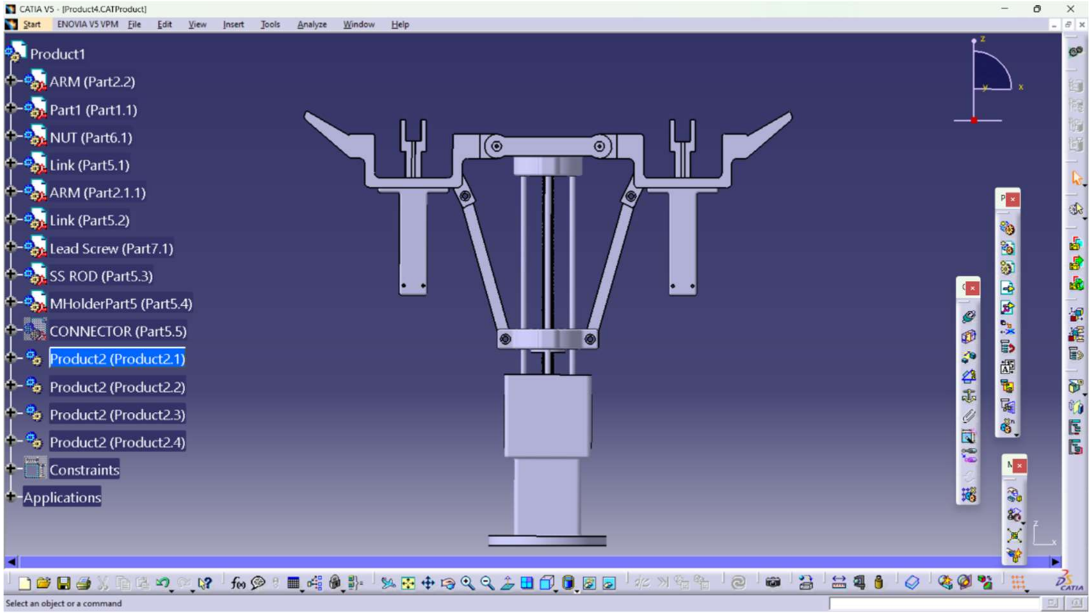

Fig 31. Side view of the end effector with linear actuator assembly.

5.2 Fabrication of Linear Actuator

Within the design of the end effector, the vacuum suction cups are strategically situated within a recessed cavity nestled on the arm's structure. This configuration ensures both protection and accessibility of the suction cups during operation. Leveraging a linear actuator mechanism, it orchestrated a seamless process wherein the cups elegantly emerge from the cavity when needed to delicately grasp fragile objects. This design not only safeguards the integrity of the suction cups but also optimizes their functionality, enabling precise and efficient pick-and-place maneuvers.

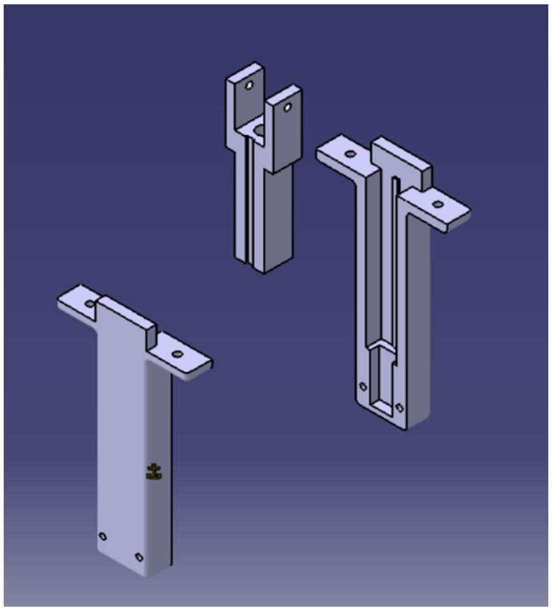

Fig 32. Parts of linear actuator.

Linear actuators are devices that convert rotary motion into linear motion. It utilizes a screw mechanism to drive the movement of vacuum suction cups. It consists of a threaded shaft (screw) and a nut. When the screw is rotated, the nut moves along its thread, thereby converting the rotary motion into linear motion. The threaded screw is attached to N20 gear motor with the help of a shaft coupler. By changing the direction of rotation of the DC Motor the plunger of the linear actuator can be moved up or down which in turn moves the vacuum suction cups.

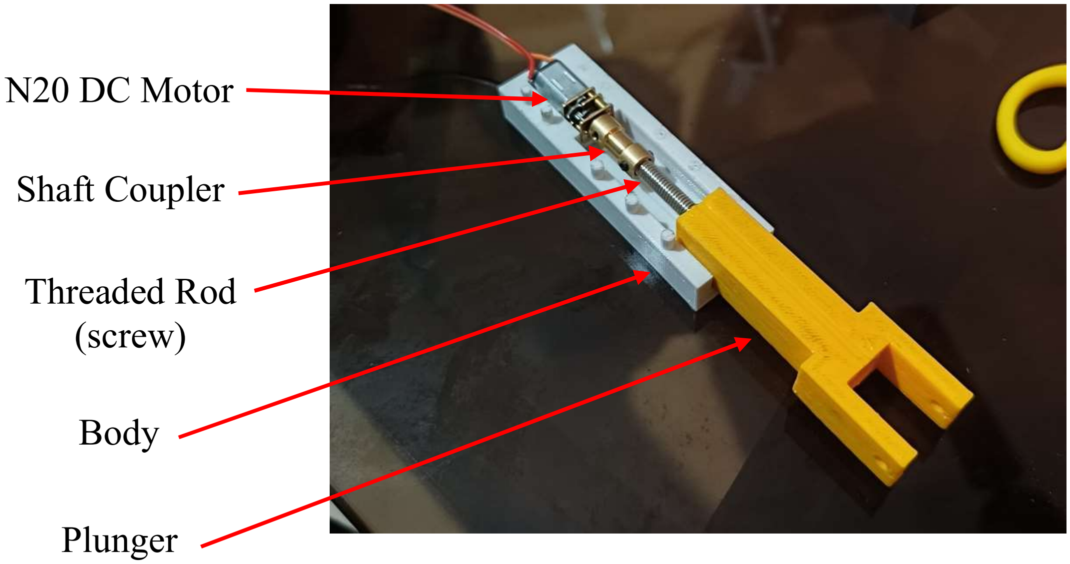

Fig 33. Linear Actuator Assembly

The parts of the linear actuator is 3d printed and the components are assembled. A linear actuator consists of two body, plunger, motor, screw and nut arrangement and a shaft coupling. The end effector design has four vacuum suction cups therefore for similar linear actuators are used with two of them in each arm.

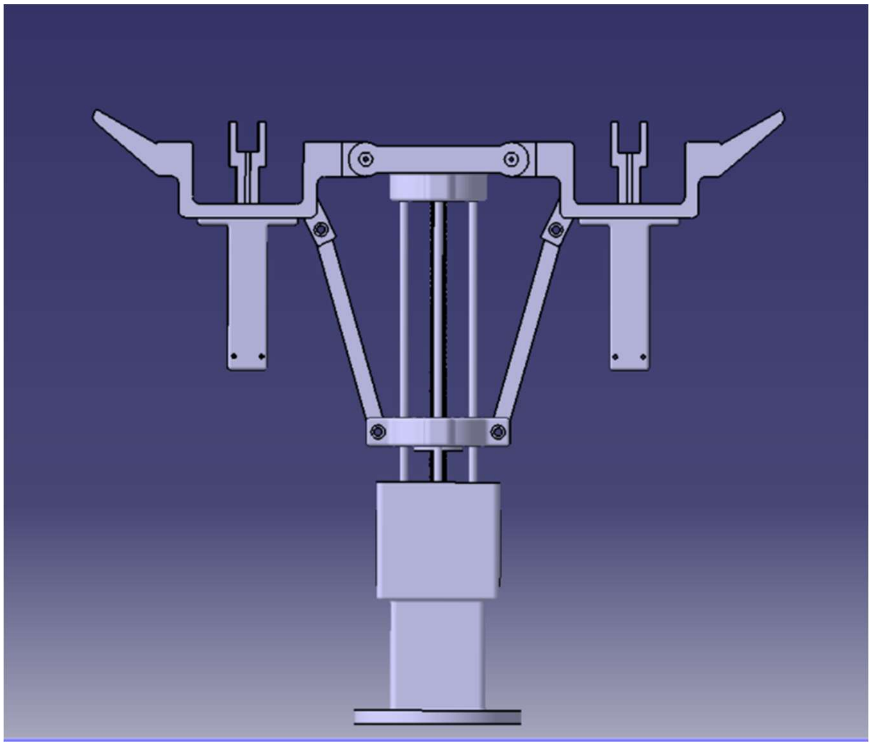

Fig 34. Linear Actuator Actuation

5.3 Wiring Circuit

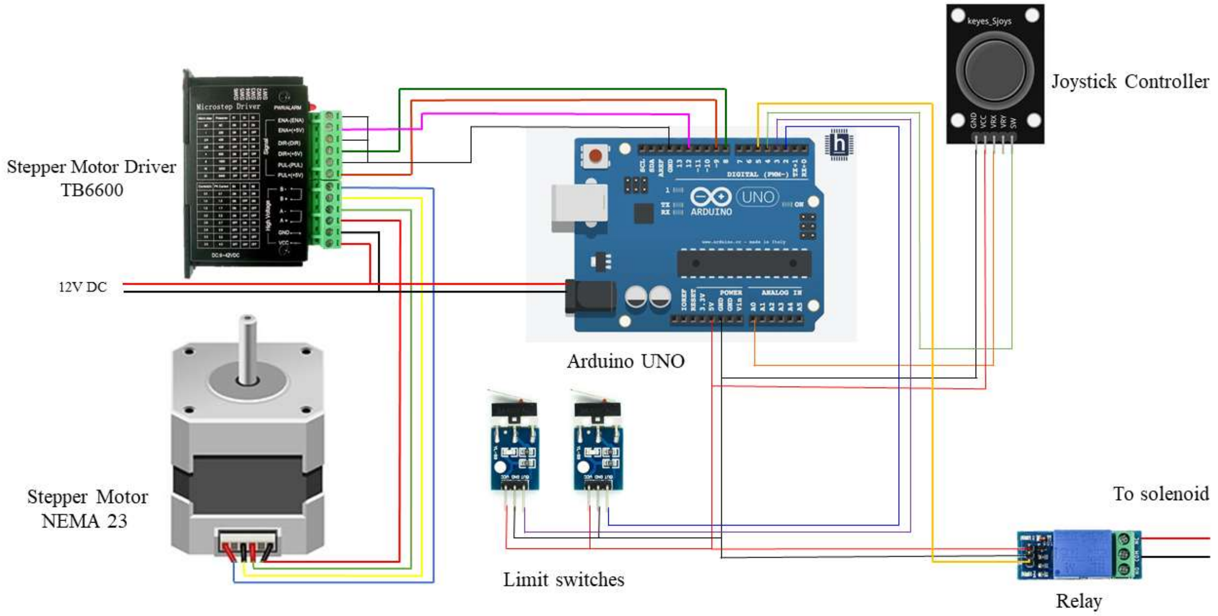

Fig 35. Circuit diagram of the gripper

5.3.1 Components

- **Joystick controller**: This provides the input signal to the Arduino. By moving the joystick in different directions, the operator can send different control signals.

- **Arduino Uno**: This is a microcontroller board that can be programmed to read input signals from the joystick and send control signals to the stepper motor driver. The Arduino Uno is powered by a separate 12V DC power supply.

- **Stepper motor driver (TB6600)**: This specialized integrated circuit is used to control the stepper motor. It receives control signals from the Arduino Uno and translates them into signals that the stepper motor understands. These signals determine the speed and direction of the motor's rotation. Stepper motors require precise current control to operate efficiently and avoid overheating or damage. The driver regulates the current supplied to the motor windings, ensuring optimal performance and preventing excessive current draw.

- **Stepper motor (NEMA 23)**: NEMA 23 stepper motors typically offer higher torque compared to smaller stepper motor sizes, making them suitable for applications requiring moderate to high torque output. This makes them well-suited for tasks such as CNC machines, 3D printers, robotics, and industrial automation.

- **Limit switches**: These are safety switches that can be used to prevent the stepper motor from moving beyond a certain point. They are not explicitly shown as connected in the diagram but their possible placement is indicated.

5.3.2 Working

The user/operator manipulates the joystick on the joystick controller to indicate the desired direction of movement for the stepper motor. The Arduino Uno, acting as the microcontroller in the system, reads the analog signals from the joystick controller. It utilizes its analog-to-digital converter (ADC) to convert the continuous analog voltage signals from the joystick into digital values that can be processed by the Arduino. Based on the digital values obtained from the joystick input, the Arduino Uno generates a control signal that determines the direction and speed of rotation for the stepper motor. This control signal typically consists of pulses with varying frequency and duration, depending on the desired movement indicated by the joystick input. The Arduino Uno communicates with the stepper motor driver via a suitable communication protocol, such as pulse-width modulation (PWM). The control signal generated by the Arduino is transmitted to the stepper motor driver, which interprets and processes it to drive the stepper motor accordingly.

The stepper motor driver receives the control signal from the Arduino Uno and translates it into signals that the stepper motor can understand and act upon. This translation involves controlling the current flowing through the stepper motor coils to generate precise sequences of electromagnetic pulses, which in turn induce step-wise rotation of the motor shaft. Finally, the stepper motor rotates in response to the signals generated by the stepper motor driver. The direction and speed of rotation correspond to the control signal received from the Arduino Uno, reflecting the user's input via the joystick controller. As the stepper motor rotates, it rotates the lead screw which in turn moves the connected mechanical components of the end effector. This creates the opening and closing of the jaws of the end effector

A relay is used to control a solenoid valve in the vacuum circuit. When the solenoid is energized, that is the relay is powered ON, it opens the valve allowing the vacuum to act on the suction cups which grasps an object. When the relay is in OFF stage the solenoid valve is de-energized which blocks the vacuum and drops the grasped object. The time required for relay activity (ON state) can be programmed based on the time obtained from real-time simulation.

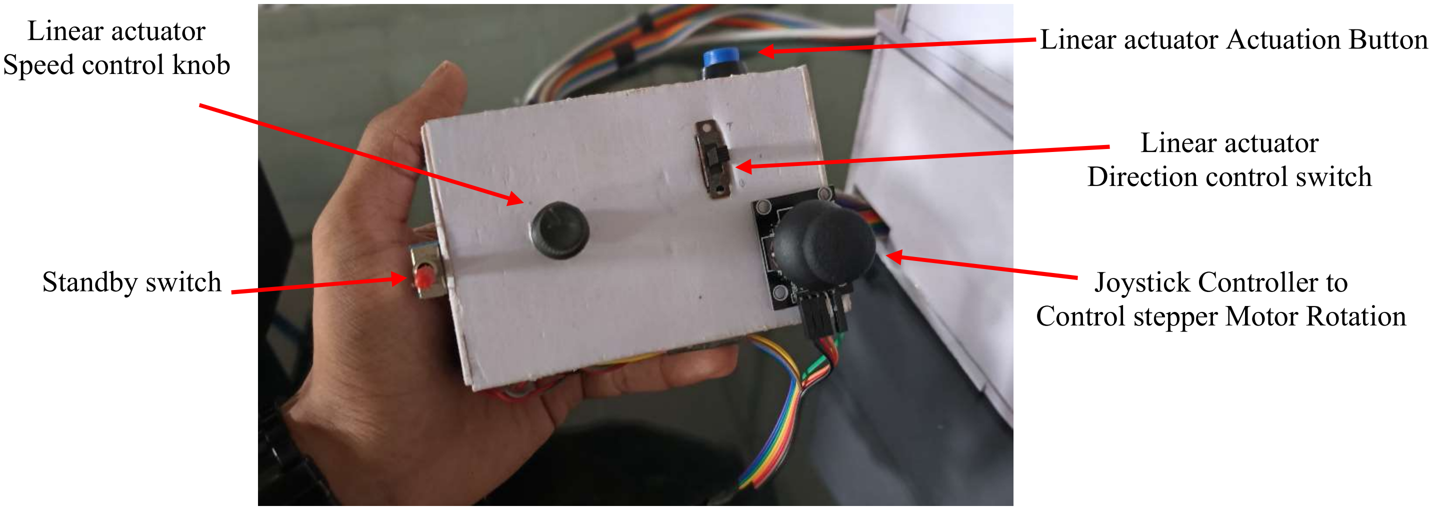

Fig 36. End effector Control Panel.

5.4 Vacuum Circuit

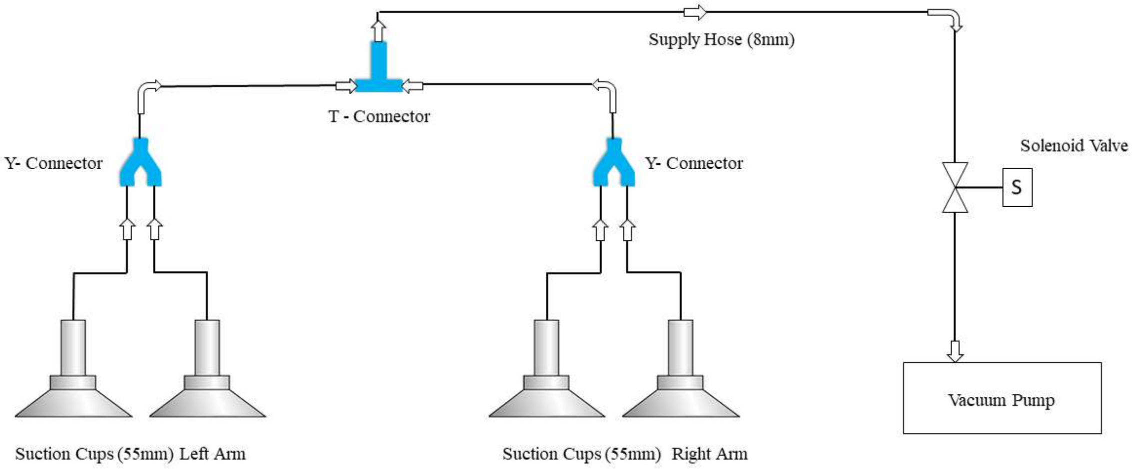

Fig 37. Vacuum circuit.

5.4.1 Components.

- **Vacuum Pump**: This is the device that creates the suction. It extracts air from the enclosed space, creating a partial vacuum.
- **Supply Hose**: This hose connects all the components together ensuring a closed circuit
- **T-Connector**: This three-way connector allows the connection of two separate hoses to the vacuum pump.
- **Y-Connector**: This is a three-way splitter that creates two branches from a single hose. There are two Y-connectors, one for the left arm and another for the right arm (jaw).
- **Solenoid Valve (S)**: This is a valve controlled by an electric current. It regulates the vacuum pressure by opening or closing the flow path.
- **Suction Cups**: These are the components that create suction against a surface. They are connected at the ends of the hoses on the left and right arms.

5.4.2 Working

When the vacuum pump is activated, initiating the process of air extraction from the system. The pump creates a negative pressure environment within the system, causing air to be drawn out. The vacuum generated by the pump travels through the supply hose, which serves as the main conduit for distributing the vacuum pressure throughout the system. The supply hose leads to a T-connector, where the vacuum is split into two paths. From the T-connector, the vacuum pressure is directed through separate Y-connectors to the left and right arms of the system. These Y-connectors ensure that the vacuum pressure is evenly distributed to both arms, allowing for balanced operation.

When a signal is provided to the solenoid valve (i.e., when it is ON and current is applied), the vacuum pressure from the Y-connectors exerts suction on the suction cups attached to the arms. This suction force enables the suction cups to securely adhere to the surface they are placed on, providing a reliable grip on the objects being handled. When the solenoid valve is de-energized (no current applied), it closes, blocking the vacuum to the supply line. This action disrupts the vacuum pressure within the system, effectively breaking the suction force exerted by the suction cups on the surface they are attached to.

As air enters the system when vacuum is blocked, the vacuum pressure decreases, causing the suction cups to release their grip on the surface. This allows for the detachment of the suction cups from the objects being manipulated, facilitating their movement or release as required.

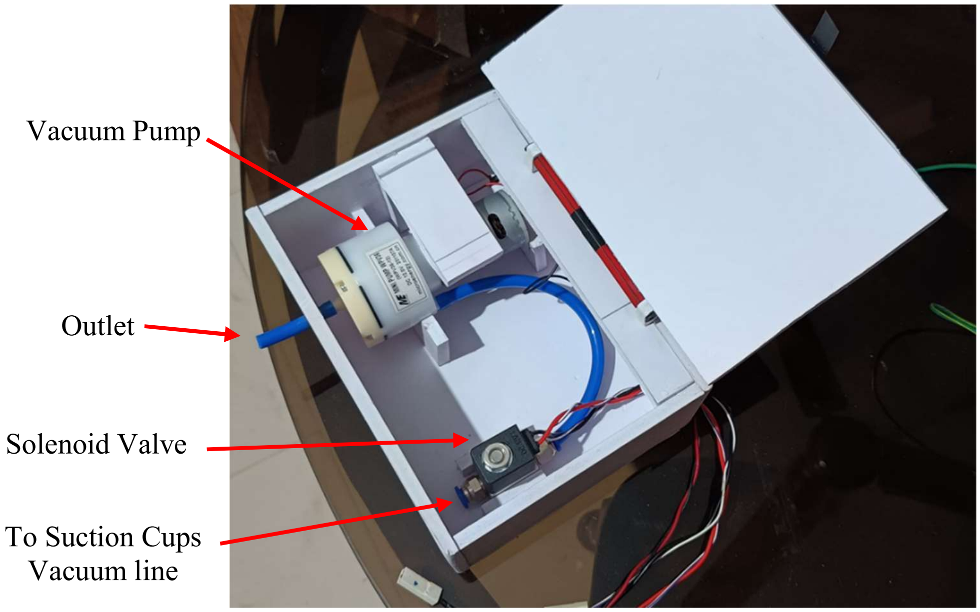

Fig 38. Vacuum Pump and Solenoid Assembly

The vacuum pump used to create suction force is the WPV36 which operate on 12V DC power supply capable of producing a vacuum pressure of – 400mbar which is sufficient to create vacuum force to grip a payload of 2kg as per calculation. The solenoid valve closes and blocks the vacuum in the line according to the trigger signal from the relay. All the electrical equipment are powered by 12V 7Ah battery.

CHAPTER 6

TESTING

The end effector is tested on various parts configurations which include non-fragile cuboid cardboard boxes and polycarbonate sheet. The card board box (Part A) of dimension 12cm x 11cm x 6cm with 1 Kg weight is picked up using the jaw gripping and the polycarbonate sheet (Part B) weighing 500g (30.48cm x 30.48cm) is picked up using vacuum gripping. Another cardboard (Part C) of dimension 26cm x 33cm x 100cm weighing 1.5 kg is lifted using vacuum gripping. The sequence for pick and place operation of each part is illustrated below.

Fig 39. Part A (PICK)

Fig 40. Part A (HOLD)

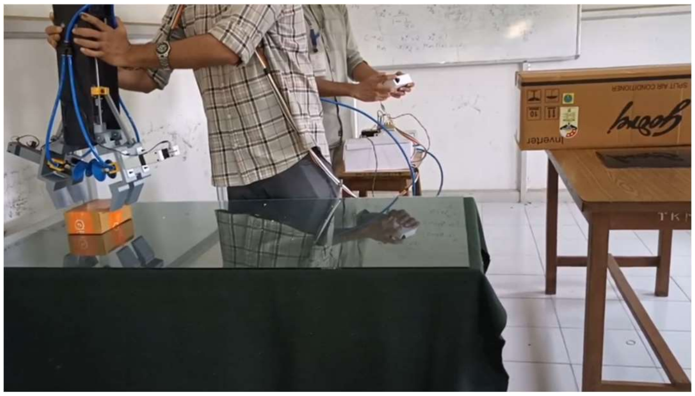

Fig 41. Part A (PLACE)

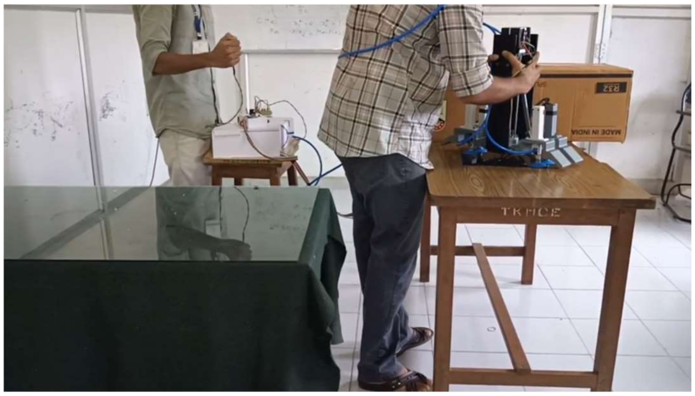

Fig 42. Part B (PICK)

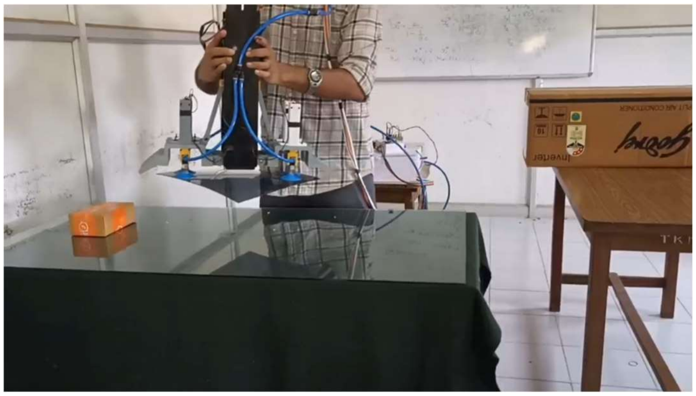

Fig 43. Part B (HOLD)

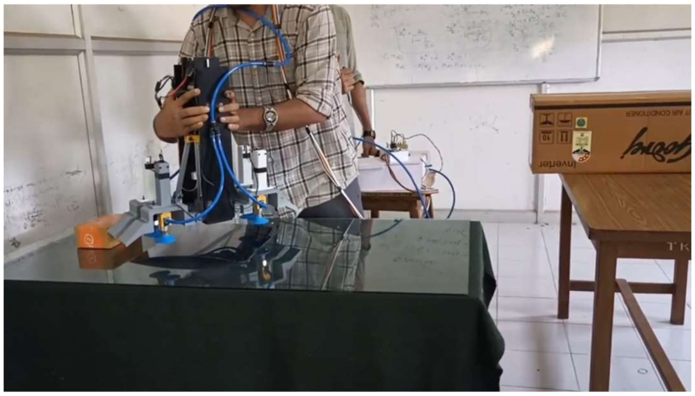

Fig 44. Part B (PLACE)

Fig 45. Part C (PICK)

Fig 46. Part C (HOLD)

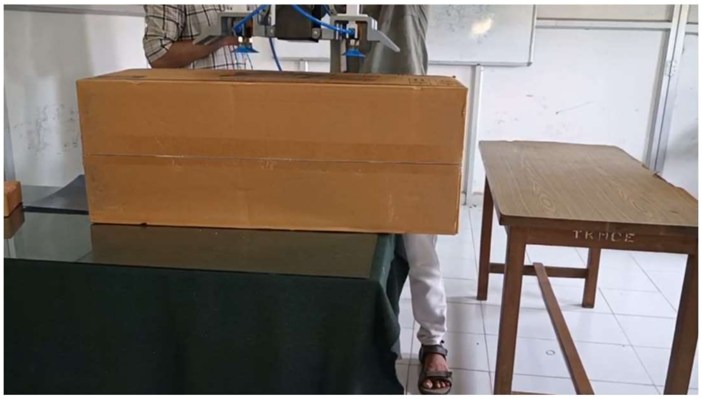

Fig 47. Part C (PLACE)

The testing operation were carried out on different objects made of different materials and of different geometrical configurations. The testing stage was completed without any slip or detachment of the object from the end effector. This ensures that the fabricated prototype can handle fragile & non fragile objects without fail.

CHAPTER 7

CONCLUSION

- The initial phase of the project include design of a versatile robotic gripper capable of handling both fragile and non-fragile objects. Throughout the design stage, multiple iterations were carried out to identify the most suitable design for subsequent simulation and prototype fabrication.
- Utilizing Delmia V5, virtual simulations were conducted, employing industry-standard robotic manipulators such as from Fanuc. These simulations served a dual purpose: not only did they validate the design choices, but they also unveiled a spectrum of possibilities for practical, real-world implementations.
- In the second phase of the project, the focus shifted towards materializing the virtual model. A tangible prototype of the envisioned gripper is crafted, building upon the foundation laid by the CAD model.
- Pick and place operations with the fabricated end effector were carried out on different objects made of different materials with different geometrical configurations. The prototype was able to lift a maximum load of 2kgs during the testing process which was the payload chosen for gripping force calculations.
- Thus the prototype can be scaled up and transformed to a real world industrial end effector according to the specific application.
- By developing a gripper that seamlessly integrates two distinct grasping techniques, a new avenue of possibilities for robotic manipulation tasks has been opened up. The solution not only streamlines the process of handling different types of objects but also improves efficiency and adaptability in dynamic environments. The integration of multiple grasping techniques within a single gripper has the potential to revolutionize industries ranging from manufacturing and logistics to healthcare and beyond.

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