EDUCATION, RESEARCH, INNOVATION
ERIN 2013
INTERNATIONAL CONFERENCE
15th - 17th of May 2013
Častá - Papiernička, Slovakia

ESTIMATED FORCE-CONTRACTION CURVES OF FLUIDIC MUSCLES BY A FIVE-PARAMETER FUNCTION

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ABSTRACT:

Pneumatic actuators convert pneumatic energy into mechanical motion. This motion can be linear or rotary. Linear motion is feasible with pneumatic cylinders (e. g. single-acting cylinder, double-acting cylinder, rodless cylinder) and pneumatic artificial muscles (PAMs). Pneumatic artificial muscle is the newest and most promising type of pneumatic actuators. PAM is a membrane that expands radially and contracts axially when inflated, while generating high pulling forces along the longitudinal axis. The force and motion produced by PAM are linear and unidirectional. Different designs of PAM have already been developed. Recently Fluidic Muscle manufactured by Festo Company and Shadow Air Muscle manufactured by Shadow Robot Company are the most popular and commercially available. This paper describes a five-parameter function for the force generated by Fluidic Muscles. For this study two Fluidic Muscles are used to compare the measured and theoretical results. The muscles have the same diameter, but one is twice as long as the other.

1. INTRODUCTION:

Electric, hydraulic and pneumatic systems are commonly used in industrial environment, robotics and education [1], [2]. Pneumatic artificial muscles have a wide range of applications, too, e. g. for tab punching, vibratory hopper, lifting device and walking robot [3], [4]. Many important daily activities, such as eating, drinking, dressing and walking depend on two-handed or/and two-legged functions. Rehabilitation and prosthetic devices driven by PAMs can help such people who have difficulties in these areas [5], [6], [7].

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There are a lot of advantages of PAMs like the high strength, good power/weight ratio, good power/volume ratio, low price, little maintenance needed, great compliance, compactness, flexibility, inherent safety and usage under rough environments, but their dynamic behaviour is highly nonlinear, therefore a nonlinear robust control technique is needed for accurate positioning [8].

The pneumatic artificial muscle is a one-way acting device. Therefore, two ones are needed to generate bidirectional motion: one of them moves the load, the other one will act as a brake to stop the load at its wanted position and the muscles have to change function to move the load in the opposite direction. This specific connection of the muscles to the load is generally named as an antagonistic set-up: the driving muscle is called the flexor or agonist, while the brake muscle is called the extensor or antagonist. The antagonistic configuration of the actuators causes the active muscle to pull against the stiffness of the passive muscle. Different investigations of PAMs in antagonistic connection are well described in [9] and [10]. Bharadwaj et al. in [11] presented the possibility of bidirectional motion with spring over muscle (SOM).

The layout of this paper is as follows. Section 2 (Materials and Methods) is devoted to describe the geometry parameters of PAMs and a five-parameter function for the force generated by Fluidic Muscles. Section 3 (Experimental Results) compares the measured and calculated results. Finally, Section 4 (Conclusion) gives the experiences.

For this study two Fluidic Muscles are selected: DMSP-20-200N-RM-RM (with inner diameter of 20 mm and initial length of 200 mm) and DMSP-20-400N-RM-RM (with inner diameter of 20 mm and initial length of 400 mm).

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 (load carrying structure) at rest (Fig. 1), and on the materials used [12]. Typical materials used for the membrane construction are latex and silicone rubber, while nylon is normally used in the fibres.

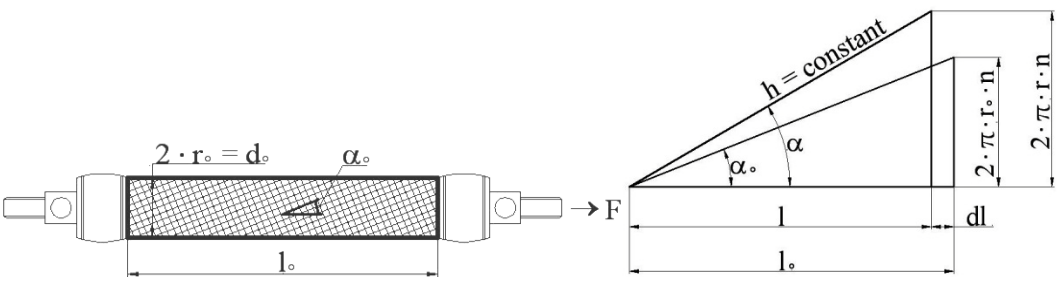

Fig. 1

Geometry parameters of PAMs

Where:

F [N]: pulling force,

r_0 [m]: the initial inner radius of PAM,

l_0 [m]: the initial length of PAM,

α_0 [°]: the initial angle between the thread and the muscle long axis,

r [m]: inner radius of the PAM when the muscle is contracted,

l [m]: length of the PAM when the muscle is contracted,

α [°]: angle between the thread and the muscle long axis when the muscle is contracted,

h [m]: the constant thread length,

n: the number of turns of thread.

The load carrying structure of Fluidic Muscles is embedded helically in its membrane. The membrane is made from chloroprene and the load carrying structure is made from aramid (Fig. 2).

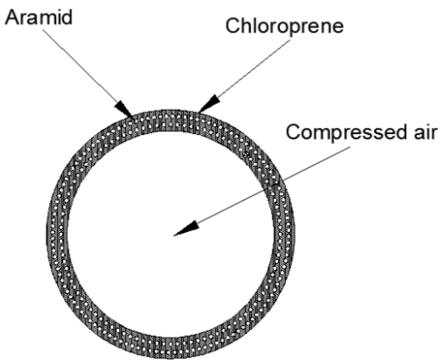

Fig. 2

Scheme of Fluidic Muscles

The basic static models of PAMs can be found in [9] and [13]. Significant differences between the theoretical and experimental results using these models have been proven in [14] and [15]. To eliminate the differences a new approximation algorithm with five unknown parameters has been developed and introduced for the force generated by Fluidic Muscles:

$$F(p,\kappa) = (p + a) \cdot \exp^{b \cdot \kappa} + c \cdot p \cdot \kappa + d \cdot p + e \qquad (1)$$

Where p is the applied pressure and κ is the contraction (relative displacement). The unknown parameters of equation 1 were found using least squares method with Microsoft Excel Solver.

3. EXPERIMENTAL RESULTS:

The muscle force as a function of contraction at constant values of pressure is the most frequently mentioned feature of PAMs. The force always drops from its highest value at full muscle length to zero at full inflation (Fig. 3). To approximate the measured force generated by Fluidic Muscles type DMSP-20-200N-RM-RM and type DMSP-20-400N-RM-RM equation 1 was used. Values of the unknown parameters of it are shown in Table 1.

Table 1. Values of the unknown parameters of equation 1

DMSP-20-200N-RM-RM		DMSP-20-400N-RM-RM	
Parameters	Values	Parameters	Values
a	286.1714546	a	274.7944784
b	-0.327523456	b	-0.32623809
c	-9.135794264	c	-9.07369264
d	288.4720479	d	296.3161465
e	-271.3462159	e	-254.042387

Fig. 3 presents the experimental and theoretical results on the same graphs for DMSP-20-200N-RM-RM and DMSP-20-400N-RM-RM, respectively. To describe the nature and strength of the relationship between the experimental and calculated results, regression and correlation analysis were used. $R^2 = 0.9994 \rightarrow R = 0.9997$ and $R^2 = 0.9993 \rightarrow R = 0.9996$ correlation coefficients approach the maximum (strongest, R = 1) correlation (Fig. 4). Consequently, equation 1 is capable of making accurate and reliable predictions of static force.

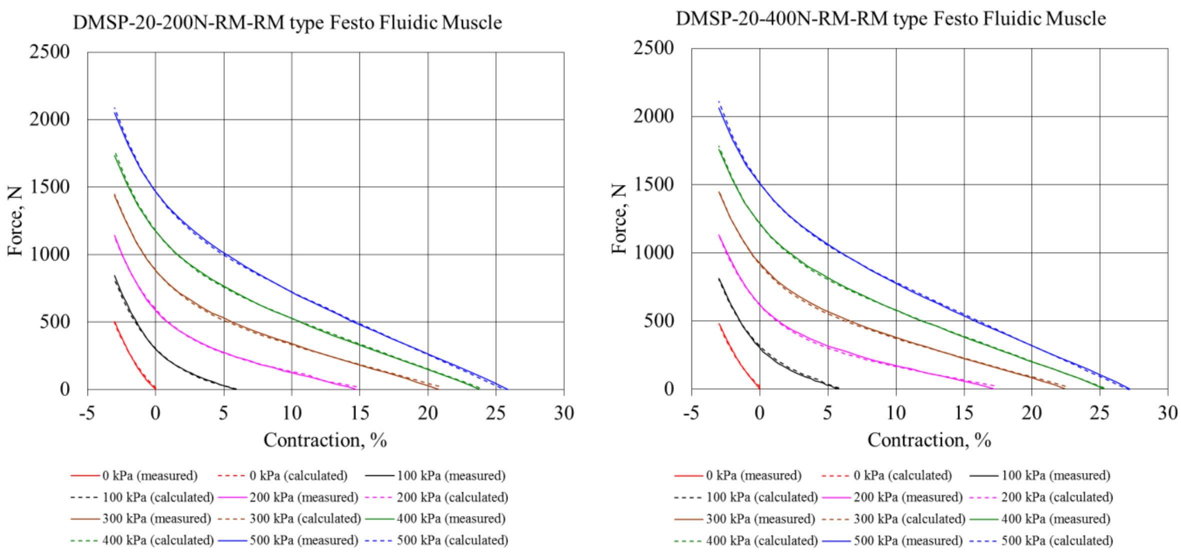

Fig. 3

Comparison of measured and calculated force using equation 1

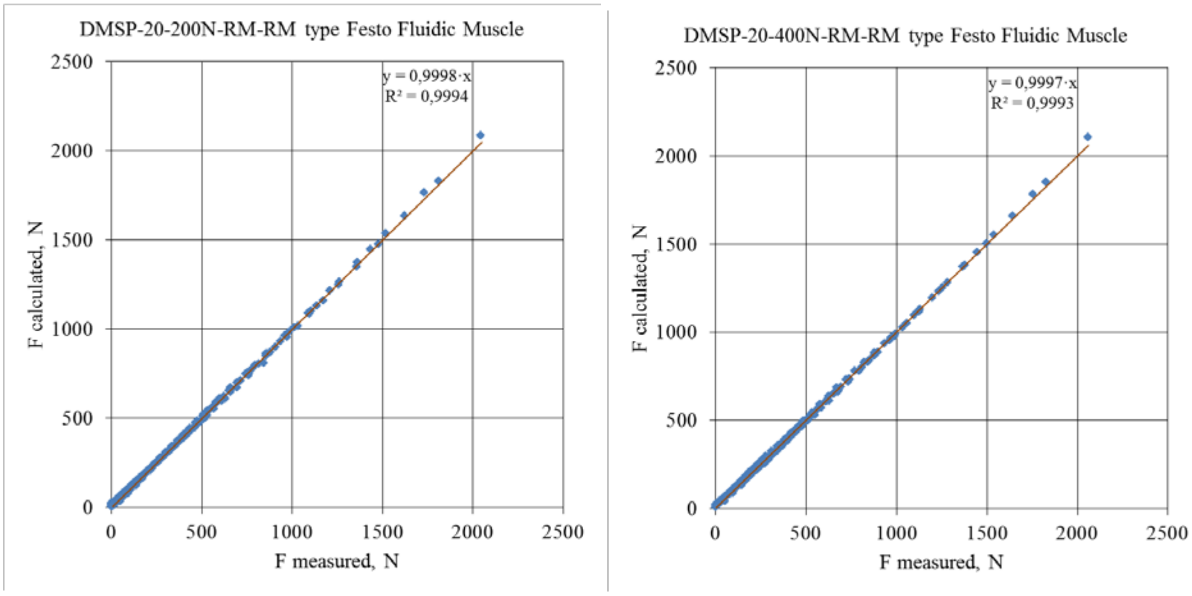

Fig. 4

Results of regression and correlation analysis

4. CONCLUSION:

According to Tondu and Lopez in [9], the static force is globally independent of initial length. On the basis of Table 1 and Fig. 3, differences can be noticed beetwen the force generated by Fluidic Muscles. The muscles had the same diameter (20 mm), but one is twice as long as the other (200 mm and 400 mm). Therefore, length has to be taken into account for high precision applications.

The regression and correlation analysis were carried out in MS Excel environment. It was proven that the five-parameter function can be used for accurate predictions of static force.

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