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MATLAB MODELS FOR PNEUMATIC ARTIFICIAL MUSCLES

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SUMMARY

Pneumatic artificial muscles (PAMs) are becoming more commonly used as actuators in modern robotics. The most made and common type of these artificial muscles in use is the McKibben artificial muscle that was developed in 1950's.
This paper presents the geometric model of PAM and different Matlab models for pneumatic artificial muscles. The aim of our models is to relate the pressure and length of the pneumatic artificial muscles to the force it exerts along its entire exists.

INTRODUCTION

McKibben muscle is an actuator, which converts pneumatic (or hydraulic) energy into mechanical form by transferring the pressure applied on the inner surface of its bladder into the shortening tension ([1]). The principle of pneumatic artificial muscle is well described in [2], [3], [4], [5] and [6]. There exists several types of fluidic muscles that are based on the use of rubber or some similar elastic materials, such as the McKibben muscle, the Rubbertuator made by Bridgestone company, Air Muscle made by Shadow Robot company, Fluid Muscle made by Festo company, Pleated PAM developed by Vrije University of Brussel, ROMAC (RObotic Muscle ACtuator), Yarlott and Kukolj PAM and some others ([2] and [7]). They possess several advantages over other types of actuators but most of all, it is their power-to-weight ratio. Due to high nonlinearity of pneumatic systems, pneumatic artificial muscles are difficult to control so a fast and robust control is necessary to achieve the desired motion ([5], [7], [8] and [9]).
The PAM that was selected as the actuator for our study is the Fluidic Muscle (DMSP-20-200N-RM-RM) manufactured by FESTO. According to its specification, maximum contraction over the nominal length is 25-27 %.

GEOMETRIC MODEL OF THE PNEUMATIC ARTIFICIAL MUSCLES

A good background of our test-bed can be found in [10] and [11].
The general behaviour of PAM with regard to shape, contraction and tensile force when inflated will depend on the geometry of the inner elastic part and of the braid at rest (Fig. 1), and on the materials used ([2]).

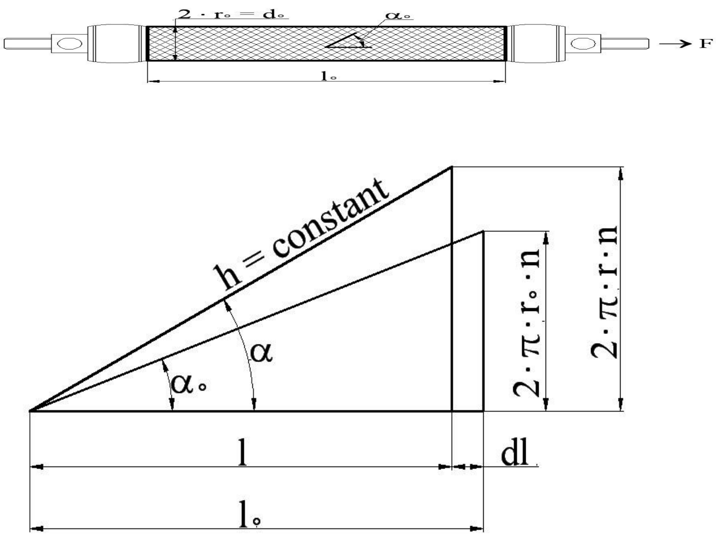

Fig. 1. Geometry parameters of PAM

Typical materials used for the membrane construction are latex and silicone rubber, while nylon is normally used in the fibres (Fig. 2).

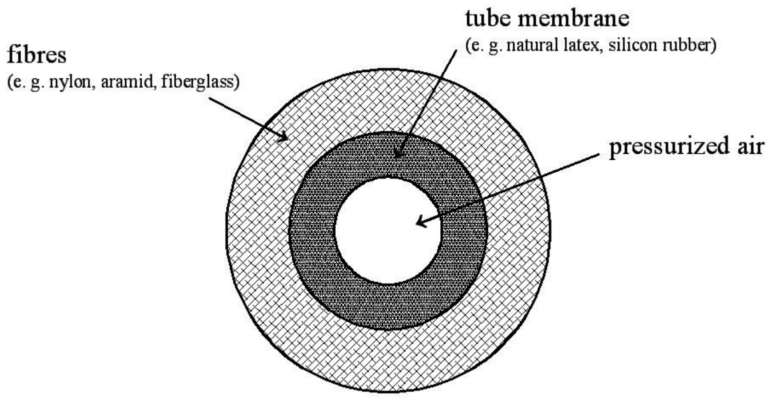

Fig. 2. PAM and its orthotropic material layers

With the help of [5] and Fig. 1, the force can be calculated:

$$F(p,\kappa) = p \cdot \pi \cdot r_0^2 \cdot \left(\frac{3}{tg^2 \alpha_0} \cdot \frac{l^2}{l_0^2} - \frac{1}{\sin^2 \alpha_0} \right) = p \cdot \pi \cdot r_0^2 \cdot (a \cdot (1-\kappa)^2 - b) \qquad (1)$$

with $a = \frac{3}{tg^2 \alpha_0}$, $b = \frac{1}{\sin^2 \alpha_0}$, $\kappa = \frac{l_0 - l}{l_0}$ and $0 \le \kappa \le \kappa_{max}$

F the pulling force, *p* the applied pressure, r_0, l_0, α_0 the initial inner radius and length of the PAM and the initial angle between the thread and the muscle long axis, *r, l, α* the inner radius and length of the PAM and angle between the thread and the muscle long axis when the muscle is contracted, *h* the constant thread length, *n* the number of turns of thread and *κ* the contraction.

In literature we can find some consideration to improve equation 1. [5] reports that we need to complete this initial approximation with a correction factor (ε), on the one hand, (1) does not pay attention to the material that the muscle is made of, on the other hand, it predicts for various pressure the same maximal contraction. This new equation is very good for higher pressure ($p \geq 2$ bar). [12] suggests to achieve similar approximation for smaller pressure another correction factor (μ) is needed so the modified equation is:

$$F(p,\kappa) = \mu \cdot p \cdot \pi \cdot r_0^2 \cdot (a \cdot (1 - \varepsilon \cdot \kappa)^2 - b) \qquad (2)$$

with $\varepsilon = a_\varepsilon \cdot e^{-p} - b_\varepsilon$ and $\mu = a_\kappa \cdot e^{-\kappa \cdot 40} - b_\kappa$

MATLAB MODELS FOR PNEUMATIC ARTIFICIAL MUSCLES

Matlab is common software for modelling, simulating and analyzing. First of all, on the basis of equation 2 we have designed the block diagram in Matlab as shown in Fig. 3. Constants are programmed and defined in an M-file.

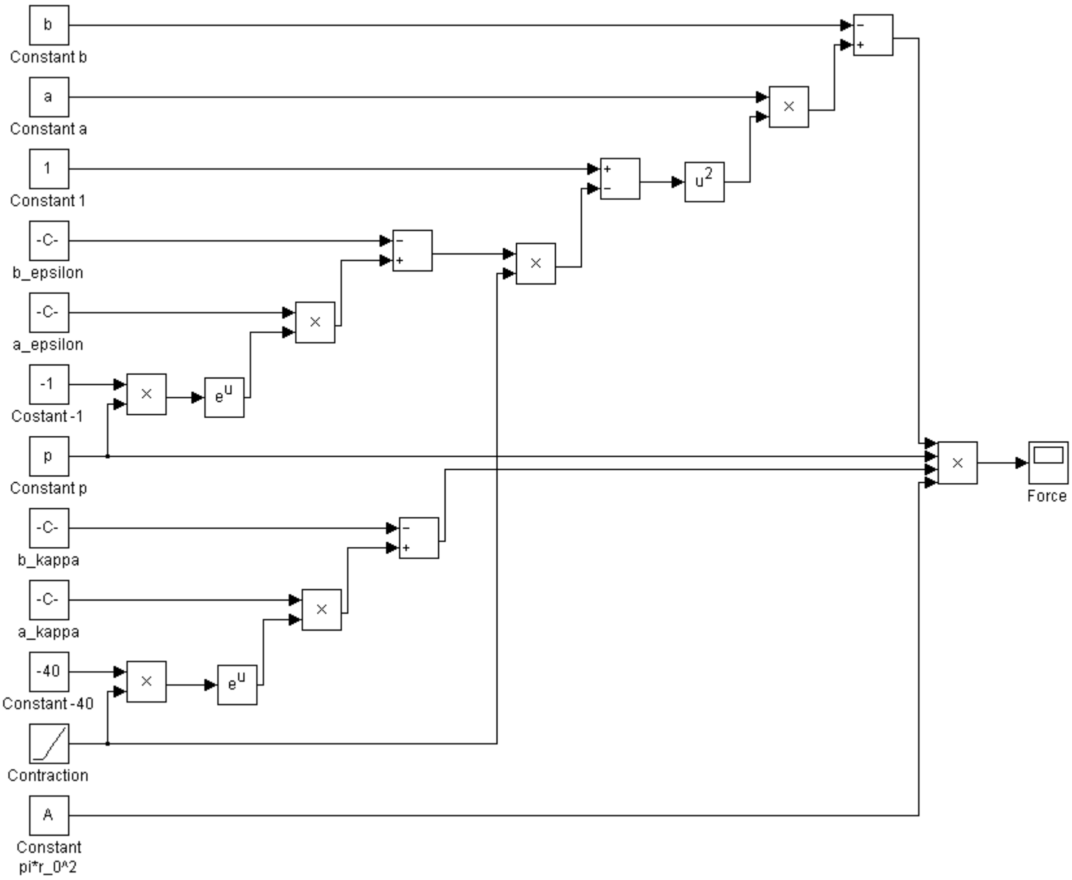

Fig. 3. Block diagram of the equation 2 in Matlab

The results of equation 2 and measured data can be compared in Fig. 4. The unknown a_ε, b_ε, a_κ and b_κ parameters were estimated using least-square method.

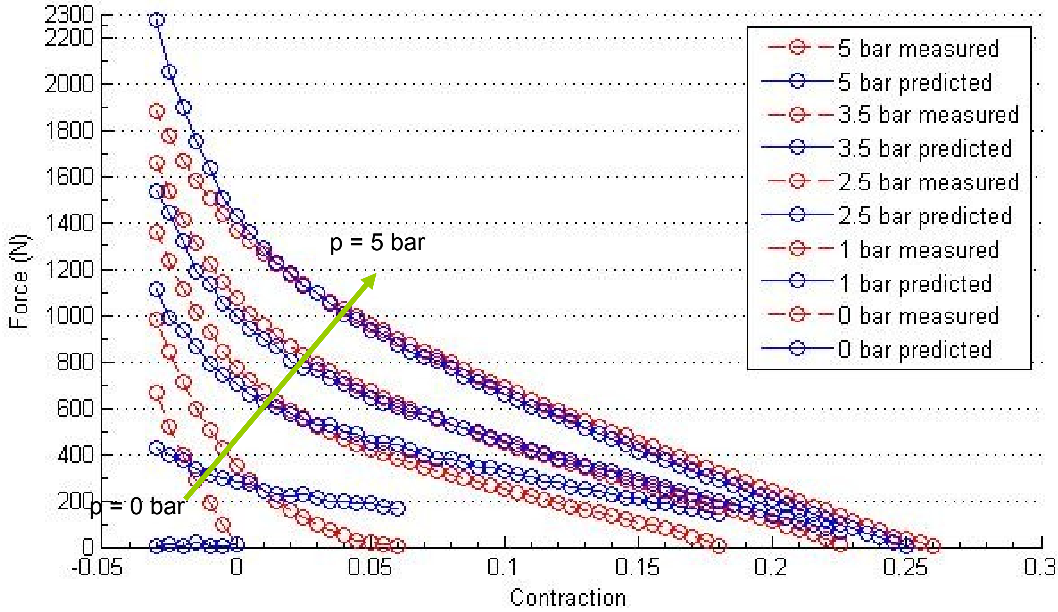

Fig. 4. Measured and predicted force under different pressures (with equation 2)

With regard to the significant differences between the theoretical and experimental results we have worked out a better approximation algorithm for the equation of force. Under fixed pressure the contraction to force function can be approximated by an exponential function (equation 3):

$$F(\kappa) = a \cdot e^{(b \cdot \kappa + c)} + d \cdot \kappa + e \tag{3}$$

In order to generalize equation 3 to attain pressure dependency, variables need to be replaced with first order polynomes of pressure. The final equation should be invertible, so the exponential part has to be simple.

$$F(p, \kappa) = (a \cdot p + b) \cdot e^{(c \cdot \kappa + d)} + (e \cdot p + f) \cdot \kappa + g \cdot p + h \tag{4}$$

For an open-looped control system an inverse model is necessary to control the system. Although the equation 4 is nonlinear, its inverse is defined as equation 5 where the pressure is the function of the desired force and contraction.

$$F(y, \kappa) = - \frac{- y + b \cdot e^{(c \cdot \kappa + d)} + \kappa \cdot f + h}{a \cdot e^{(c \cdot \kappa + d)} + \kappa \cdot e + g} \tag{5}$$

On the basis of equation 4 we have constructed the block diagram in Matlab as shown in Fig. 5. Constants were estimated using least-square method and defined in an external M-file.

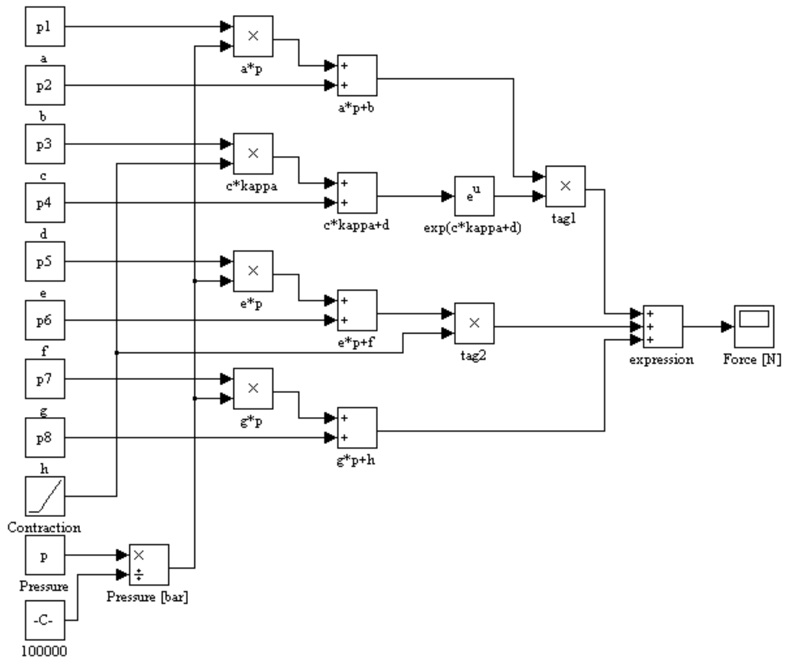

Fig. 5. Block diagram of the equation 4 in Matlab

The results of equation 4 and measured data can be compared in Fig. 6.

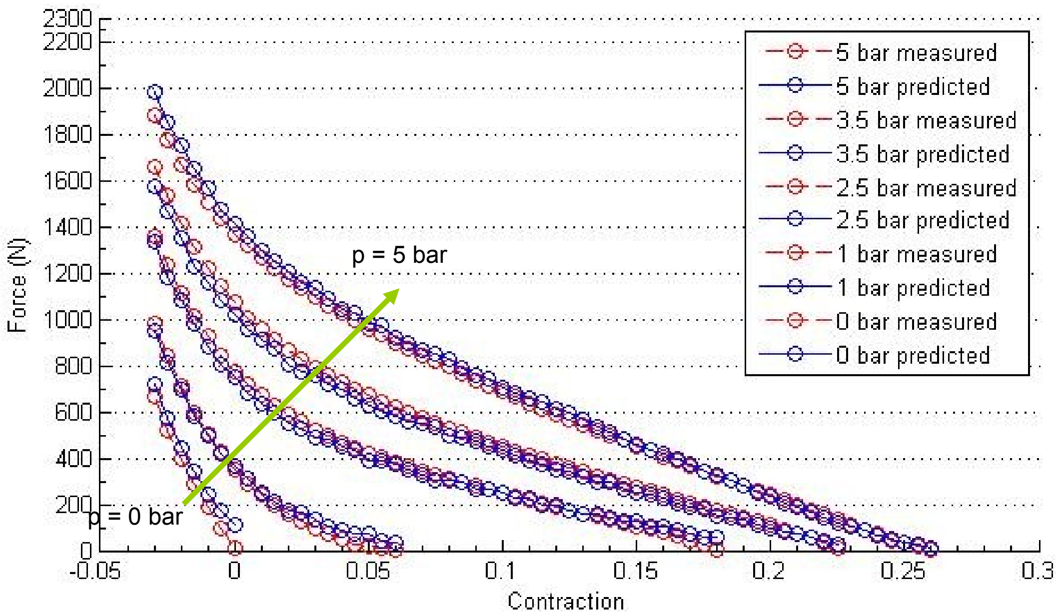

Fig. 6. Measured and predicted force under different pressures (with equation 4)

CONCLUSIONS AND FUTURE WORK

Pneumatic artificial muscle or McKibben muscle has outstanding capabilities due to its extreme power to weight (and volume) ratio. Designing an adequate control mechanism for this highly non-linear system needs accurate modelling. In this paper an invertible yet accurate and simple model of the pneumatic muscle is shown. The agreement of simulation results on the experimental results confirms the viability of the proposed model. Future work will be devoted to designing an open-looped control system based on the presented model, and improving it with dynamic properties like hysteresis and aging.

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