LAB Report #1: Design and Characterization of Pneumatic Artificial Muscle

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Results

1. Provide photos of your three muscles with dimensions and experimental setups.

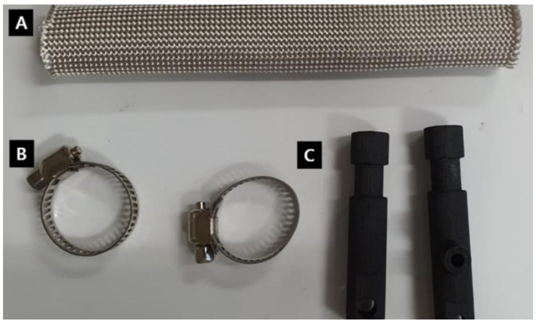


Fig 1 Materials for building the McKibben Muscle

Fig 2 Assembly order for the McKibben Muscle

Fig 3 Pressure Regulator(Left) and Test Machine(Right)

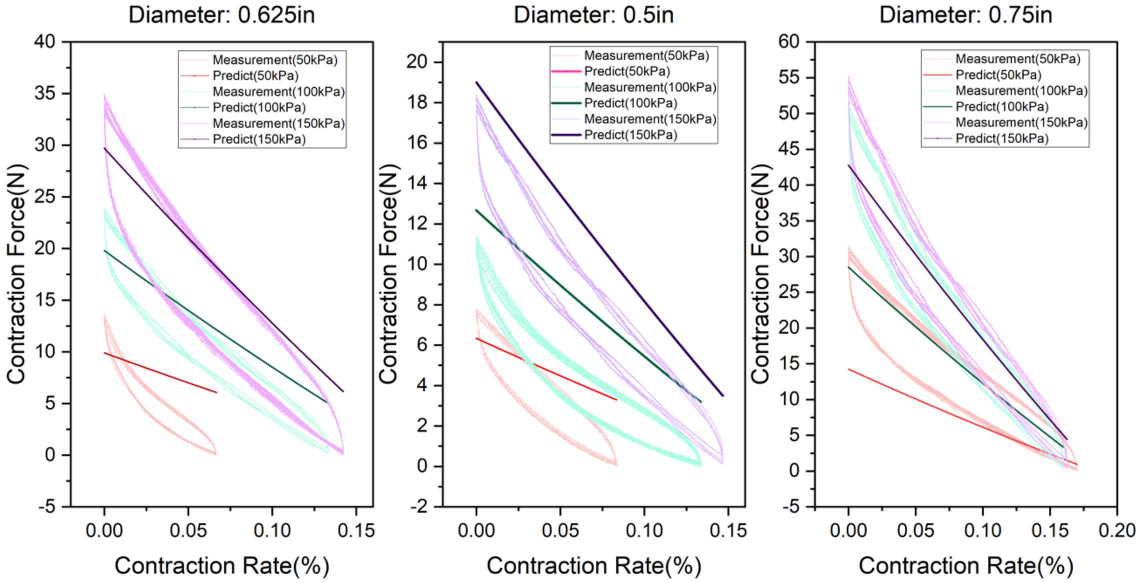
Fig 4 Assembly Result(From left to right, 0.5, 0.625, 0.75in)

Figure 1 has shown the materials for building the McKibben Muscle, and the label A is the glass fiber coated tube with 150mm initial length, label B is the hose clamp, and label C are the air valve parts. In this examination, we are provided three different radius size of the sleeves that could be seen in Figure 4. All of the materials required for the McKibben Muscle are prepared in the lab session, and our group members assembled the McKibben Muscle with in the order of Figure 2.

We used two types of air caps. One of them is the blocked cap which will seal the end of the sleeve and the other one is the inlet type cap which will function as the valve on the other side of the sleeve. The inlet cap will be connected with the 4mm tube which is directly connected to the pressure regulator. And the air regulator used to control the output air pressure with PWM and source pump.

After assembling, the examination run with the air pressure regulator and force test machine. We have three types of McKibben Muscle and they will be tested in force test machine with 3 different air pressure (50kPa, 100kPa, 150kPa). And Result 2 will show you about the graph of the recorded data.

2. Process the data and compare your results with the model provided: Provide a characterization graph for each muscle. Each graph should contain measurement data for three different air pressures. In the same plot, superimpose your theoretical predictions for the three air pressures, referring to the results from the published papers related to McKibben's muscles. You may refer to the references or Equation 1. The design parameters are given in Table 1.



Notice: The medium part is Diameter with 0.5in, that might in the left is appropriate to check. But I have not arrange time with my reason.

3. Provide a table that contains the stroke lengths and maximum force according to fiber diameters.

Fiber Diameters (D)/m	Stroke Lengths (δl)/m	Maximum Force (F_{max})/N
0.0127	0.150-0.13747	7.85 (50kPa)
0.0127	0.150-0.13000	11.47 (100kPa)
0.0127	0.150-0.12802	18.40 (150kPa)
0.01588	0.150-0.14000	13.67 (50kPa)
0.01588	0.150-0.13001	23.92 (100kPa)
0.01588	0.150-0.12866	34.95 (150kPa)
0.01905	0.150-0.12450	31.45 (50kPa)
0.01905	0.150-0.12602	51.52 (100kPa)
0.01905	0.150-0.12562	55.20 (150kPa)

Discussion

1. What would be the motivations of using pneumatic artificial muscles instead of electric motors?

One advantage of the pneumatic artificial muscle is that an artificial muscle has no static friction.

Another advantage of the artificial muscle is that alignment is not critical.

A third advantage is its weight. The main disadvantage of pneumatic artificial muscles is their inability to produce a great force through a great excursion. They are lightweight and have high force to weight ratio comparing with electrical motors.

And it can explain its main application in the design of powered finger prehension orthosis instead of an electric motor. In another aspect, the renewal of interest in pneumatic artificial muscles is linked to the recent development of bio-robotics or bio-inspired devices.

2. What are the assumptions in the model used?

1) The ideal model assumed the possibility of a soft pantograph network in the form of a cylinder and the side of each 'bent' pantograph can effectively remain constant during the 'contraction-elongation' process.

2) The displacement of the McKibben muscle from the zero force-length(l_0), u, satisfies $u \ll b$ (each thread of nylon mesh length)

3) Moreover, it is assumed that the pressure is sufficient to assume a full transfer of pressure forces to the braided sheath. In any contraction state of the artificial muscle, the full pantograph network remains in contact with the exterior surface of the rubber tube.

4) The assumption of a zero-thickness inner tube. The spring effect of the inner tube is dominant in radial direction compared to the axial direction, and the damping effect of the inner tube is negligible.

5) The effect of the top and the bottom edges of the McKibben muscle is negligible. Current lengthl_c of each conical portion is proportional to the contraction ratio ε as follows: $l_c = k_c l_0 \varepsilon$, where k_c is a constant to be chosen between 0 and a maximum value so that $l_c \leq l - l_c$ in the maximum contraction ratio rate, which induces $k_c \leq (1-\varepsilon_{max})/2\varepsilon_{max}$; when $\varepsilon = 0$, $l_c = 0$ and, as a consequence, the model has a cylindrical shape only in its initial state. During contraction, the current position of the fixed tip along the muscle axial direction is denoted z, with $0 \leq z \leq l_c$, and the current radius r_z corresponding to z positions related to z by the linear relationship: $r_z = r_0 + (r - r_0)(z/l_c)$ can subsequently be written for the free conical tip.

6) Static force is linear elasticity assumption.

7) The internal friction of the McKibben muscle would result from a double phenomenon: strand-on-strand friction and stand-on-inner tube friction.

3. What are the assumptions in the experiments?

1) The pipe is sufficiently narrow that the air charge and discharge happen slow enough for the system to maintain the static force equilibrium

2) The pressure at the outlet of the regulator is instantly switched between the ambient and the source pressure

3) The entire process is isothermal as the pipe is sufficiently narrow.

4) The Darcy friction factor is constant for the entire process.

5) Defining the scale factor as the ratio: $S_{scale} = (D_s/2r_{contact})$, and whose the expression can be written as follows: $S_{scale} \approx 0.69 \times \frac{E^{1/3}}{(1-v^2)^{1/3}P^{1/3}}$.

4. In Result 2, how are your experimental results different from the theoretical predictions? What causes the difference? What are the methods to increase the precision of the estimation than equation 1?

First, the Result 2 has shown the hysteresis with counter-clockwise directions. Because the thread-on-tread dry friction of braided fibers is negative effect on the actuating force of McKibben muscles when the muscles contract and positive effect when the muscles expand, the actuating force on contraction is smaller than that of expansion.

1) Role of the braid: The virtual work theorem as was used in the model does not explain how the braided sheath makes the transmission of pressurized forces possible. This understanding needs to consider a more detailed force analysis. If take into account pressure force versus free extremity of the artificial muscle, obtain the following expression of the force generated by what can be called a real cylindrical McKibben muscle – in which any possible friction or elastic effects are naturally not considered.
2) Role of the rubber inner tube: This elongation breaking imposes maximum muscle variation radius on McKibben muscles, and in the case of a cylindrical model a minimum initial braid angle can be deduced from equation.
3) Tip effects: these non-cylindrical tip portions represent some end effect peculiar to the real McKibben muscle, which induces a natural contraction loss with respect to the purely cylindrical artificial muscle
4) Elastic force
5) Static friction and muscle hysteresis

5. What are some strengths and limitations of McKibben muscles in general?

Strengths:

It could be used in robotics with the aim of developing more human-friendly robots mimicking natural skeletal muscle compliance.

And it also could be used as purely mechanical fluidic artificial muscles as an alternative actuation mode, in either mechatronics or robotics.

It is lightweight and has high force to weight ratio comparing with electrical motors.

Limitations:

The main disadvantage of McKibben's muscles is their inability to produce a great force through a great excursion. And its use required a heavily embedded pressurized CO_2 tank due to its high gas consumption (explained in the following). Thus, it seems that after brief commercial use, it was forgotten once small electric motors with lighter batteries became effective and cheap.

And its accurate modelling is particularly arduous because it combines multiple difficulties in the physics of elastic and soft materials