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A study on contraction of pneumatic artificial muscle (PAM) for load-lifting

W S W A Najmuddin[1], M T Mustaffa[2]

School of Manufacturing Engineering, Universiti Malaysia Perlis, Kampus Pauh Putra, 02600 Arau, Perlis, Malaysia.

wahmad@studentmail.unimap.edu.my[1], mohammadtaufiq@unimap.edu.my[2]

Abstract. Pneumatic Artificial Muscles (PAMs) have been known for its wide application in various aspects of industrial automation and robotic equipments. Many advantages in terms of high power-to-volume ratio, high power-to-weight ratio, stick-slip-free operation and high degree of safety offer by PAM compare to traditional actuators. However, behind this benefits lie a limitation of significant compatibility of PAM mechanism which have to be considered so as to fully understand how the PAM works during load-lifting. In this study, the mesh suitability experiment and the effect of force load on PAM contraction experiment have been carried out. PAM is constructed and compatibility of bladder and the braided mesh to produce uniform expansion is investigated. Moreover, the first experimental result of finding compatibility is used to verify the contraction value under various loads.

1. Introduction

Robots become significant to serve and assist human, especially for older people and disabled people. However, high rigidity of robot joints will be hazardous to a human because a human has soft arms and compliant joints activated by numerous muscles. Necessity for human-like actuators system, many researchers have motivated to study in this field and created the Pneumatic Artificial Muscle (PAM). The PAM is used for converting pneumatic power to pulling force and eventually causing movements of the mechanism. These are the systems that have performance characteristic alike to and stronger than that of human muscle. Besides PAM, it has another name which are Fluidic Muscle [1], Pneumatic Muscle Actuator [2], Air Muscle [3], Axially Contractible Actuator [4], Tension Actuator [5-6], Fluid Actuator [7] and Fluid-Driven Tension Actuator [8].

Muscles of human involve biceps and triceps which help to move the human hand, are roughly classified as flexor and extensor muscles. Biceps included in the flexor group and it will bend the arm by decreasing the angle between the forearm and upper arm whereas, triceps muscle included in the extensor muscle. In flexion condition, biceps muscle will contract while triceps muscle will relax. While in extension condition, the biceps will relax and triceps contracted. The length of muscle shorter and the contracting force becomes smaller [9]. The PAM uses a layer that demonstrates a muscle and pneumatics as its source of activation force. The membrane ought to have the capacity to either radially stretch or alter its radial section.

The PAM has a long history with few accomplishments in different applications. In the 1950s, the rubber-tube type of PAM was initially developed by the physician, Joseph L. McKibben for an artificial limb of the handicapped [10]. McKibben muscle basically made from an inner rubber tube or called bladder and a non-extendable double- helix woven sheath or called braided mesh shell. The PAM was upgraded in the 1980s and turn out to be all the more capable. It had been presented by Bridgestone Company and was utilized for painting applications as a part of the industry and a few applications to help debilitated people and administration mechanical autonomy [11].

The PAM used to various types of humanoid applications and propelled robots. The PAM is basically utilized as an automated actuator where consistence and low power to weight proportion are essential, e.g. strolling or running machines or even humanoid robots. There are few companies manufactured PAMs for robotic and modern applications such as Case in point, Shadow Group and FESTO [3,10-11]. PAM can be classified into four types which are embedded muscle, netted muscle, pleated muscle and braided muscle [11]. PAM has numerous natural focal points for human-machine interface. For example, PAM is low weight, high force to weight proportion, working principle same as human, safe energy and can change the stiffness of PAM.

It is important to understand the correlation of main components includes braided mesh and bladder PAM's design. In this study, the mesh suitability and the effect of force load on PAM contraction experiment have been carried out. PAM is constructed and compatibility of bladder and the braided mesh to produce uniform expansion is investigated. The first experimental result of finding compatibility is used and the performance of PAM is accessed through testings using various loads and the contraction value is verified.

2. Experimental

2.1 Materials

The PAM consists of bladder and braided mesh. Material for the bladder is rubber while for braided mesh is polyethylene. The PAM experiment setup is illustrated in figure 1a where one side is the air inlet and the other side is the closed end and connected with the load. Figure 1b shows the equipment involved and assembled for PAM's load lifting test. The material and experiment apparatus includes bladder or inner tube, braided mesh shell or expandable braided cable sleeve, pressure regulator, connector and loads.
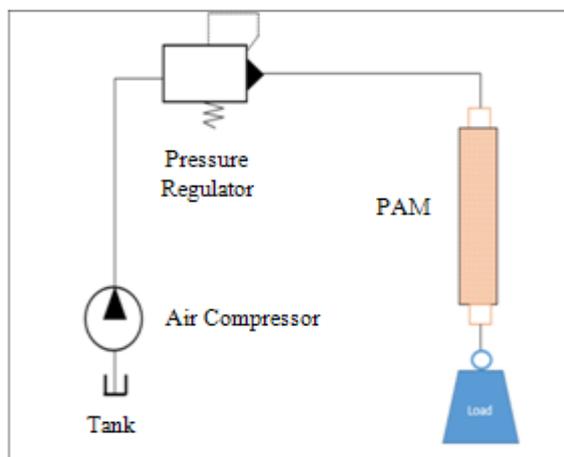
| (a) | (b) |

Figure 1. Pneumatic diagram (a) and assembled PAM's load lifting test (b)

2.2 Mesh Suitability

The purpose of this test is to prove the significance of choosing the suitable braided mesh and how using the optimum size braided mesh can lead to maximum contraction. Contraction percentage can be achieved by using formula as shown in Eq. 1.

$$Contraction = \frac{Displacement}{Initial\ Length} \times 100\% \qquad (1)$$

The parameter used for this experiment is specified in table 1. Three samples are used with each different bladder diameter and constant length. The experiment is set up according to the figure 1. For the first sample includes 2.5cm braided mesh with 3kg of selected load is attached to PAM.

Table 1. Experimental parameters.

No. of Sample	1	2	3
Bladder Diameter (cm)	2.0	2.5	3.0
Bladder Length (cm)		17	
Braided Mesh Diameter (cm)		2.5, 3.0, 3.5	
Load (kg)		3	

Next, PAM is pressurized manually and the displacement result of the PAM is recorded. The experiment is then repeated using different diameter of braided mesh and samples accordingly.

2.3 Effect of Force Load on PAM

The primary objective of this experiment is to study how the contraction percentages of the bladder changes as the different amount of loads are applied to the bladder. Contraction percentages can be calculated by using Eq. 1. The parameter used for this experiment is specified in Table 2.

Table 2. Experimental parameters.

No. of Sample	1	2	3
Bladder Length (cm)	12	17	22
Bladder Diameter (cm)		2.0	
Braided Mesh Diameter (cm)		3.5	
Load (kg)		3, 4, 5, 6, 7, 8, 9, 10	

The experiment is conducted according to the figure 1. For the first sample includes 12cm of bladder length with fix bladder and braided mesh diameter. Minimum of the 3kg load is used until maximum of 10kg loads is reached. The PAM is pressurized manually and the displacement of the PAM is recorded. Each data taken includes different loads with three different samples accordingly.

3. Results and Discussion

3.1 Mesh Suitability Experiment

Figure 2a, figure 2b and figure 2c show contraction percentage versus pressure of the 2 cm, 2.5 cm and 3 cm diameter of bladder respectively. Each diameter using three different diameters of braided mesh. The compressed air pressure of 1, 2, 3 and 4 bar have been tested. The experiment was performed by using load 3 kg. It can be seen that if air pressure increase, the contraction will also increase.
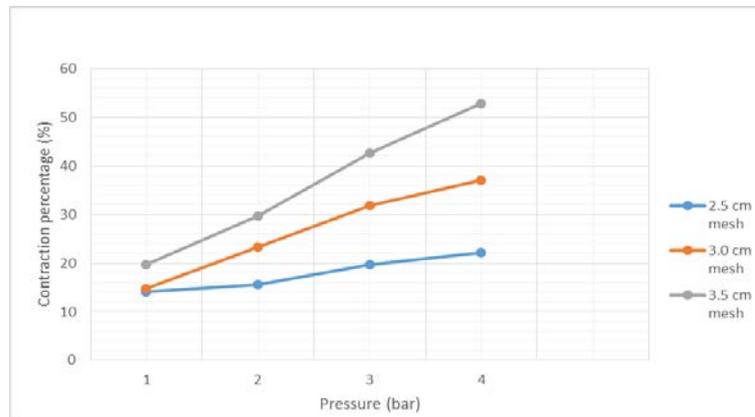
(a)
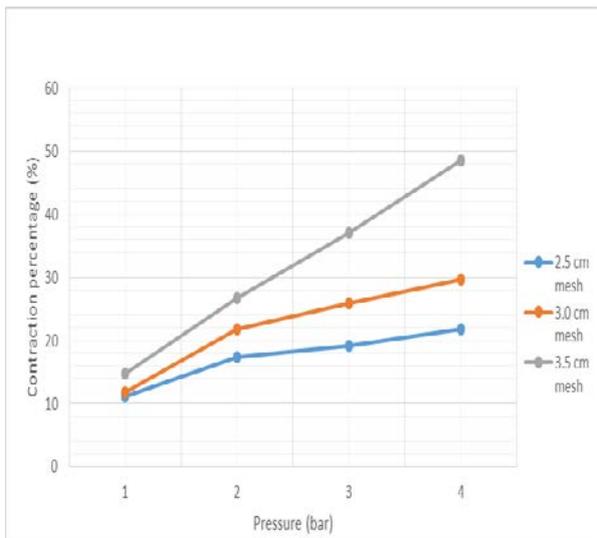
(b)
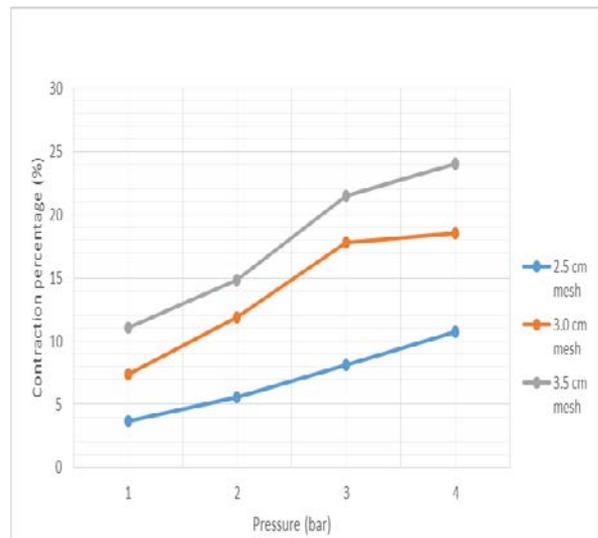
(c)

Figure 2. Contraction percentage versus pressure of diameter bladder (a) 2 cm (b) 2.5 cm (c) 3 cm

Figure 3 shows the contraction percentage versus pressure of 3.5 cm braided mesh using three different diameters of bladder. Value of 2.0 cm bladder (green line) gives the best result in contraction percentage which is 51.85%. It shows, the mesh gives fully cooperating with the expansion of the bladder. The mesh can be categorized as the mesh that has optimum size when it can contract half from its original length.
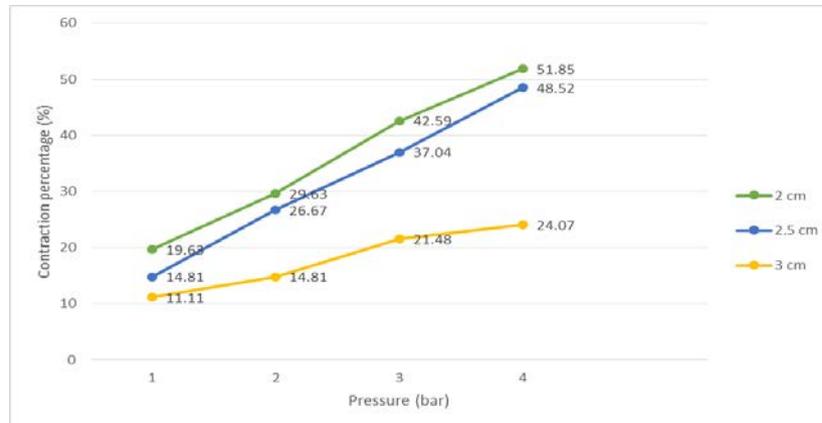
Figure 3. Contraction percentage versus pressure for 3.5 cm braided mesh

3.1.1 Compatibility braided mesh with bladder.
The bladder has braided sleeve mesh around it and uniformly expands as seen in Figure 4. The bladder is compressed against the mesh when the PAM is pressurized manually. Tension from the braid will act as restricting agent and therefore balance the pressure from the bladder. Besides that, tension from the material is mingled at the end points of braided mesh to balance external load [11]. The mesh is suitable with the bladder when it can balance the constrictive force of mesh and expanding force from the bladder.

Figure 4. Uniform expansion of PAM
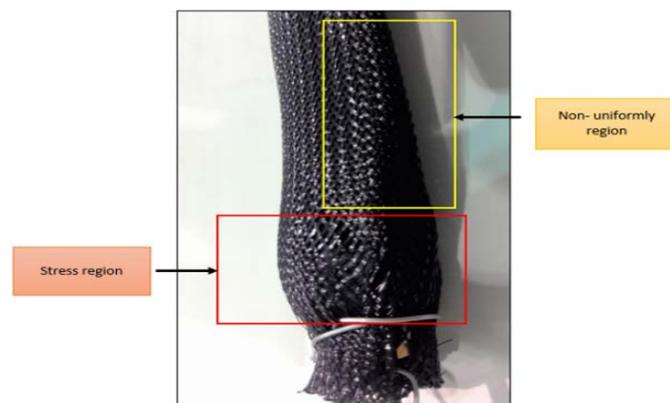
Figure 5. Non-uniform expansion of PAM

3.1.2 Incompatibility braided mesh with bladder.
Figure 5 shows the stress regions where the non-uniformly of bladder expanded. Other diameter bladder is incompatible with the braided mesh due to the mesh that unable to support and balance when the air pressure installed. When bladder fails to expand uniformly, the energy is loss and contraction percentage is reduced. The condition of PAM at the stress concentration region in red line and non- uniform expansion region of the bladder in yellow line with low concentration percentage is seen in Figure 5. From observation, the red region will be torn and the yellow region indicates the flat surface of the tube due to non-uniform expansion. The reading of displacement and contraction percentage can be taken only from 1 bar to 4 bar due to the capability of the rubber tube.

3.2. Effect of Load on PAM Contraction
The contraction percentage versus load for 2 cm diameter bladder using 3.5 cm braided mesh is illustrated in figure 6. From this experiment, when bladder is stress-free which is no air pressure is applied it will elongate twice of its original length. When air is supplied to the PAM, it will expand horizontally instead of vertical direction which causes the PAM to contract.

The 22 cm length of bladder presents the higher contraction percentage compared to 12 cm and 17 cm of bladder length. This means that the length increment will increase the value of PAM contraction. The result of contraction between 22 cm long and 17 cm are slightly similar since both have a limitation contraction. The bladder will reach the maximum potential to contract at certain point of length. The contraction of PAM has a limited value which is PAM unable to develop any forces and its volume has reached a maximum value.

The contraction percentage is decreased when a large amount of load is applied. This is because the force transmitted by the muscle remains constant even though the amount of load is increasing. The force remains the same due to the diameter of PAM which is constant. Thus, the experiment shows that diameter and length of bladder are the main factors to increase the performance of PAM.
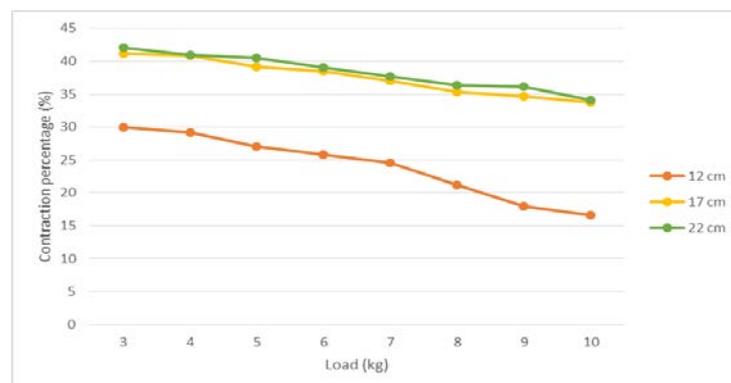
Figure 6. Contraction percentage versus load for 2 cm diameter bladder using 3.5 cm braided mesh

4. Conclusion
In the present study, the compatibility of braided mesh shell with bladder has been identified in uniform and non uniform condition. Research efforts were important on the new developed of PAM to provide an option for load-lifting mechanisms, while possessing the safety, portability, reliability and low cost. The experimental results showed the effectiveness value of mesh suitability. The suitable result indicates the value of 2.0 cm bladder in contraction percentage which is 51.85%. Under various loads, the PAM contraction indicates that the value of 22 cm length of bladder present the higher contraction percentage compared to others. Obviously, these experiments contribute knowledge on correlation of PAM mechanisms as well as assisting by avoiding the failure of PAM during PAM contraction process.

Future recommendation for this project is to increase the thickness of bladder's wall. If the tube thickness is high, it can withstand more pressure applied. Besides that, the type of braided mesh can be recommended for better efficiency of PAM.

5. Acknowledgment

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