Design optimization of a soft bending actuator

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ABSTRACT – This paper discussed the design optimization of a soft bending actuator. It has been reported that machinery has caused injuries and deaths in the industries, where most actuated by hard conventional actuators. Due to their hard physical features, it is difficult to implement in various environments. Due to such difficulties, these issues are mitigated by introducing soft actuators. This research aims to design and optimize two classes of soft bending actuator by employing FEM analysis. Two types of soft actuator designs were done, i.e. (a) PneuNets soft bending actuator and (b) fibre-reinforced bending actuator. For both designs, varying of the parameters was validated and then Abaqus software was employed for optimization. The fibre-reinforced actuator achieved 217.5mm bending motion in compared to PneuNets actuator, with 160.9mm bending motion.

1. INTRODUCTION

Typically, soft actuators are built from fluidic channel structures with compatible materials like shape memory alloys, elastomers, electroactive polymers, hydrogels, or composites that go through a phase transition in a solid-state [1]. There are numerous triggers for the actuation of soft actuator, which include chemical reactions, electrical charges as well as pressure fluids. In particular, the most suitable candidate for robotic applications is pneumatic and hydraulic powered soft actuators because of their low material cost, lightweight, high power-to-weight ratio as well as the associated ease of manufacturing [2]. Once pressurised, expansion of the chambers pertaining to the soft actuator occurs in the directions that involve low rigidity, which also leads to twisting, bending and extending or contracting motions. Also, integration of these actuators as actuators as well as structural elements into the soft robotic systems' structure can be done [3]. There is a need to test and ensure variety of design parameters to optimize the soft actuators. Various kinds of soft actuators have varying parameters that affect their behaviour and performance. Table 1 shows the example of parameters that may affect the design performances.

2. CONSTRUCTION AND DESIGN OF THE SOFT ACTUATOR

For the analysis and optimisation of the soft actuators, two designs were chosen; i.e.: (a) PneuNets soft bending actuator and (b) fibre-reinforced bending actuator.

Table 1 Soft actuator parameters

PneuNets Bending Actuators	Fibre-Reinforced Actuators
• Gap between chambers [18] • Material used for fabrication [18] • Rate of inflation [18] • Number of chamber [19] • Chamber wall thickness [19] • Chamber length [19]	• Actuator cross sectional shape [1] • Radius of actuator [1] • Length of actuator [1] • Wall thickness [1] • External sleeve [20] • Fibre arrangement (angle of fibre) [20]

To perform the FEM analysis, the two designs were design in the SolidWorks before being transferred to Abaqus software for optimization analysis. The parameters for the two designs were then made to vary. Figure 1 shows the PneuNets design, where the design consist internal fluid channel structures made of extremely stretchable elastomer materials that deform when the internal channels are pressurized to create a predefined movement. The PneuNets soft actuator design consists of three parts; i.e (i) main body, (ii) paper layer and (iii) bottom layer. Elastosil M4601 silicone rubber is used for the materials for the main body and bottom layer. Paper served as the strain limiting layer and was positioned between the bottom layer and main body parts. This is done to ensure that only the silicone parts will expand during pressurisation. For analysis, the pressure applied for testing purposes is between 1 psi to 9 psi.

Figure 2 shows the design of the fibre-reinforced bending actuator The main body is partitioned into 2 segments: the upper and the lower segments. The material for the upper segment is set as Dragon Skin 10 silicone rubber. The material for the lower segment is set as Smooth-Sil 950 silicone rubber. For the cap part, the material used is Smooth-Sil 950 silicon rubber. Compared to the upper segment, the lower segment and caps have stiffer materials. This ensures that the upper segment can be inflated more easily compared to the lower segment. Kevlar was chosen as the fibre material. The fibre is wrapped around the actuator's main body by following a 3° symmetry arrangement. This is to ensure that during pressurisation, expansion will only take place within the silicone parts and that the actuator will be constrained by the fibre, thereby allowing the actuator to bend. For testing purposes, forces with values of 1 psi until 8 psi were applied inside the chambers.

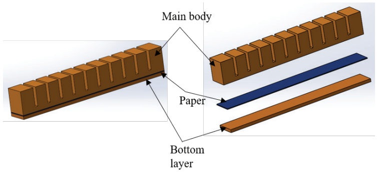

Figure 1 PneuNets soft actuator design.

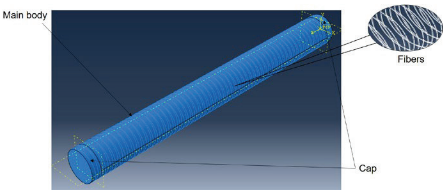

Figure 2 Fibre-reinforced bending actuator

3. PNEUNETS SOFT BENDING ACTUATOR AND FIBRE-REINFORCED SOFT ACTUATOR COMPARISON

Table 2 and Table 3 show the optimized bending and stress and comparisons for the three (3) parameters for the PneuNets design and Fiber-Reinforced design. Table 2 shows that the chamber height generated the least amount of stress at a value of 33.04N/m^2 and the chamber length parameter exhibited the largest bending with a value of 160.9mm.. In Table 3, the chamber length produced the lowest stress value at 284.2N/m^2 and the chamber diameter generated the largest bending out of the three (3) parameters, with its value of 217.5mm. Table 4 presents each design's optimized parameters as well as their respective displacement stress values. Out of the two designs, the PneuNets soft bending actuator produced the least amount of stress at 33.76N/m^2. On the other hand, the fibre- reinforced with higher design produced higher stress values 434N/m^2, which signifies that it is capable of handling more stress. In terms of the bending motion, a larger bending was achieved by the fibre-reinforced actuator, 217.5mm compared to the PneuNets soft actuator. One can also control the direction of the fibre-reinforced actuator's bending motion by varying the angle of the fibre. This gives the actuator a broader range of motion. To bending motion, the fibre-reinforced actuator was chosen as the optimized soft actuator.

4. CONCLUSIONS

Based on the results of the FEM analysis for the two designs, it can be concluded that the fibre-reinforced actuator was chosen as the optimized design, where the bending motion can be increased by increasing the chamber diameter. Furthermore, the fibre angle has a vital part in controlling the ending motion direction of the actuator. The direction of bending motion can be control and vary the by varying the angle of the fibre. For purposes of bending motion, the fibre-reinforced soft actuator served as the optimized actuator since it achieved higher bending motion.

Table 2 Stress and displacement results comparison between the three (3) parameters for PneuNets design

Parameter	Optimized value (min stress & max bending)			
	Stress		Bending (displacement)	
	Optimized parameter	Optimized stress	Optimized parameter	Optimized bending
Height of chamber	Height= 12.5mm	33.04 N/m^2	Height= 13.5mm	160.6mm
Length of chamber	Length= 5.9mm	33.1 N/m^2	Length= 6.1mm	160.9mm
Width of chamber	Width= 10.9mm	33.1 N/m^2	Width= 11.1mm	160.8mm

Table 3 Stress and displacement results comparison between the three (3) parameters for Fiber-Reinforced design

Parameter	Optimized value (min stress & max bending)			
	Stress		Bending (displacement)	
	Optimized parameter	Optimized stress	Optimized parameter	Optimized bending
Diameter of chamber	Diameter= 12.5mm	383.6 N/m^2	Diameter= 12.9mm	217.5mm
Length of chamber	Length= 156mm	284.2 N/m^2	Length= 156mm	214mm
Fiber angle	Fiber angle=30°	341.5 N/m^2	Fiber angle= 3°	213.1mm

Table 4 Optimize Soft Actuator parameters

Design	Optimized parameter	Optimized parameter	Optimized bending
PneuNets actuator	Height=13.5mm Length=6mm Width=11mm	33.76 N/m^2	160.9mm
Fiber-Reinforced Actuators	Diameter=6.45mm Length=155mm Fiber angle=3°	434 N/m^2	217.5mm

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