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Analysis of Pneumatic Soft Finger Actuator Using Finite Element Method

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Abstract: A soft pneumatic actuator is a soft robotics part that increases the ability of a robotic rehabilitation system to exercise the hand and grasp an object. Curving angle of the actuator and the right deformation consider important parameters that affects the grasping area and the closing and opening exercises movements while applying air pressure. This study presents a Finite Element Analysis of soft finger actuator (SFA), by applied internal pressure into inner cavities of the chambers to analysis the movement after pressurized using modelling with (ANSYS Workbench 2022 R1). Initially a pressure of 2psi was applied , The amount of deformation was (0.0407mm) and the bending angle was (17.6°) , Secondly applied (3 psi) pressure the deformation was (0.0622mm) and the bending angle is (36.6°),then Thirdly, applied (4 psi) pressure to the internal chamber and the result of total deformation is (0.0926mm) and the bending angle was (62.5°), Finally, applied (5psi) pressure to the internal chamber and the result of total deformation is (0.1153mm) and the bending angle was (105.1°). The results show that the deformation effected by the pressure amount and the curving angle of the actuator, also the analysis of SFA is recommended to perform optimized liner bending motion.
Keywords: Pneumatic, Rehabilitation, Soft robotics

I. Introduction

The developing area of flexible robotics plans to create robotic structures created from soft materials to achieve complex movement in different conditions and to deal with their basic surroundings in a safer and better approach. The soft robotic systems performance is depending on the performance of the actuators. Soft actuators are expected to be soft and compliant like natural muscles [1, 2], they are safe through human–robot connections, inexpensive, lightweight, and be able to provide great power degrees with a significant mechanical production [2-4]. Pneumatic actuators can produce bending and linear movements, present great ability to be used in soft robotics and medical applications due to their characteristic conformity and safety. The SFA geometry and mechanism must study utilizing a simple theoretic simulation [5]. This prototype can be applied as a design basis for designing soft pneumatic fingers actuators. The consequence of pressurized air and bending angle on the functioning of the actuator is defined. The movement of this soft actuator is generated by pressurizing the internal chambers, and the configuration of the actuator is determined by the structure of the channels.

Reference [5] Examine how different design constraints affect a pneumatic network actuator's (PNA) ability to actuate, then use the finite element method (FEM) to optimize the structure and measure the performance of the resulting actuator topology experimentally. A Global Analysis of Variance (ANOVA) was performed. The optimized FE model results were verified experimentally. And results also show that the design optimization method based on the FEM and ANOVA analysis can be extended to the topology optimization of other soft actuators.

In reference [6] the authors Examines the factors and cross-section ratios that affect bending performance. The ratio of the first and last chamber sizes is the study's optimal parameter. The ratio is optimized by finite element analysis. Compared the actuator models with small and large cross-section ratios by simulation using the finite element method. The simulation results show that increasing of the model cross-section ratio provides the wider bending angle than the reduced cross-section ratio model or the basic configuration model at the same input pressure.

Reference [5] provided an optimization method that chose the best values for factors like the thickness of the bottom layer, the distance between adjacent chambers, the thickness of the walls, and the cross section of the chambers. The work also demonstrated the benefits of using the finite element method (FEM) to optimize geometric variables and experimentally verified the results.

Reference [7] utilizing an efficient upgraded model with multiple-point contact technique for modeling and analysis of the soft pneumatic actuator with significant bending deformation. In [8] conducted various actuation experiments and finite element analysis to show the deformation characteristics of the actuators by varying the chamber angle, and then proposed a programmable design to enable pneumatic actuators to realize coupled bending and twisting actions in three-dimensional space.

Reference [9] analyzed in detail how the deformations of fiber-reinforced soft actuators were affected by adjusting the fiber angle, and they performed a series of finite element simulations to examine the relationship between fiber angle and actuator deformation.

The soft pneumatic actuators that can produce deflection have considerable ability for medical uses, However, the design characteristics of the channels have a significant impact on the bending performance of these types of actuators. As a result, an effective technique to maximize the bending angle of the pneumatic actuators is required. The goal of this paper is to confirm that the deformation movement (resulting from applying the air pressure inside the SFA chambers) is linear, to verify the efficiency and success of the design before starting the manufacturing process. The soft actuator design is improved using the finite element method to achieve the required bending performance. A statistical analysis-based methodology is used to raise the effectiveness of a pneumatic actuator that is suggested for usage in soft robotic applications.

2. Materials and Methodology

2.1 SFA Design and Configuration

The bending actuator design, which can create the liner deformation, had lower thickness silicon layer at the bottom SFA layer but thicker silicone layer in the upper one. And the SFA had two main air inlet channels, and 9 chamber cavities with half circular cross section shape. And it's made from silicone rubber material. The channels expanded when the actuator was inflated, leading the actuator to bend longitudinally sees Figure(1).

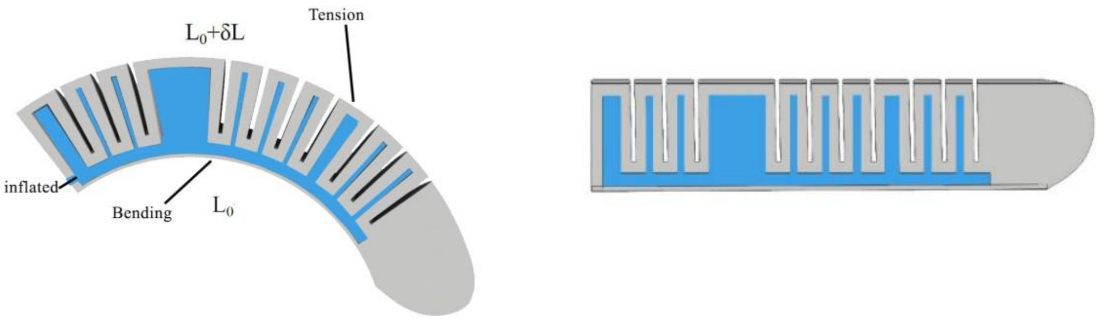


Figure 1: Bending SFA Cross Section

For several reasons, silicone rubber has been selected as the actuator material. This material demonstrates the qualities desired for the actuator, is affordable, and can be molded into a variety of shapes with little actuation pressure or stress.

2.2 Actuator Mechanism and Analysis

The geometry of the SFA shown below in Fig. 2, and the actuator length (L), diameter D, and volume V are defined in the equation below:

$$L = b\cos\theta \quad (1)$$
$$D = (b\sin\theta)/n\pi \quad (2)$$
$$V = (\pi D^2 L)/4 \quad (3)$$

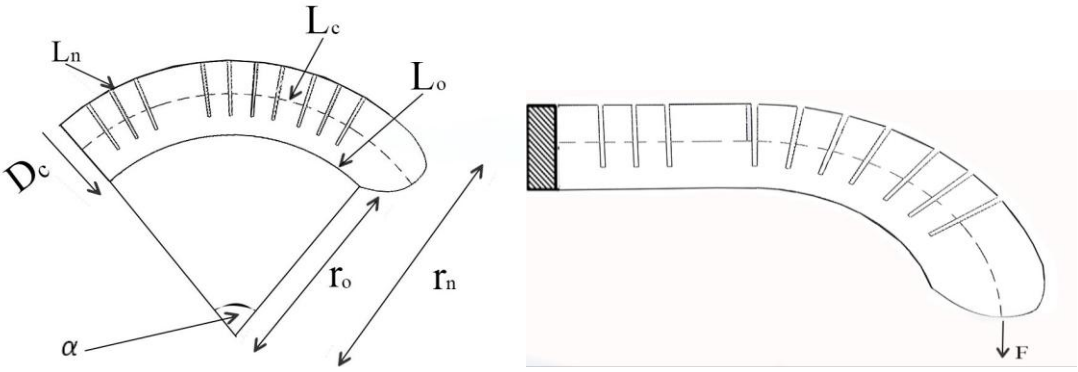


Figure 2. The bending SFA geometry and force direction

When the actuator is going to pressurized, the actuator's length expands on its upper side, and the actuator length and diameter after being bent will change to:

$$Lc = (L_o + L_n)/2 \quad (4)$$

$$Dc = r_n - r_o \quad (5)$$

And the length of two opposite sides of the bending actuator can be created from Combining actuator original length and bending length to get the below equations:

$$L_o = b\cos\theta_{max} = r_o\alpha \quad (6)$$

$$L_n = b\cos\theta = r_n\alpha \quad (7)$$

And by using (2) , the diameter of the bent actuator will be:

$$r_1 = D1/2 = b\sin\theta/2n\pi \quad (8)$$

$$r_2 = D2/2 = b\sin\theta_{max}/2n\pi \quad (9)$$

But $Dc = r_1 + r_2$

$$Dc = (b\sin\theta + b\sin\theta_{max})/2\pi n \quad (10)$$

Also it can develop the kinematic equations of the actuator bending which describe the radius of curvature ro, length of central axis of the actuator L_c, and the bending angle α as follows:
By using (5) and (7) we get:

$$L_n = (Dc + r_o)\,\alpha \quad (11)$$

And use (6), (7) and 11 we will get:

$$L_n = (Dc + Lo/\alpha)\alpha = Dc\,\alpha + Lo = b\cos\theta \quad (12)$$

From (12) and (6) the curvature angle can derive as a function of θ and θmax by use the bellow equation:

$$\alpha = (b\cos\theta - b\cos\theta_{max})/(Dc) \quad (13)$$

3. Methodology

3.1 A Finite Element Analysis

After that the properties of silicone rubber material put in ANSYS (2022) like Density, Young's modulus, passion ratio, Tensile strength, Coefficient of thermal expansion. A finite element model was done to expect the performance of bending or mechanical output of the soft actuator in (ANSYS Workbench 2022 R1) using static structural analysis.

3.2 Meshing

A meshing process was firstly done. The mesh approach may have an impact on the accuracy and convergence of the simulation results with number of node (149381) and element (719376) for each part see Fig. (3).

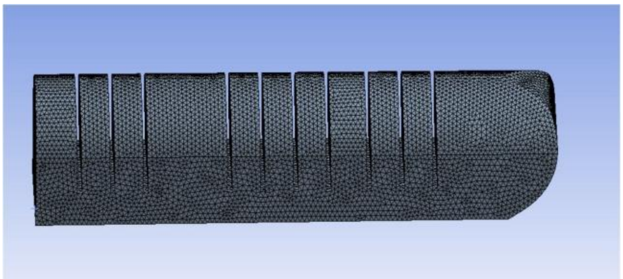


Figure 1: Meshing process

3.3 Boundary Condition

The boundary condition was determined starting with making the actuator like a cantilever beam by fixed one end (The left surface in purple color) and free the other end, then the pressure inputs (red color Arow) were applied equally on the inner surfaces of each chamber and stander earth gravity was used (Yellow color Arow) As shown in the figure (4). Then Two layers was determined (Inner active layer -red region-, and passive outer layer-blue region-), see Fig.(5).

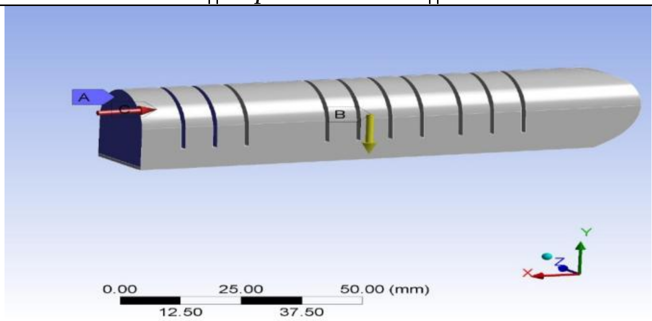


Figure 4. Determine the boundary condition

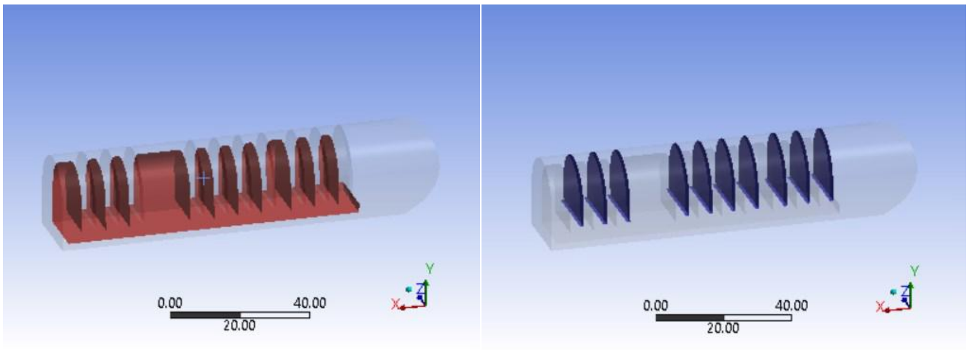


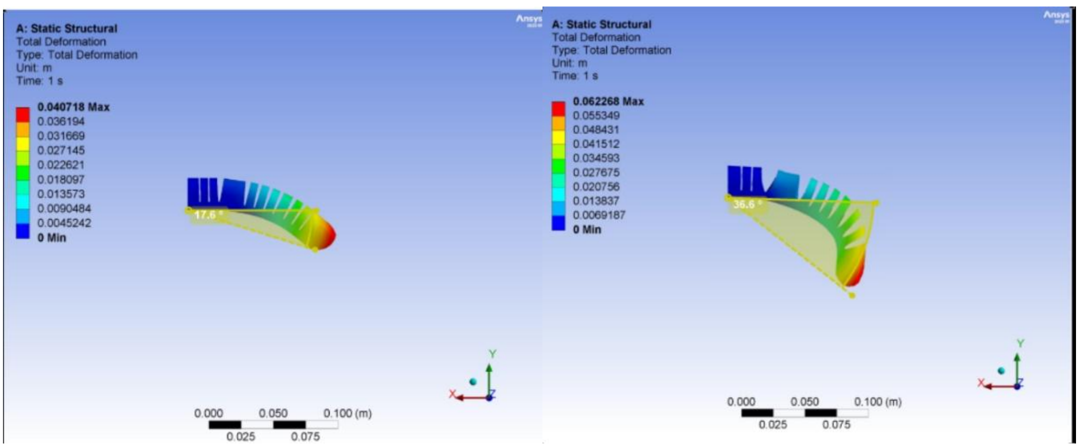
Figure 5. Define the passive outer layer and inner active layer

4. Tests and Results

These results include a study of finite element analysis by applying the boundary condition that have already mention above. And its Includes the result of pressure force and bending angle test.

4.1 The effect of pressure on the bending angle

We started with ANSYS program testing; the angle has been measured using the kinovea software program. When applying varied amounts of pressure, the deflection angle of a soft actuator finger was tested. It was observed that the higher the pressure, the greater the bending angle. Firstly when applied 2 psi pressure the deformation was 0.0407mm and the bending angle was 17.6° , Secondly applied (3 psi) pressure to the internal chamber and the result of total deformation is (0.0622mm) and the bending angle reach to 35.6°, Thirdly applied 4 psi pressure the deformation was 0.0926mm and the angle was 62.5°, Finally when applied 5psi pressure the total deformation reach to 0.1153mm and the bending angle was 105.1°. See Fig. 6.



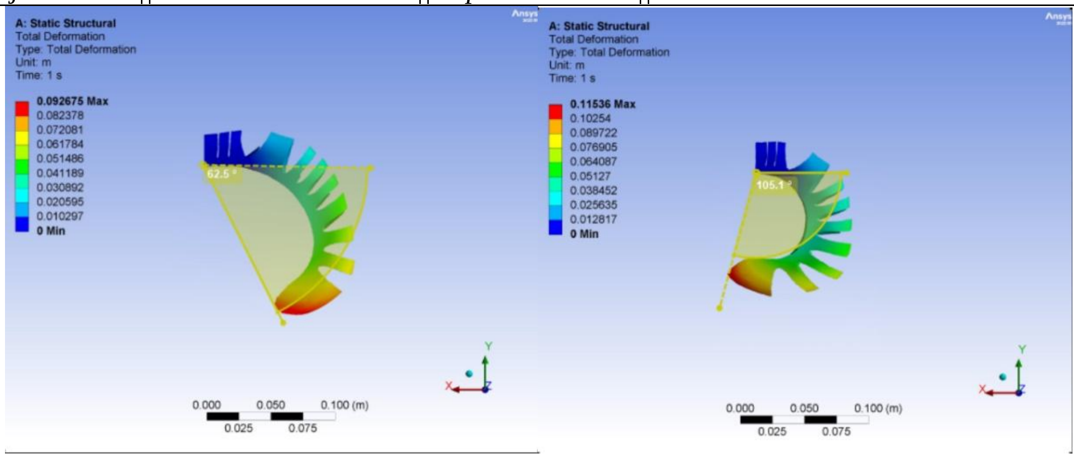


Figure 6. Total deformation and bending angle for SFA for different applied air pressure

Result shows the deformation of the soft Actuator finger is affected by the bending angle which is related to the internal pressure applied to the chamber. When increase the applied pressure to internal chamber the bending deformation was increase slightly and the soft finger actuator is working correctly.

4.2 The effect of pressure on the deformation

Force pressure test was done by using force sensor (FRS 402) to calculating the interaction force of SFA. They were fixed on one end and different pressure applied on it. By putting the bending end of actuator on a force sensor, Single soft actuators were examined with different pressure until produced the maximum force. Firstly, beginning with applied 2 psi air pressure then increase it to 3 psi, and then to 4 psi, and to the maximum pressure 6.4 psi as shown below in Fig. 7.

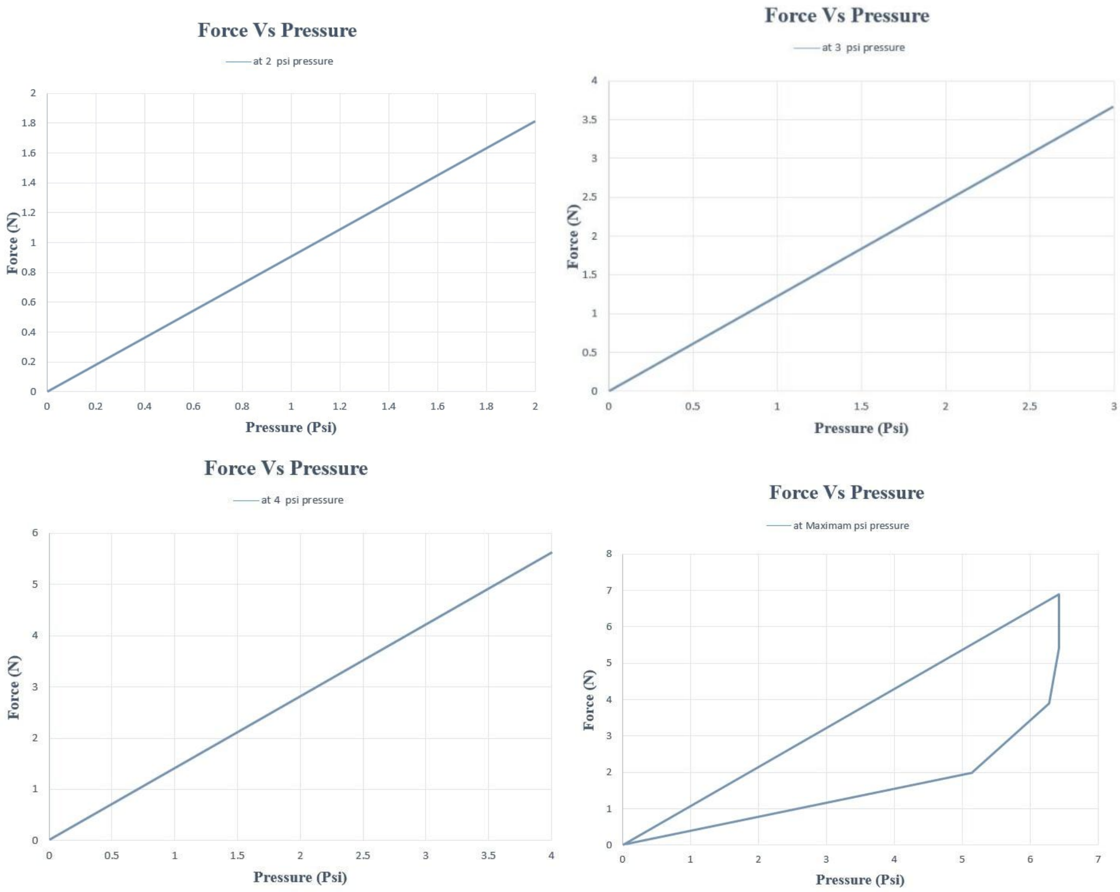


Figure 2. Applying different air pressures on SFA

The results showed that the greater the pressure, the greater the forces generated by the finger, and thus the increase in the amount of bending, so the relationship between pressure and forces is linear. And the Sufficient amount of pressure for complete bending motion was 5 psi. And the critical pressure value for the SFA was about 6.4psi

5. Conclusion

This paper has shown the deformation movement employing finite element modelling. To better understand the actuation bending performance for the SFA to be employed for soft robotic applications, the effects of various factors were investigated. The investigation was done to determine which factors were significant in determining deformation and, consequently, the bending angle of the pneumatic actuator and the amount of air pressure applied. Our analysis leads us to the conclusion that the overall deformation of the SFA represents the liner's true bending movement when various air pressures are applied inside the chambers. And this analysis process showed the correct workto the SFA design. The soft actuator with optimum parameters was created following the FE simulations. To measure the performance of the optimized soft actuator, experiments were carried out. Results from simulations and experiments are consistent. It is simple to extend our efforts to create different soft robotic structures to enhance the performance of the design before construction. The main goal of this work was to create flexible pneumatic actuators that could be placed strategically on a hand and finger rehabilitation glove.

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