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Design and Analysis of Robotic Gripper with Complaint Mechanism

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Abstract:- Robotic grippers have become widely common in recent years for a variety of tasks in a variety of industries. Grippers work with industrial robots to manipulate and handle objects. Grippers can also be used for hard automation such as micro-assembly, machining, and packing.

In a variety of fields, compliant mechanisms have made a significant impact. Several approaches have been proposed to study and build these compliant mechanisms that depend on the deflection of flexible members rather than moveable joints alone for part of their motion. To perform their functions, traditional rigid-body systems require a variety of components. As a result, they face issues like backlash, wear, an increase in part count, weight, assembly cost and time, as well as ongoing maintenance. Reducing these issues will improve the performance of the machine and reduce cost.

Keywords:- *Compliant mechanis, robotic gripper*

I. INTRODUCTION

A mechanism is a mechanical device used to transfer or transform motion, force, or energy. Traditional rigid-body mechanisms consist of rigid links connected at movable joints. A compliant mechanism is a mechanism that gains at least some of its mobility from the deflection of flexible members rather than from movable joints only.

II. PROBLEM DEFINITION

SAM Robotics and Automation is an industry situated in Coimbatore that is a manufacturer and exporter of a wide range of Automatic Bottle Filling Machine, Automatic Packaging Machine, and Automatic Food Grains Packing Machine. They use robotic grippers to pick and place objects to pack them in cartons.

The robotic grippers that are currently being used have to undergo a lot of complex assembly processes since it involves a lot of parts and tiny fasteners to achieve the desired action. If these grippers are made out of a single piece, the time and cost involved in producing them can be reduced.

III. OBJECTIVES

The objectives of this project are as follows:

- To replace existing servo-electric grippers using a compliant mechanism made as a single piece which can be actuated using a servo motor.
- To design the gripper suitable to pick and place deodorant bottles for SAM Robotics and Automation.

IV. METHODOLOGY

The following methodology shown in the figure is adapted for the design and analysis of the robotic gripper with the compliant mechanism.

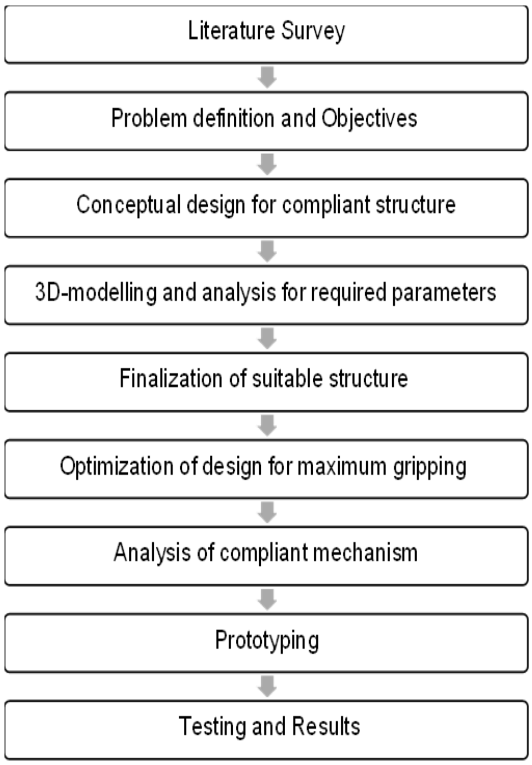

Fig. 1: Methodology

V. CONCEPT SKETCHES

Concept designs are made with respect to achieve the objective of picking and placing of perfume bottles in a assembly line. They are designed to be a single part and to have good compliant property. Various concept sketches were made. Motion and deformation of the design were analyzed to find the more suitable design. Various concept sketches produced were shown in figures. From the below concept sketch 3 is selected as a compliant gripper design.

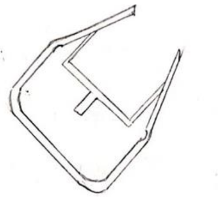

Fig. 2: Concept sketch 1

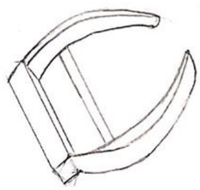

Fig. 3: Concept sketch 2

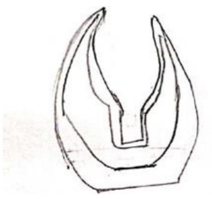

Fig. 4: Concept sketch 3

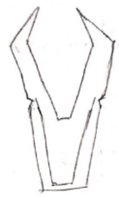

Fig. 5: Concept sketch 4

VI. MATERIAL SELECTION

Material selection is an important step in the process of designing a compliant structure. The primary purpose of material selection for this design is to keep the weight as low as possible while still achieving product performance goals. Material Density and Stiffness are the primary factors in the Selection and sorting of the materials for this design. Other factors like machinability and the cost are also considered during the finalization. The use of material index and performance index is very helpful in the material selection process. In this project, we use Ashby's chart for material selection.

A. Ashby's Chart

It is very useful in identifying the suitable material for our required design, In this chart, two or more material properties are compared and plotted as an ellipse or a bubble. These plots are useful to compare the ratio between different properties. It can be used manually or an equation for the better performance index is derived, if variables are high and suitable material is selected. Various charts are used to compare various properties of the material properties. Commonly used are density, modulus, and yield stress charts.

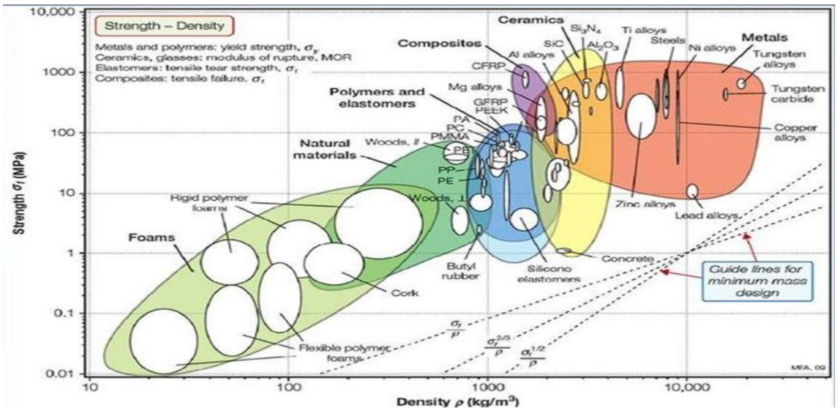

Fig. 6: Ashby's Strength – Density Chart

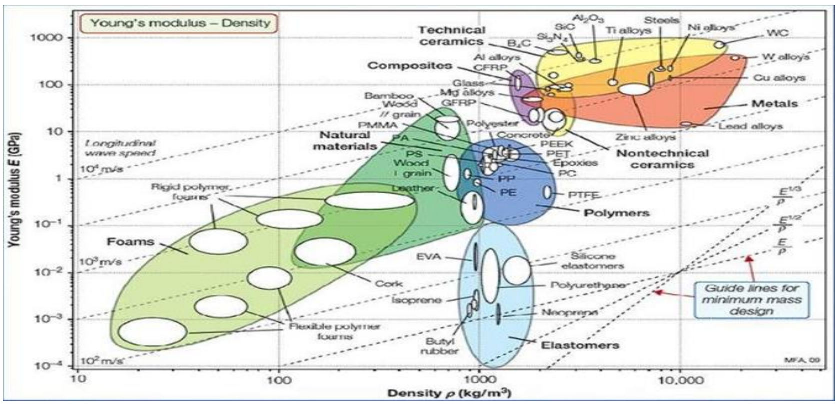

Fig. 7: Ashby's Young's modulus – Density Chart

B. Selection Process

Material selection for the compliant mechanism is done with the use of Ashby's charts. The primary goal of this process is to select the material with minimum density, high modulus and high strength. Based on the requirement few constraints are set for the material selection, which are:

- Density <= 2000Kg/m^3
- Displacement min of 1% of the total length
- Strength >= 1Mpa
- Readily available for manufacture

By using the above parameters in Ashby's strength–density chart, we found that the following material is suitable and meets all the constraints set. The suitable materials are: Wood, Polymers, Elastomers, and Carbon fiber reinforced polymers (CFRP).

By using the above parameters in Ashby's young's modulus–density chart, we found that the following material is suitable and meets all the constraints set. The suitable materials are Bamboo wood, Polymers, Carbon fiber reinforced polymers (CFRP), and Rigid polymer foams.

C. Pugh Matrix for Material Selection

Pugh Matrix is a criteria-based decision matrix that uses criteria scoring to determine which of several potential alternatives should be selected. Here we form a matrix by arranging various criteria used for selection vertically and alternative material available in horizontally. We may or may not give weightage for each criterion and score each material. By totaling the scores, we can choose the most suitable material. Here we have issued ranking based on the total and polymers got the highest score and ranked as 1.

Criteria	Weightage	Materials				
		Wood	Polymers	CFRP	Elastomers	Polymer foams
Density	5	0	1	1	1	1
Modulus	4	0	1	1	1	-1
Strength	3	-1	0	1	0	-1
Cost	2	1	1	-1	0	1
Manufacturability	1	-1	1	-1	0	0
Total		-1	4	3	2	0
Ranking		**5**	**1**	**2**	**3**	**4**

Table 1: Material Selection table

From the Ashby charts and based on the other factors like cost and machinability, we are chosen the polymers as the material for designing this compliant mechanism gripper

For mass production of the component in industries, we can recommend the use of Acrylonitrile Butadiene Styrene (ABS), High-density Polyethylene (HDPE) or Low-density Polyethylene (LDPE) as they have the required properties. We choose polylactic acid (PLA) for the prototyping purpose, as it is highly suitable for 3D printing and has very similar properties to the above-mentioned polymers.

- Material properties of PLA
  - Density – 1.24 g/cm³
  - Tensile Strength – 46 Mpa
  - Flexural strength – 79 Mpa
  - Modulus of Elasticity – 2.96 Gpa
  - Co-efficient of friction – 0.15

VII. 3D MODELLING

The gripper is designed and modelled in Solid works software for better visualization and analysis purposes. Many iterations of the design were made and tested for better results and manufacturing feasibility. Models produced using Solid works are shown below.

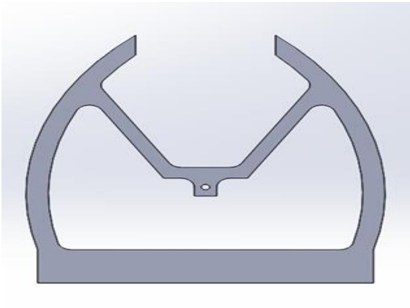

Fig. 8: Gripper 3D model

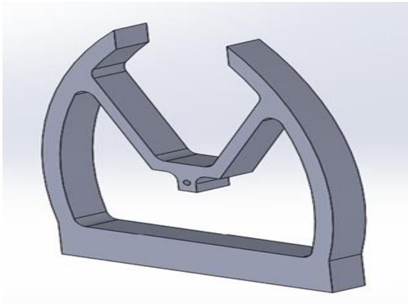

Fig. 9: Gripper Isometric view

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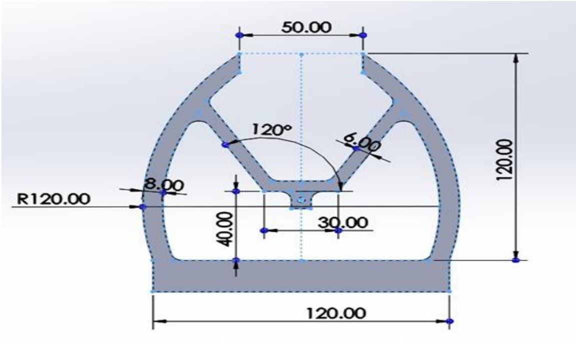

Fig. 10: Gripper Dimensions

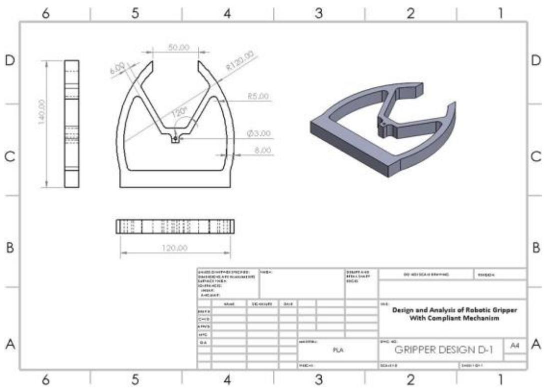

Fig. 11: Gripper Engineering Drawing

VIII. CALCULATIONS

A. Force acting on the mechanism

As the mechanism is actuated by a servo motor, the force applied by the servo motor on the mechanism is calculated using the output torque of the motor.

Torque out = 3 N-m

Length of the link = 25 mm

Force produced = $(3*10^3)/25$ = **120 N**

B. Required gripping force

Diameter of the bottle ⌀ = 45 mm

Mass = 60 g = 0.06 Kg

Required gripping force, Fg = ((m(g+a))/μ)S = ((0.06(3*9.8))/0.1)2

F_g = 35.28 N

Where, m is the mass of the object in kg

g is the acceleration due to gravity in m/s^2

μ is the coefficient of friction

C. Stress on the bottle due to gripping

Gripping area = (5 x 15)x 2 = **150 mm^2**

Stress acting on the bottle due to gripping **= (35.3 / 150)**

= 0.25MPa

IX. ANALYSIS

The mechanism was analyzed using Ansys Workbench 16.0 and the results are tabulated below.

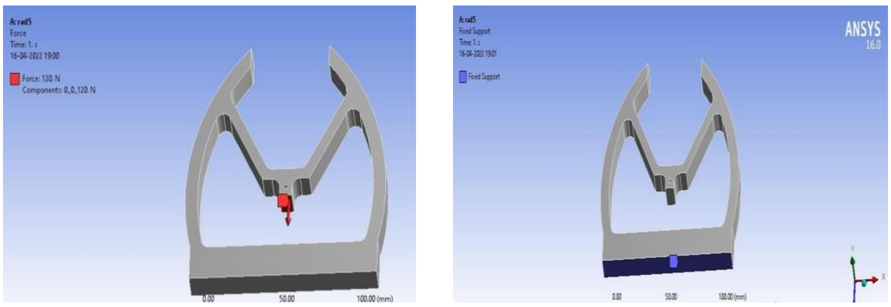

Fig 12(a): Input Parameters

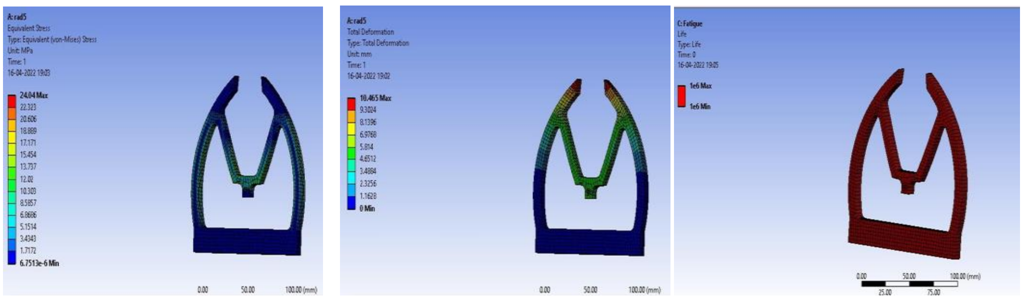

Fig 12(b): Ansys Output

A. Results

The results from Ansys analysis are collected and tabulated. From the result we can understand the following

- The design is safe as the maximum stress is less than the yield stress of the material
- Maximum deformation of 10mm occurs at the desired place which is sufficient to hold the object
- The fatigue test performed shows that the material is capable of withstanding infinite lifecycles

Maximum Stress	24 MPa
Total Deformation	10.5 mm
Fatigue Life	10^6 Cycles

Table 2: Ansys results

X. PROTOTYPING AND TESTING

A. Prototyping

Prototyping is method of developing, testing and improving the design before the actual application. Prototyping of compliant gripper is done to understand and evaluate the design with real world testing to make improvements if necessary. The prototyping is done using the 3D printing technology to its actual dimension for the testing and evaluation.

B. Ultimaker 3

Ultimaker 3 offers only the best and most reliable dual extrusion FDM 3D printers on the market. Dependable Dual Extrusion - Combine build and water-soluble support materials to create complex mechanical parts and intricate surfaces or choose to print with two colors. It offers an impressive range of resolutions from 20 microns all the way to a sizeable 600 microns, which it sets it apart as one of the most accurate fused deposition modelling printers on the market. It is desktop 3D printer with a build volume of 215x215x200 mm. Separate nozzles for support material, high quality sensor and easier maintenance.

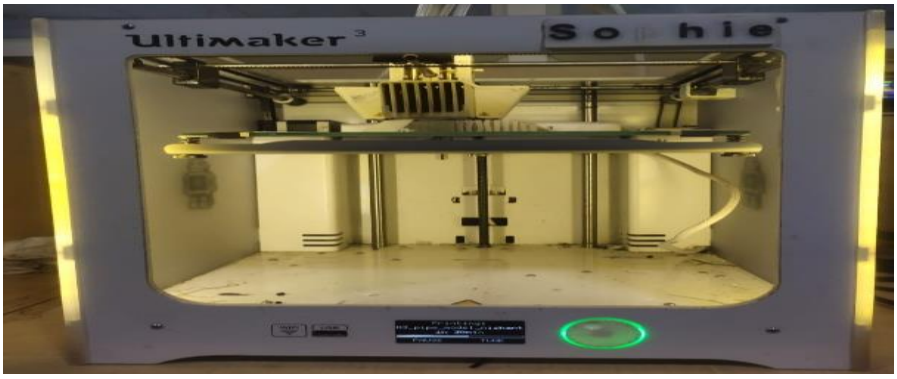

Fig 13: 3D Printer Ultimaker 3

C. 3D Printing Process

3D printing uses computer-aided design (CAD) to create three-dimensional objects through a layering method. Sometimes referred to as additive manufacturing, 3D printing involves layering materials, like plastics, composites or bio-materials to create objects that range in shape, size, rigidity and color. Process involved in the prototyping are

- CAD Modelling- the geometry of the required prototype is prepared using a 3D modelling software and part files is converted into STL format.
- Converting the file - Then the file is sliced into multiple layers using the free cura software and can be printed with wifi or they can be stored in a USB and plugged into the printer.
- Pre setting - Initially the print bed is levelled and the required print filament (PLA) of 2,8mm diameter is loaded.
- We can use the standard setting or advanced setting based on the printing requirement.
- Part is printed layer by layer using PLA material and doesn't require any post printing processing
- Finished part is removed from the printer and ready for testing.

D. Prototype Images

Fig 14: 3D Printed Prototype

E. Testing

The prototype is tested for its functionality, which is shown in the images blow. Mass of the prototype is found to be approximately 96 grams

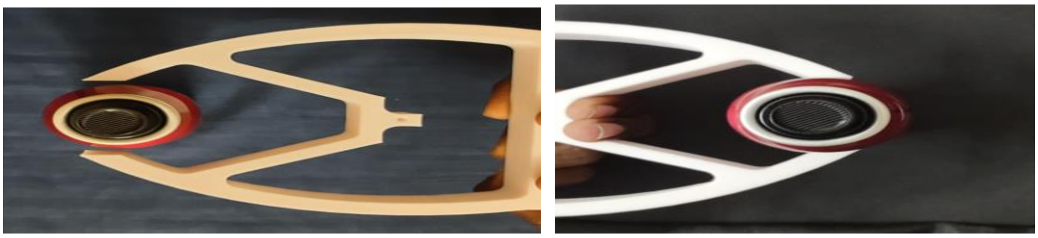

Fig 15: Gripper open and Closed Condition

F. Observations

Testing the prototype by manually actuating it shows that the gripper works as expected but has to be tested in the actual environment before implementation

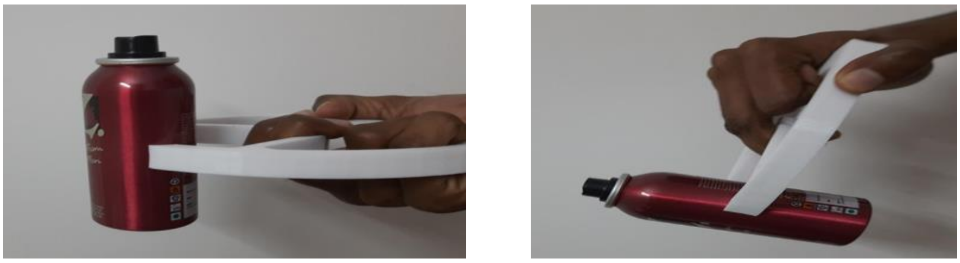

Fig 16: Gripping In Different Orientation

XI. CONCLUSION

The selected concept sketch was made into a 3D model and analyzed using Ansys Workbench to check how the design works under actual loading conditions and the following conclusions were made.

- The equivalent stress analysis shows that the design is safe and does not fail.
- The deformation analysis shows that the deformation required to pick the bottles occurs.
- The fatigue test shows that the component has infinite life (more than 10^6 cycles).

The prototype was made and its functionality has been tested.

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