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Design, Modelling and Analysis of Soft Gripper for Material Handling

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***Abstract*: Soft robots have many attractive features compared to their hard counterparts, developing tractable models for these highly deformable nonlinear systems is challenging. A novel soft-robotic gripper design is presented with three soft bending fingers and one passively adaptive palm. The material selected for palm is hard material (grey cast iron) and for finger is soft material (silicone rubber). Each soft finger comprises three pneumatic chambers to make bending action. With novel soft finger design, the gripper could pick up small objects, as well as conform to large shaped objects with reliable contact using positive and negative air pressures. The design, analysis and control operations are presented in detail.**

There are two different software's used here for performing the above processes. The design and analysis are carried out in SOLIDWORKS software. The modelled gripper could reliably grasp objects of various shapes and sizes, even with external disturbances.

***Keywords*: Soft gripper; soft materials; hard materials**

I. INTRODUCTION

Soft robotics is an emerging field and it differs from the traditional robotics not only because the robot itself includes soft deformable parts but also the manipulating targets involves soft and deformable objects. Soft Robotics is the specific subfield of robotics dealing with constructing robots from highly compliant materials, similar to those found in living organisms. Soft robotics draws heavily from the way in which living organisms move and adapt to their surroundings. In contrast to robots built from rigid materials, soft robots allow for increased flexibility and adaptability for accomplishing tasks, as well as improved safety when working around humans.

Shnichi Hirai et al (2017) developed prestressed fluidic elastomer actuators to generate more than two times larger opening distance compared with the non prestressed gripper. Soft finger is fabricated with 3D printed technology. The actuator with prestress and without prestress were tested. The result obtained from the prestressed gripper was found to generate more than 2 times larger opening distances compared with the gripper without prestress.

Shnichi Hirai and Zhongkui Wang (2016) designed, analysed and fabricated a single chambered finger. A mold is made of 3D printed using the object 260cinnex system. This gripper's working is based on the principle of beam theory or elastica theory or rod theory. When the bending angle increases, the output voltage from the sensor also gets increased and the output voltage can be recorded with Arduino board.

Barry Trimmer et al (2013) discussed about soft robotics which mimics the animal behaviour and the different actuation techniques. To handle the complex natural environment, soft structures was designed which mimics some activities or behaviour. It also reduces the mechanical and algorithmic complexity and these soft robots are highly deformable. For medical appliances, these soft robotics can be integrated with tissue engineering. The soft material which is mostly preferred due to its lower modulus value. Forward and inverse kinematics are not suitable for these robots. Because these robots are highly deformable in nature. Hence soft robotics are limited to kinematic analysis.

Oliver Brock and Raphael Diemel (2013) analysed different types of soft grippers. The gripper is made of soft material such as silicone rubber and it is very flexible in nature due to its low modulus property. Actuator used here is pneumatic type which is made of flexible materials. The reinforced finger made of woven fabric materials wounded circumferentially and longitudinally. Sewing thread made of PET (Polyethylene terephthalate) material to prevent the actuator to bulge like a balloon. A silicone tube is inserted at one end of the actuator surface to connect air chamber/ to supply air. Pneumatic anthromorphic hand reduces the ability to match the shape of objects during grasping and the starfish gripper is very flexible but it will work on very lower pressures which leads to weaker actuation and grasping forces.

Conor J.Walsh et al (2013) analysed three different soft materials separately with various pressures. The Molds are made up of 3D Printed with an object connex 500 and a reinforcement material is made of woven fibre glass. A traditional technique is used here. The bellows bends according to the fluid pressure.

Section 1 describes over view of the soft gripper and its applications. Section 2 explains the material properties which is selected for fabricating the gripper. Section 3 presents the designing and modelling from the SOLIDWROKS software. Section 4 shows the analysis of soft gripper under different air pressure loadings.

II. MATERIAL PROPERTIES

There are different types of soft materials available, such as Ethylene propylene rubber, Chloroprene rubber, Fluoro rubber, Natural rubber and Silicone rubber etc.

TABLE I. MATERIAL PROPERTIES

Properties	Minimum Value (S.I.)	Maximum Value (S.I.)	Units (S.I.)
Thermal conductivity	0.2	2.55	W/m.K
Young’s modulus	0.001	0.05	Gpa
Poisson’s ratio	0.47	0.49	-
Tensile strength	2.4	5.5	Mpa
Elastic limit	2.4	5.5	Mpa
Specific heat	1050	1300	J/kg.K

Silicone rubber material is mostly preferred due to its excellent properties when compared to other soft materials mentioned above.

III. DESIGN OF SOFT GRIPPER

The finger is designed with three chambers to mimic the human finger.

A. *Design of finger*

The vent holes are provided as shown in figure 3.1 to insert the air tubes to produce bending action to the finger for the applied load.

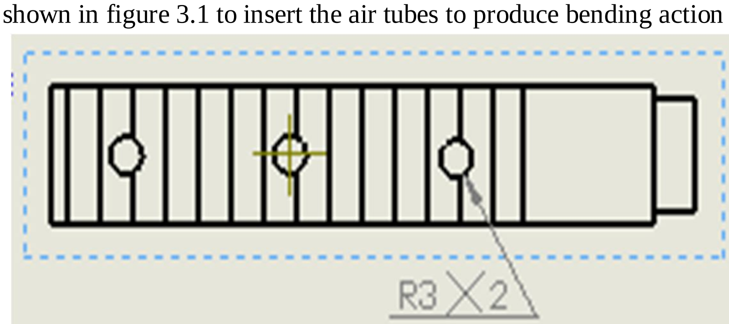

Fig 1. Top View of Finger

The curves shown at the bottom of the figure 5 is used for providing maximum bending that can be produced by this model for the given loads

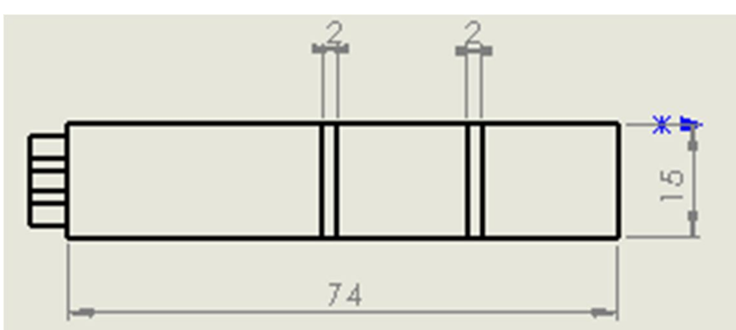

Fig 2. Bottom View of Finger

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B. Design of Connector

The design shown in Figure 1 is common for both connector part and the extruded part at the front end of the finger.

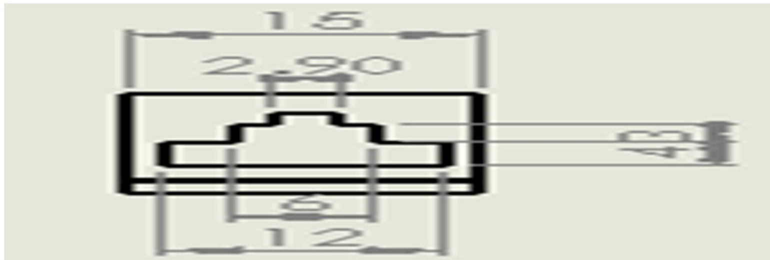

Fig 3. Connector Model

After connecting the finger, this connector part should be welded with the holder like fixing fingers with the palm.

C. Holder Design

Hexagon structure as shown in figure 4 is initially chosen for connecting 6 fingers. In future more number of fingers can be added by altering the structure of the model.

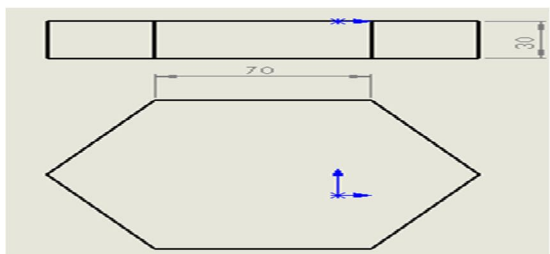

Fig 4. Holder Design

It is made of grey cast iron since this holder has to be fixed with the manipulator which is made of a hard material grey cast iron. So particularly the same material is chosen for holder also.

D. Design of gripper

The soft material which is flexible in nature and the hard material which is rigid one. When the pressure is applied in the vent hole, the flexible part alone will bend to grasp the object.

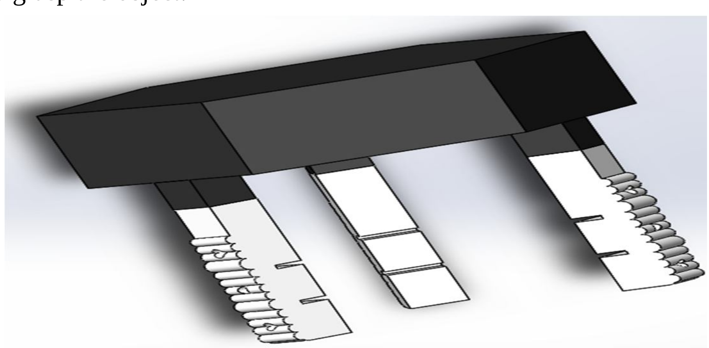

Fig 5. 3D View of Gripper

IV. RESULTS AND DISCUSSION

A. Analysis of Single Finger by Applying Positive and Negative Air Pressure

The soft gripper is bend in both the directions according to the pressure values applied either positive pressure or negative pressures. In the following sections, the positive pressure is considered for analysis. As shown in the figure 6, the vertical bar shows the variation of properties from minimum to maximum value with different colour coding.

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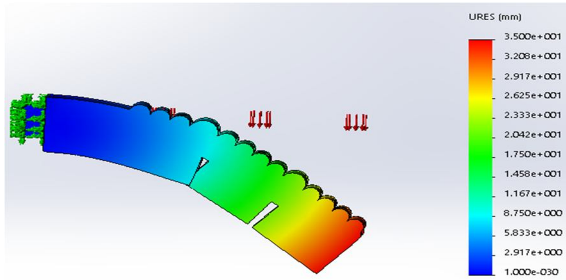


Fig 6. Soft Gripper under Positive Air Pressure Loading

When a positive pressure (+500N/m^2) is given to the finger it bends in the downward direction. So that it can grasp even the objects which is smaller in their size.

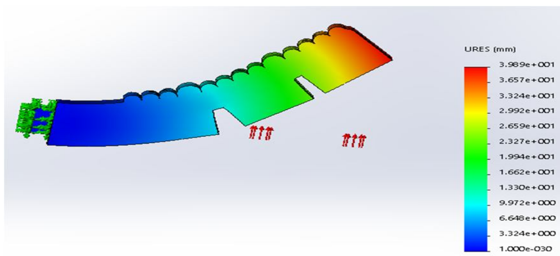
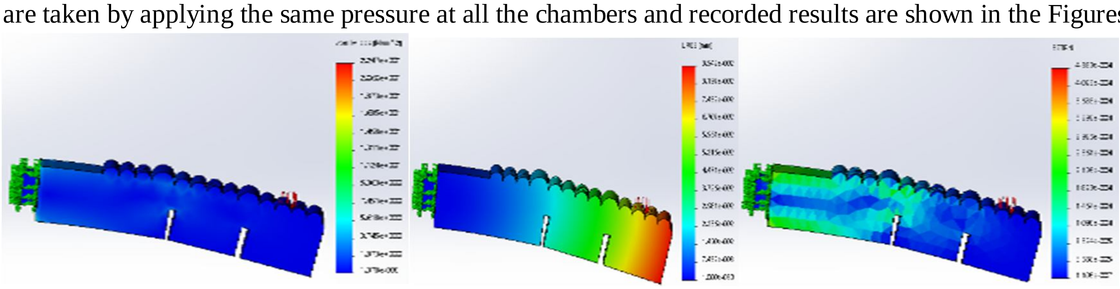


Fig 7. Soft Gripper under Negative Air Pressure Loading

When a negative pressure (-500N/m^2) is given to the finger, it bends in the upward direction. So that it can grasp even the objects which is larger in their size according to its material properties.

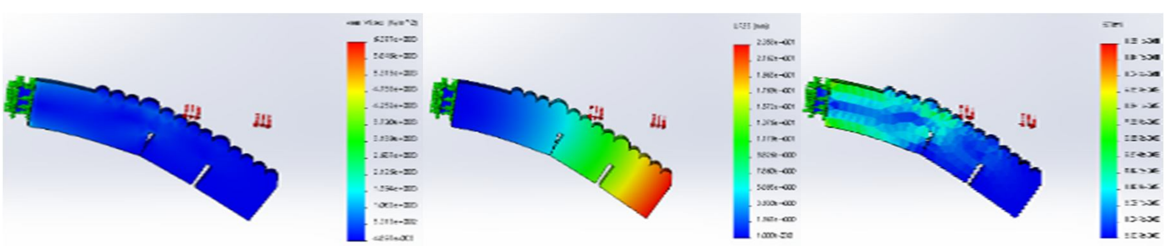
B. Analysis of Single Finger by Applying Same Pressure at All Chambers

Analyses are taken by applying the same pressure at all the chambers and recorded results are shown in the Figures 8 to 12.



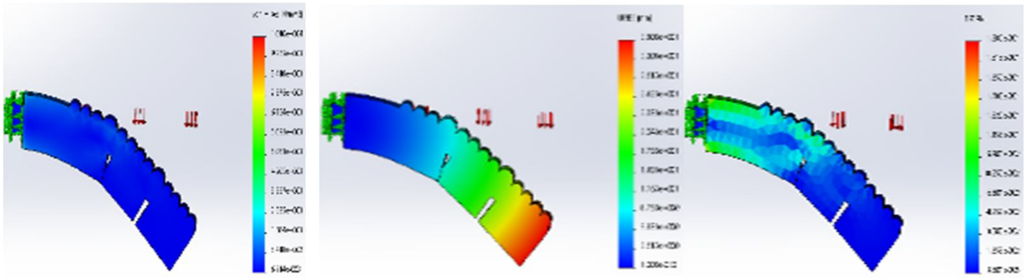
Stress (N/m^2)   Displacement (mm)   Strain

Fig 8. Stress, Displacement and Strain of Single Finger at 1 N/m^2



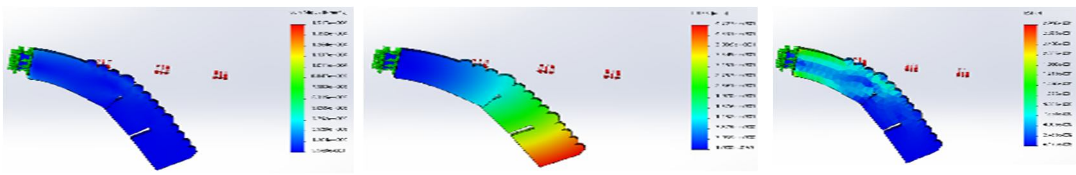
Stress (N/m^2)   Displacement (mm)   Strain

Fig 9. Stress, Displacement and Strain of Single Finger at 300 N/m^2



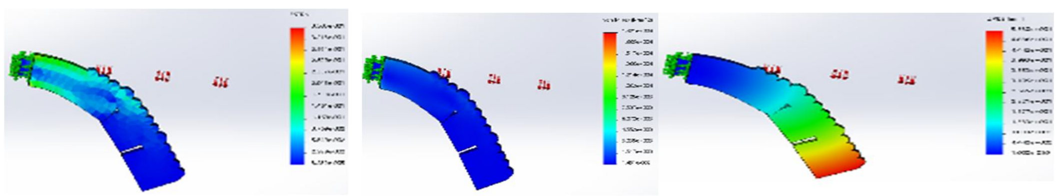
Stress (N/m^2) Displacement (mm) Strain

Fig 10. Stress, Displacement and Strain of Single Finger at 500 N/m^2



Stress (N/m^2) Displacement (mm) Strain

Fig 11. Stress, Displacement and Strain of Single Finger at 800 N/m^2



Stress (N/m^2) Displacement (mm) Strain

Fig 12. Stress, Displacement and Strain of Single Finger at 1000 N/m^2

From Fig 8 to 12, the stress, displacement and strain of the gripper is shown clearly for various pressures applied on it. The results reveal that the designed gripper could withstand even for larger pressure values. Because the edge of the gripper is not fixed with the rigid surface. Hence its edge is left free, it can withstand high pressures. Even for the larger pressure values, the stress part is not turned to red colour, which means it doesn't not break even up to 1000 N/m^2 pressure applied. Table 2 shows stress, displacement and strain values for different pressures.

TABLE II APPLYING SAME PRESSURE LOADINGS AT ALL THE CHAMBERS

S. No	Pressure (N/m^2)	Stress (N/m^2)	Displacement (mm)	Strain (no unit)
1	1	$2.247e^{+001}$	$8.942\ e^{-002}$	$4.389\ e^{-004}$
2	300	$6.377e^{+003}$	$2.358\ e^{+001}$	$1.251\ e^{-001}$
3	500	$1.010e^{+004}$	$3.500\ e^{+001}$	$1.980\ e^{-001}$
4	800	$1.517e^{+004}$	$4.727\ e^{+001}$	$2.940\ e^{-001}$
5	1000	$1.821e^{+004}$	$5.330\ e^{+001}$	$3.505\ e^{-001}$

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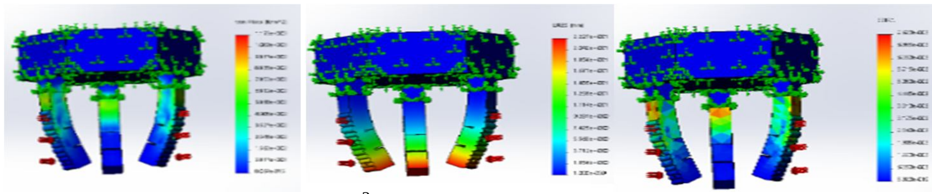
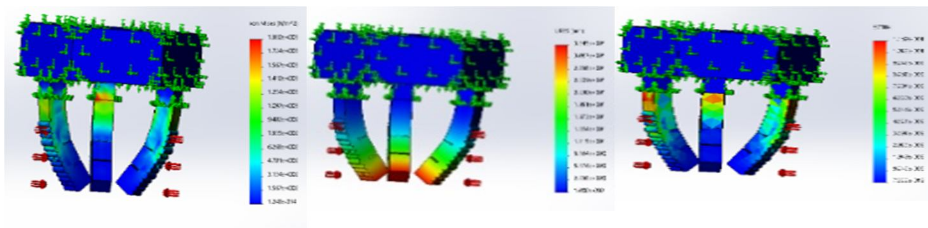
D. Analysis of Soft Gripper with Three Fingers

Analyses are taken by applying the various pressures at all the three fingers and the results are recorded as shown in the Fig 13 to 17



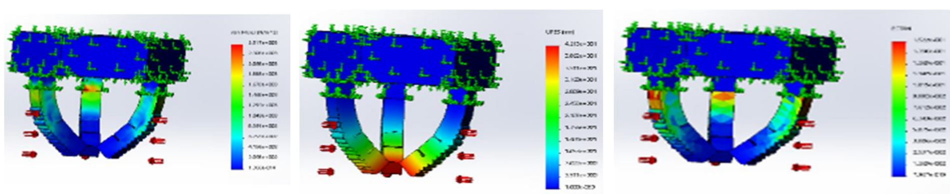
Stress (N/m^2) Displacement (mm) Strain

Fig 13. Stress, Displacement and Strain of Three Fingers at 1 N/m^2



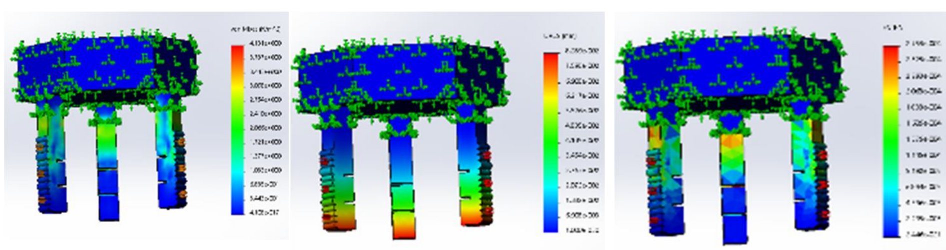
Stress (N/m^2) Displacement (mm) Strain

Fig 14. Stress, Displacement and Strain of Three Fingers at 100 N/m^2



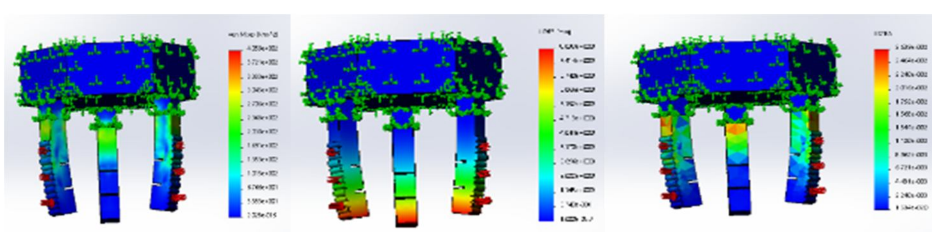
Stress (N/m^2) Displacement (mm) Strain

Fig 15. Stress, Displacement and Strain of Three Fingers at 300 N/m^2



Stress (N/m^2) Displacement (mm) Strain

Fig 16. Stress, Displacement and Strain of Three Fingers at 500 N/m^2



Stress (N/m^2) Displacement (mm) Strain

Fig 17. Stress, Displacement and Strain of Three Fingers at 700 N/m^2

The maximum displaced value is shown in the table 6 at the pressure 500 N/m^2. The fingers are fixed with a rigid material which is said to be holder part. From 500 N/m^2 to 700 N/m^2, in figures, it is identified that more stress is applied on the joint area. Hence its bending action is restricted at minimum pressure ranges itself.

TABLE VI ANALYSIS OF SOFT GRIPPER

S. No	Pressure (N/m^2)	Stress (N/m^2)	Displacement (mm)	Strain (no unit)
1	1	4.131e^{+000}	8.289e^{-002}	2.758e^{-004}
2	100	4.059e^{+002}	8.088e^{+000}	2.689e^{-002}
3	300	1.178e^{+003}	2.227e^{+001}	7.620e^{-002}
4	500	1.880e^{+003}	3.345e^{+001}	1.169e^{-001}
5	700	2.517e^{+003}	4.213e^{+001}	2.744e^{-001}

V. CONCLUSION

The soft gripper with three fingers was designed and analysed using SOLIDWORKS software. The soft materials used for the proposed gripper design was Silicon Rubber and the grey cast iron was chosen for holder design. The results such as stress, displacement and strain were taken for the following cases, (i) By applying same pressure at all chambers of finger (ii) by applying different pressure at each chambers of finger (iii) by applying same pressure with three fingers.

From the above analysis, it was found that the maximum pressure that can be given to the designed gripper is around 400 N/m^2 to 600 N/m^2. If more pressure is applied, it leads to tare the material. If the given pressure is not sufficient to grasp the targeted object, the design has to be changed since the finger was modelled with sharp edges. Hence, it bends very minimum when compared to the smooth edges. But due to the chamber design, it can able to displace up to 3.345 e^{+001}mm.

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