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MATHEMATICAL ANALYSIS OF THE NEWEST MODEL FOR THE FORCE GENERATED BY FLUIDIC MUSCLE

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Abstract

The less well-known type of pneumatic actuators is the pneumatic artificial muscles (PAMs). Different designs have been developed, but the McKibben muscle is the most popular and is made commercially available by different companies (e. g. Fluidic Muscle manufactured by Festo Company). Many researchers have investigated the relationship of the force, length and pressure to find a good theoretical approach for the equation of force produced by PAMs. In most cases, significant differences have been noticed between the theoretical and experimental results. In this paper our goal is to present our newest precise approximation algorithm for the force of Fluidic Muscle.[1]

1 Introduction

The working principle of different pneumatic muscles is well described in literature (Caldwell et al. (1993), Chou and Hannaford (1996), Daerden (1999), Tondu and Lopez (2000), Daerden and Lefeber (2002), Balara and Petk (2004)). PAMs have various names: Pneumatic Muscle Actuator, Fluid Actuator, Fluid-Driven Tension Actuator, Axially Contractible Actuator, Tension Actuator, etc. (Daerden (1999), Daerden and Lefeber (2002), Ramasamy et al. (2005)). Most types of PAMs consist of a rubber bladder enclosed within a helical braid that is clamped on both ends. A PAMs energy source is gas, usually air. The muscle will expand radially and contract axially when inflated, while generating high pulling forces along the longitudinal axis. The tensile force depends on the contraction and the applied pressure. This feature is totally different from pneumatic cylinders, because a cylinder develops a force that depends on the applied pressure and piston surface area and independent from

[1]Keywords and phrases: *Fluidic Muscle, Static Model, Force Function, MS Excel Solver*

displacement (Daerden and Lefeber (2002)). Typically, the air muscle can contract by about 25 % of its initial length.

The layout of this paper is as follows. Section 2 (Materials and Methods) presents the static modelling of PAMs and our newest force equations. Section 3 (Results and Discussion) compares the measured data and calculated data. Finally, Section 4 (Conclusion and Future Work) gives the investigations we plan. Fluidic Muscle type DMSP-20-200N-RM-RM (with inner diameter of 20 mm and initial length of 200 mm) produced by Festo Company is selected for our newest study.

2 Materials and Methods

The general behaviour of PAMs with regard to shape, contraction and tensile force when inflated depends on the geometry of the inner elastic part and of the braid at rest (Figure 1), and on the materials used (Daerden (1999)). Typical materials used for the membrane construction are latex and silicone rubber, while nylon is normally used in the fibres.

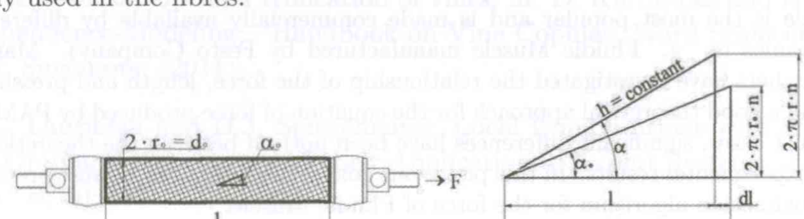

Figure 1: Geometry parameters of PAMs

Where F the pulling force, r_0, l_0, α_0 the initial inner radius, 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.

Good description of the general static model of PAMs can be found in Chou and Hannaford (1996), Daerden (1999), Tondu and Lopez (2000) and Kerscher et al. (2005). On the basis of them the force equation has been found:

$$F(p,\kappa) = r_0^2 \cdot \pi \cdot p \cdot (a \cdot (1-\kappa)^2 - b) \tag{1}$$

Where: $a = \frac{3}{tg^2\alpha_0}$, $b = \frac{1}{sin^2\alpha_0}$, $\kappa = \frac{l_0 - l}{l_0}$ and
p – applied pressure,
κ – contraction.

Equation (1) was modified with correction factors ε (Tondu and Lopez (2000)) and μ (Kerscher et al. (2005)):

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

Significant differences between the theoretical and experimental results using (1) and (2) have been proved in Sárosi and Fabulya (2012). To eliminate the differences new approximation algorithms with six and five unknown parameters have been introduced for the force generated by Fluidic Muscles:

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

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

Equation (3) can be generally used with high accuracy for different Fluidic Muscle independently from length and diameter under different values of pressure and (4) can be used with high accuracy for Fluidic Muscle with inner diameter of 20 mm, only.

The unknown parameters of (3) (a, b, c, d, e and f) and (4) (a, b, c, d and e) can be found by Solver in MS Excel 2010.

3 Results and Discussion

Our newest investigations were carried out in MS Excel. Firstly, the measured data and calculated data using (1) were compared. As it is shown in Figure 2, the measured force always drops from its highest value at full muscle length to zero at full inflation and position and there is only one intersection point between the measured and calculated results and no fitting.

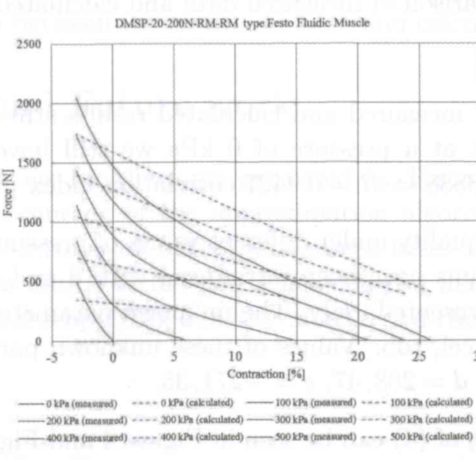

Figure 2: Comparison of measured data and calculated data using (1)

$R^2 = 0.5397 \Rightarrow R = 0.7346$ correlation index proves the inaccurate fitting for the measured data.

In the interest of fitting the simulation was repeated with (2) (Figure 3). The coefficients of (2) were found using Solver in MS Excel.

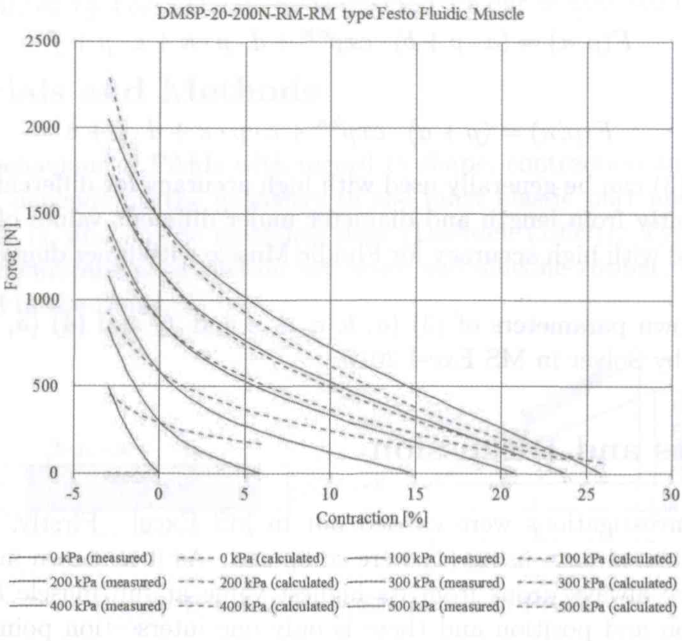

Figure 3: Comparison of measured data and calculated data using (2)

Figure 3 shows the measured and calculated results still do not fit. Better fitting was attained, but at a pressure of 0 kPa we still have a rather substantial inconsistency. $R^2 = 0.8888 \Rightarrow R = 0.9427$ correlation index proves this difference.

To improve fitting quality under different values of pressure including 0 kPa new approximation algorithms have been introduced with 6 and 5 parameters. In this paper result of (4) is presented, only. The unknown parameters of (4) can be found using Solver in MS Excel, too. Values of these unknown parameters: $a = 286,17$, $b = -0,33$, $c = -9,14$, $d = 288,47$, $e = -271,35$.

The accurate fitting of (4) can be seen in Figure 4 and Figure 5. $R^2 = 0.9994 \Rightarrow R = 0.9997$ correlation index proves the tight relationship between the measured data and calculated data.

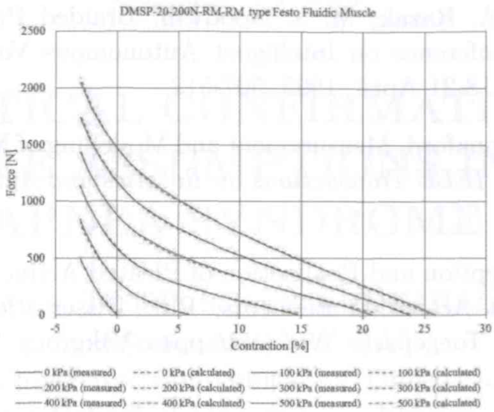

Figure 4: Comparison of measured data and calculated data using (4)

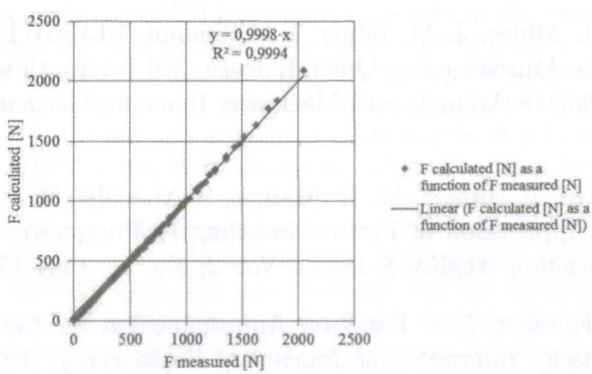

Figure 5: Relationship between the measured force and calculated force using (4)

4 Conclusion and Future work

In this work new functions for the force produced by Festo Fluidic Muscle have been introduced. The accuracy of the approximation algorithm with 5 unknown parameters ($R = 0.9997$ correlation index) was proved here. The analysis was done in MS Excel. Our main aim is to develop a new general mathematical model for pneumatic artificial muscles applying our new models and results.

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