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CONCEPTUALIZATION AND CONSTRUCTION OF RACK AND PINION TYPE ELECTRICAL GRIPPER

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ABSTRACT:
This project focuses on the design, development, and analysis of a rack and pinion type electrical gripper, aiming to enhance the capabilities of robotic manipulation systems in industrial and manufacturing settings. The gripper utilizes the rack and pinion mechanism for efficient grasping and releasing of objects, with the added advantage of electrical actuation for precise control and automation. This research presents a comprehensive study on the design and implementation of a flexible robotic gripper. Conventional grippers utilized in articulated robotic arms are often limited in their capabilities, being restricted to specific tasks or fixed object sizes. The research findings highlight the promising capabilities of the compressible gripper in enhancing the versatility and efficiency of robotic grasping systems, offering a significant contribution to the field of robotics.
Keywords: Soft gripper; grasping mechanism; grasping various size and shape; flexible robotic gripper.

I. Introduction

In many industrial systems, the final task of a robot is to grasp and reposition an object. Recent research and development efforts in the field of robotics have focused on designing grippers with high torque and accuracy for grabbing various objects and replacing humans with robotic systems in dangerous or difficult jobs. Common types of robotic grippers in industries are vacuum grippers, pneumatic grippers, hydraulic grippers, and servo-electric grippers. Currently, the state of the art in compliant mechanisms, as seen in, requires sophisticated control structures, as well as having a low torque motor that is able to only lift small and light objects. The major problem with using these grippers is related to their rigidity and limitation in grasping a variety of objects, specifically when we are dealing with objects with fragile or soft surfaces. One potential approach involves using pressure sensors to replicate a human-like sense of touch. However, due to cost-effectiveness and concerns regarding the reliability of the gripper's tip strength, alternative options need to be explored and taken into consideration. An alternative emerging technology that has significant potential is flexible and inexpensive materials that can be 3D-printed and used in designing robotic grippers. One of these materials, thermoplastic polyurethane (TPU), is starting to become more available in the market, however, it is not being used in many gripper tasks effectively, as most grippers only use it as a finger cushion. TPU, because of its high resistance, is used in many grippers on the end-effectors to help in picking up objects. This flexible material is also used on tactile sensors that can be implemented into robotic grippers or be designed in a way to create a compressible mechanic for the end of a gripper mechanism. With recent advancements in the technologies of electronic components like electrical motors and additive manufacturing, industrial grippers are continuously going to be better and cheaper. Moreover, the increasing influence of automation and robots in various aspects of human life highlights the necessity of grippers with the capability to perform multiple tasks in a single setting. Many grippers already come equipped with a tactile end effector to increase friction and grip strength, however, to grab a wide variety of objects, the gripper needs compressible material on the surface of it. Compressible material on the end-effector reduces the damage to the object being grasped while increasing the friction between the object and the surface of the robotic hand, allowing a variety of objects to be grabbed. A compressible gripper can work in any condition or environment that is considered hostile to humans, as well as being able to grab any object. One such example of a common commercial

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application would be the inspection of and work in radiation zone. Another example of a potential application is manufacturing production lines. Most of the current robotics grippers have been made for certain applications and are designed based on exact synthesis. Therefore, they can grasp only similar objects with minimal changes in the application, and even for that, they need readjusting (physical/program adjustment). This is not ideal for applications and industries that want to use robotic arms for grasping a variety of objects with different sizes, shapes, weights, etc., during a process without changing robotic grippers. On the other hand, the total weight that a robot can lift is partially dependent on the gripper (end-effector) it is carrying. This is one of the main concerns of designers, which can be solved by minimizing the number of actuators, applying the optimization algorithms, and making the parts hollow. These parameters become even more important in designing a gripper for robotic arms with limitations in maximum load (most small industrial robots) as well as mobile robotic arms, like an autonomous robot with a robotic arm in a radiation zone. Existing robotic grippers are relatively heavy, often featuring many actuators to provide dexterity, and some of these mechanisms even have counterweights or interchangeable ends. Although these features provide stability in the design and allow for different objects to grab, they result in increasing the weight of the robotic gripper, which is not ideal. While additional weight may not be a concern for large-scale industrial robotic arms, it is important for small-scale robots in daily applications. Lower weight and, as a result, minimal energy consumption is another advantage of using compressible material in designing the robotic end-effectors. The arm must support its weight as well as the weight of the gripper, plus the weight of whatever objects it grasps. Thus, a heavy multipurpose gripper for robotic arms can be a major drawback. On the other hand, the current grippers are often designed for one application, and they must be completely changed when objects are changed. This drawback makes some companies see grippers as useless in their applications. Efforts are currently underway to make grippers easily interchangeable with robotic arms, thus enabling more companies to recognize their potential. However, this technology can still be further improved. This paper studies a compressible robotic gripper with the ability to deform and grab objects, grasping objects with different sizes, weights, and shapes. This mechanism is made of flexible and dexterous plastic (TPU) which acts as a combination of form closure and force closure mechanism to be able to grasp objects in a range of sizes and weights. The current scientific challenges in robotics gripper technology revolve around developing a grasping system capable of safely and securely gripping objects of different sizes and shapes across a wide range. Given the significance of these considerations, the primary focus of this research is to design a compressible gripper with the capability to grasp diverse objects with varying sizes, shapes, and textures.

II. Literature

In Paper [1]: Muhannad Zaidan Khalifa on November 2021 Periodicals of Engineering and Natural Sciences (PEN) University of Technology-Iraq Proposed a study on “Design and Manufacturing of Rack and Pinion Steering System”. This research and comparing the three types of rack and pinion gears, the following conclusions were reached: The design requirement is to choose a high-strength material for gear with the specified helix angle, and a larger face width in the gear shape is preferred. 2-Total deformation varies from one type of rack pinion gears to another, but it seems that the single helical gear elastic deformation is high value. The rack-pinion (herringbone gears) the best of the three types in this research is according to the values of the distribution of stresses, strains, and elastic deformations, which results were obtained by used Ansys program.

In Paper [2]: Lakshmipathy Panchanathan andShyh-Chour Huang Department of Mechanical Engineering, National Kaohsiung University of Science and Technology, Kaohsiung 807618, Taiwan Author to whom correspondence should be addressed. Presented at the 3rd IEEE International Conference on Electronic Communications, Internet of Things and Big Data Conference 2023, Taichung, Taiwan, 14–16 April 2023. This paper presents the design of a compliant rack and pinion mechanism with the support of a compliant rolling contact joint (CRCJ). The flexible strips are

mounted to connect the rack and pinion to accelerate the mechanism. Two types of rack and pinion mechanism are proposed: rack and pinion mechanism and double rack and pinion actuator. The 3D model is created with finite element analysis (FEM) for structural analysis to observe the maximum strength and the deformation of the flexible strip. A 3D-printed model is proposed by using a fused deposition method (FDM) by printing layer by layer for experimental and demonstration purposes. In this study, we propose a set of examples to convert a traditional rigid body mechanism to complete a complaint mechanism to accumulate the actual function and also to increase the high possibilities of mounting.
In Paper [3]: Hammad Khurshid, Md Hassaan, Mansha Alam,on Sept 2023 Student from Department of Mechanical Engineering, Faculty of Engineering & Technology, Jamia Millia Islamia, New Delhi, India proposed on "Design and Analysis of a Steering System for a Formula Student Electric Vehicle" This paper specify that Steering system is the most prominent system of a vehicle. It provides direction to the motion of the vehicle. Thus, it is required to have such a system that is robust and free of failure points. In this paper, we have discussed the desi and analysis of the steering system of a formula student The parameters by vehicle requirements. The main goal of this paper is to design a responsive steering system for the vehicle with compliance to the rules of formula bharat 2021 Electric Vehicle specifications described in the 2021 rulebook. In a vehicle a steering system is the key element to the control and direction of the movement and the response to turning effect at the corners, it also defines the handling and stability of the car. The system should give direct feel to the driver of what is happening at the front tires. The components of the system must be capable to withstand the loads experienced by the driver input and the vehicle motion. The steering system should be responsive enough to high speed as well as low speed turns and possess some self-returning action. While designing important parameters like castor angle, kingpin angle, scrub radius, mechanical trail etc. must be taken into consideration.

III. Materials and Methods

The mechanism of this gripper is made of ten different parts, as shown in Table and Figure, excluding the electrical components. The gripper operates by a high-torque stepper motor and a 22.5W (max) power bank. The output rotational motion of this motor will be changed to the linear motion of the gripper by using a rack–pinion system. The rack is merged into a handle at the end and slides inside the rail in the main body of the gripper. The handles will be covered by the grasping segment, which includes a hard shell and a flexible element. A custom lock mechanism is implemented to keep the flexible element securely inside the hard shell, while a stop is added to maintain the handle's position on the main body. Also, for the controlling system of the gripper and other electrical components, a specific box is designed which will be attached to the back of the main body. The box is secured to the body through a connection piece that is also able to attach directly to the robotic arm.

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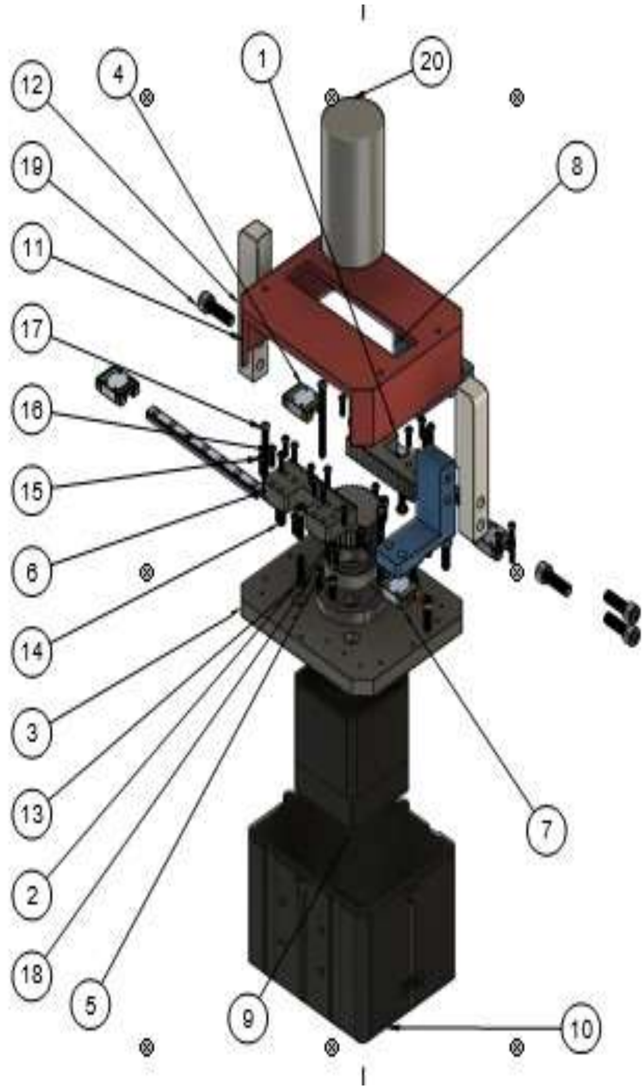

Figure. Rack and Pinion type Electric Gripper

Parts List			
Item	Qty	Part Number	Material
1	1	2485N217_Metal Gear Rack - 20 Degree PressureAngle	Steel
2	1	2664N549_Metal Gear - 20 Degree Pressure Angle	Steel
3	1	Base	Steel
4	1	LinearRail-LWL7B-Assy v1	Steel
5	1	Skf_bearing_16003_2 35x17	Steel
6	1	2485N217_Metal Gear Rack - 20 Degree PressureAngle (1)	Steel
7	1	LinearRail-LWL7B-Assy v1 (1)	Steel
8	2	Jaws	Steel
9	1	Nema 17 10 kgcm	Steel
10	1	Canopy	Steel
11	1	Base 2	Steel
12	2	Jaw	Steel
13	4	91290A572_Alloy Steel Socket Head Screw	Steel
14	5	91290A306_Alloy Steel Socket Head Screw	Steel
15	14	91292A833_18-8 Stainless Steel Socket Head Screw	Steel
16	16	91290A017_AlloySteel Socket Head Screw	Steel
17	4	92095A474_ButtonHead Hex Drive Screw	Steel
18	4	91290A115_AlloySteel Socket Head Screw	Steel
19	4	96144A120_Fine-T head Alloy Steel Socket Head Screw	Steel
20	1	Round 34	Steel

Table: Gripper Element

Most parts of this gripper are made of NYLON 12 carbon fiber because of its low weight and high tensile strain. The flexible element is made of TPU with superior flexibility and longevity compared with non-polyurethane or thermoplastic elastomeric materials (TPE). The controller box is made of ABS-ESD, which is acrylonitrile butadiene styrene with electrostatic discharge properties. This material is resistant to electrostatic discharge with rigidity and is ideal for keeping all electrical components of this gripper. Further, most of the background knowledge and information about the materials is obtained from.

IV. Result

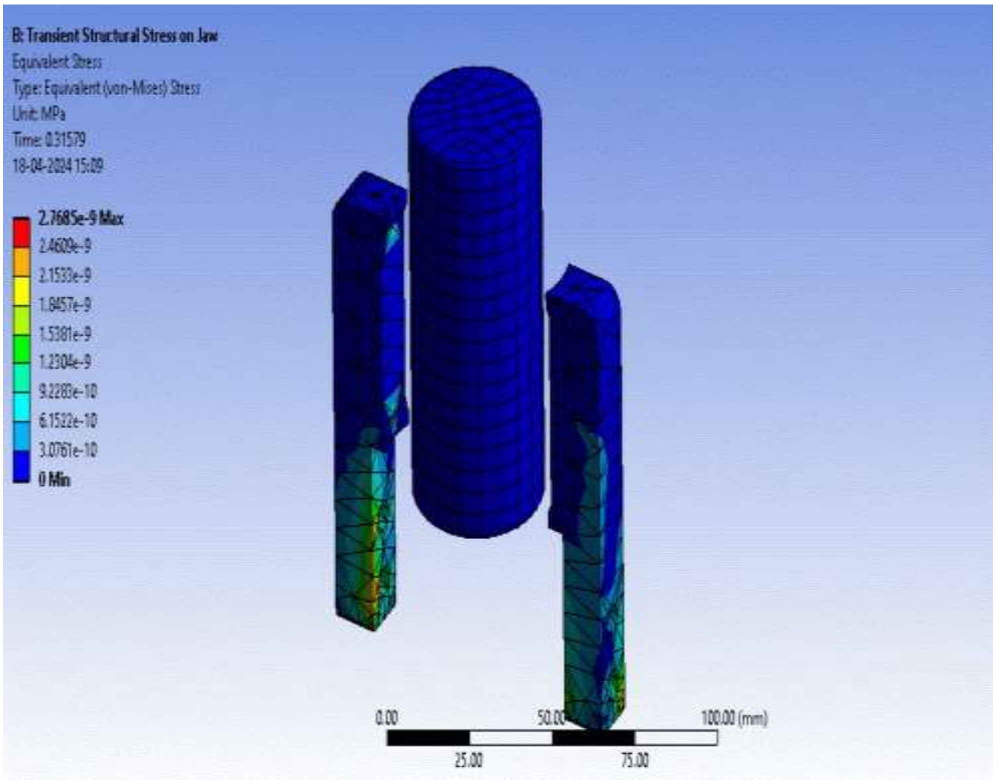

Figure. Deformation

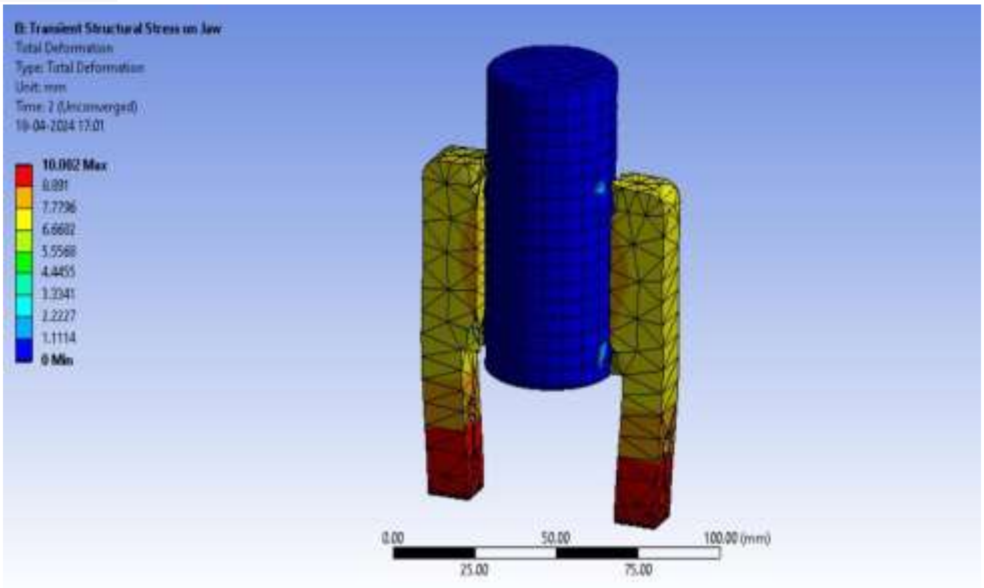

Figure. Stress

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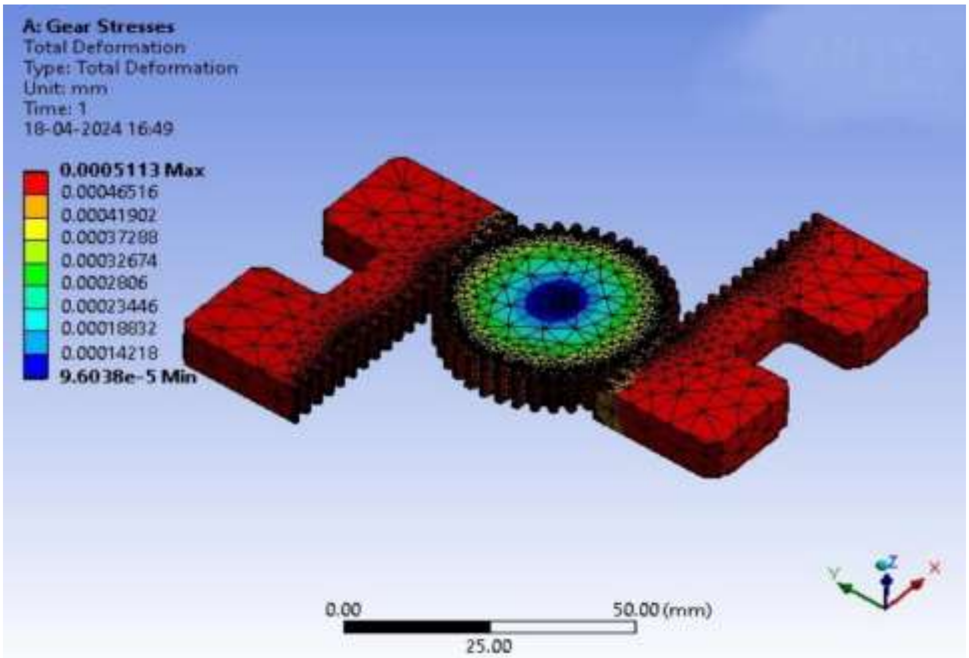


Figure. Gear Stress

An ideal gripper, in addition to having the ability to grasp various objects, must be lightweight, strong, and reliable. After finalizing the gripper design, various analyses were conducted to ensure its performance in grasping various objects. Topology and stress analyses were carried out in CAD software to minimize the total weight of the gripper without compromising its grasping capability or risking broken parts. The motor was carefully selected based on calculations to ensure it could exert the required force to push the handles and overcome the compression force from the flexible elements for a complete grasp. Once all the analyses were completed in the CAD environment, the gripper components were 3D printed, assembled, and tested with real objects for their grasping performance. illustrates the final assembly of the gripper design in CAD software. The prototype of the gripper was developed using additive manufacturing technology, specifically NYLON Carbon 12 for the main body and TPU material for the flexible grasping element. After 3D printing, all components were assembled according to the CAD model and subjected to testing to assess their performance in grasping objects of different sizes and shapes. The lightweight structure of this design is achieved by utilizing a single actuator, which significantly reduces the device's weight. The overall weight of the prototype mainly depends on the motor, gearbox, and the density of the 3D-printed material used. To further reduce the gripper's weight, the infill can be minimized, and a less dense 3D printing material can be utilized. These measures were implemented in the completed gripper prototype. During experimental evaluation, the gripper demonstrated outstanding performance in grasping objects of different sizes, shapes, and textures, meeting all expectations. It effectively grasped objects with a size difference of up to 7 cm (with a maximum size of 15 cm), as demonstrated by the successful grasping of the six objects presented later in this document, each exhibiting diverse sizes and shapes.

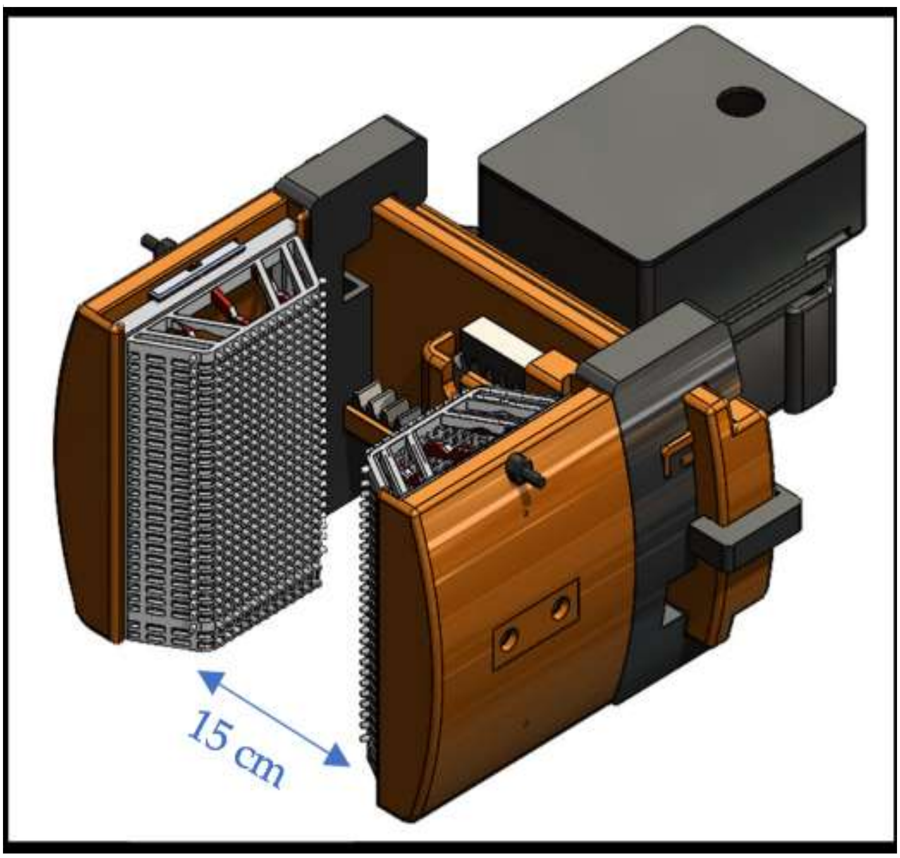


Figure Final design and assembly of the gripper (CAD model)

To ensure the safety and protection of the electronic components, including the microcontroller, battery (power source), motor driver, and infrared sensor for the remote-control system, they were securely enclosed within a box to shield them from potential liquid exposure in the workspace. provides a visual representation of the physical prototype, which is attached to the articulated robotic arm and constructed based on the specified requirements. The figure demonstrates that the gripper effectively grasps and lifts objects with varying sizes, shapes, and textures.

IV. Analysis

Analysis of Jaw for stress and Deformation:

• Consideration:

Jaw Material: Structural steel Component Material: Structural steel Type of Analysis: Transient structural Results:

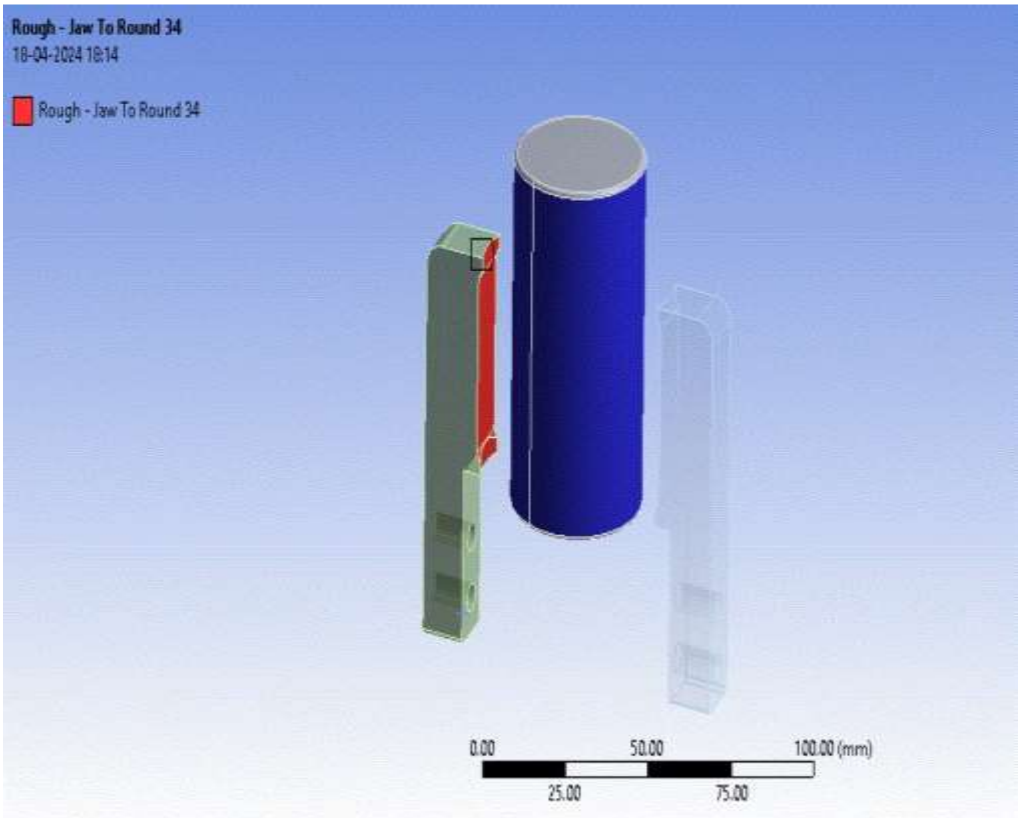
• Von mises equivalent stress.

• Total Deformation.

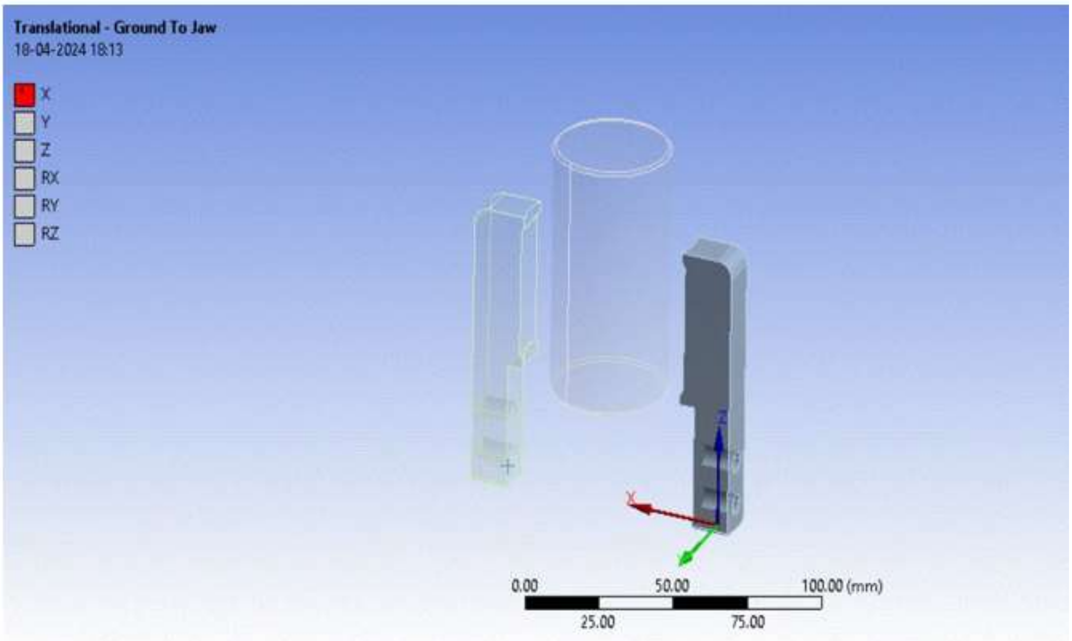
• Boundary Condition

• Geometry is solved for the transient structural analysis. In this case only jaws and component to be pick is considered. The jaws travel of 10mm is considered for holding grip of object. Below mention picture represents a boundary condition that has been applied during the solution.

Rough bond between surface



Body to ground contact for 10 mm jaw travel



Joint force of calculated Gripping force i.e. 16.35 Newton

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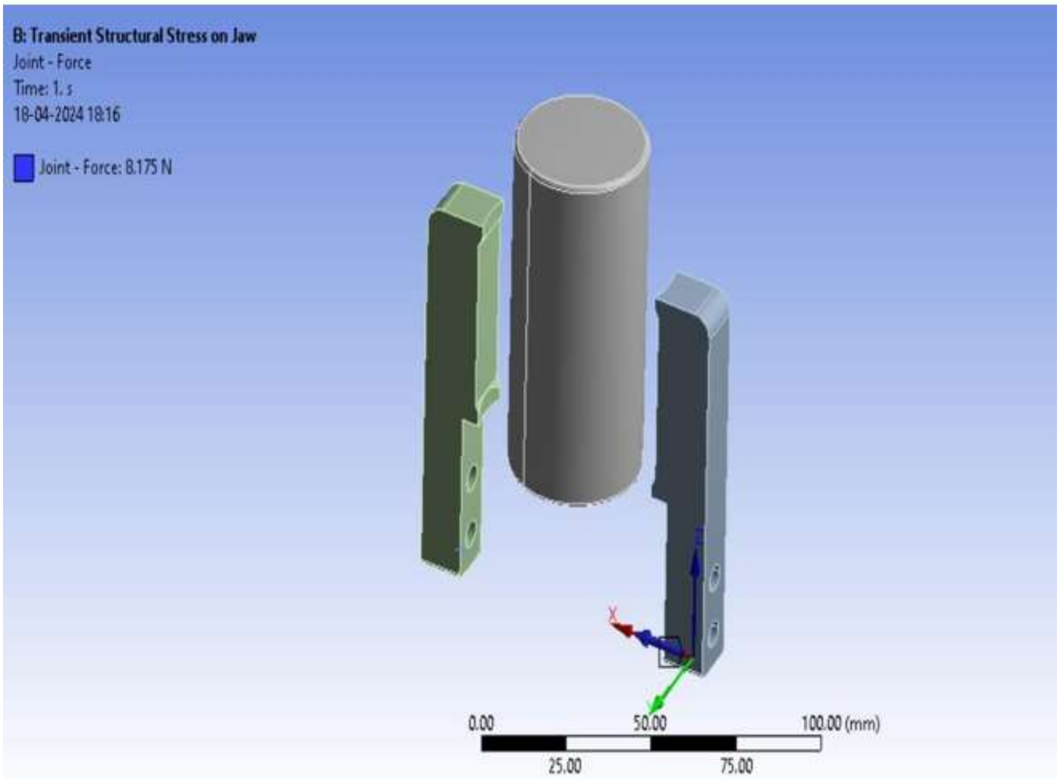
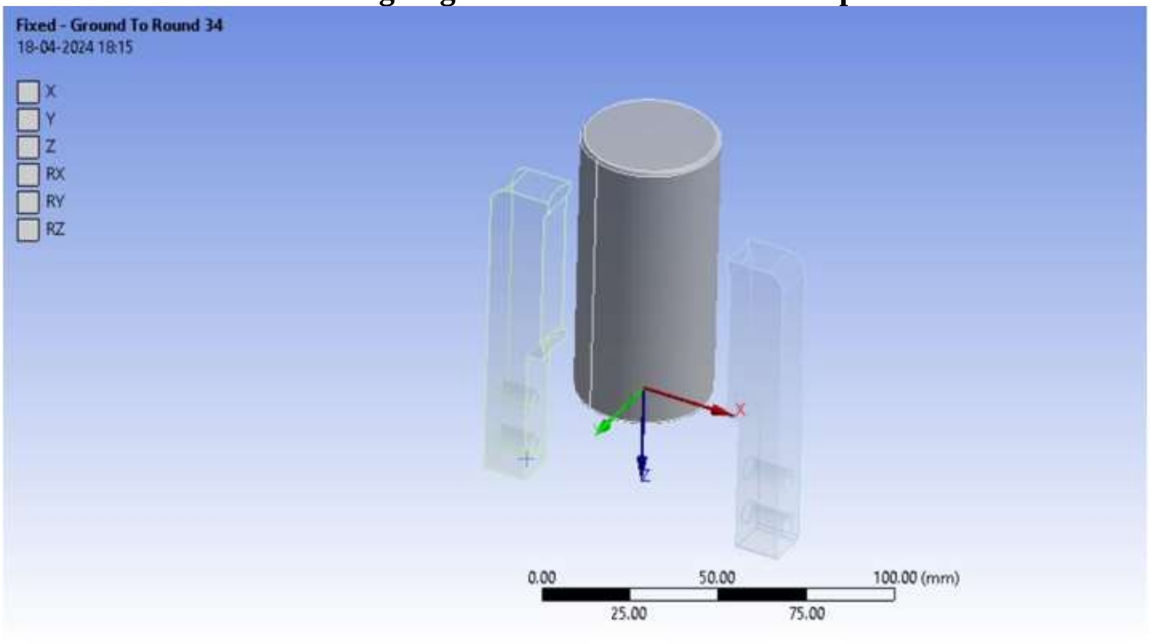


Assigning the fixed contact to the component



Analysis of Gear for stress and Deformation:

Consideration

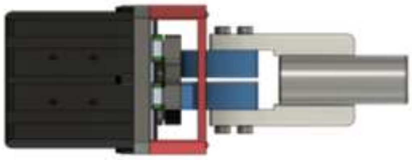
Rack Material: Structural steel Gear Material: Structural steel Type of Analysis: Static Structural Results:

- Von mises equivalent stress
- Total Deformation

Boundary Condition:

Geometry is solved for the Static structural analysis. In this case only Gear and rack is considered. The torque of motor we considered is applied on the pinion and checked the stresses on the teeth of rack. Below mention picture represents a boundary condition that has been applied during the solution.

V. Calculation:



Gripping Force - MG/μN
M – Mass to be lift
G – Gravitational Force
μ - Coefficient of friction
N – Number of jaws
Gripping Force = MG/μN
= 1X9.81/0.3X2
= 16.35 Newton
Torque - Force x Perpendicular Distance
16.35 0.05
Torque = 0.8175 N.M.

VI. Conclusions

This article discussed the design and implementation of a flexible gripper for robotic applications. The primary objective was to address the limitations of traditional grippers by developing a flexible gripper capable of grasping objects of various sizes and shapes. The gripper utilizes a combination of a hard shell and flexible structures, allowing for versatile grasping capabilities. It incorporated a high-torque stepper motor and a rack–pinion mechanism for precise control of linear motion. The controlling system operated on an open-loop control system, offering user-friendly operation while producing precise and secure grasping with a combination of form and force closure grasps. Extensive stress analysis ensured the gripper's components could withstand the required forces, ensuring reliability and safety. The successful testing of the gripper in grasping various objects demonstrated exceptional performance, with the ability to grasp objects effectively using different flexible patterns. This flexible gripper design represents a significant advancement in the field of robotics, particularly for industrial applications. Its versatility, reliability, and efficient grasping capabilities offer practical solutions for handling diverse objects.

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