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SIZING FLUIDIC MUSCLE USING STATIC FORCE MODEL

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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 lifting device using PAM that is selected by our static force model.

KEYWORDS: Sizing, Fluidic Muscle, Lifting Device, Static Force Model

INTRODUCTION

Electric, hydraulic and pneumatic systems are commonly used in industrial environment, robotics and education [1], [2], [3]. Pneumatic artificial muscles have a wide range of applications, too, e. g. for tab punching, vibratory hopper, lifting device and walking robot [4], [5]. 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 [6], [7], [8].

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 [9].

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 [10] and [11]. Bharadwaj et al. in [12] presented the possibility of bidirectional motion with spring over muscle (SOM).

The layout of this paper is as follows. Section 2 (The Study) is devoted to describe the static force model as a six-parameter function and the lifting device. Section 3 (Results and Discussion) illustrates different solutions to move a load. Finally, Section 4 (Conclusions) gives the experiences and future work.

For this study DMSP-20-400N-RM-RM (with inner diameter of 20 mm and initial length of 400 mm) type Fluidic Muscle is selected.

THE STUDY

In the simplest case, Fluidic Muscle can be operated as a single-acting actuator against a constant load. Then the lifting device consists of only one muscle (Figure 1, where m is the load, x is the stroke and p is the applied pressure).

Figure 1. Lifting device using Fluidic Muscle

The diameter and nominal length of the Fluidic Muscle can be found on the basis of required force at rest, required stroke, required force at contracted state and operating pressure (Figure 2) [4].

Static force model was used to size the muscle of lifting device. The basic static models of PAMs can be found in [10], [13] and [14]. Significant differences between the *theoretical and experimental results using these models have been proven in [15] and [16]. To eliminate the differences a new approximation algorithm with six unknown parameters has been developed and introduced for the force generated by Fluidic Muscles:*

$$F(p,\kappa) = (a_1 \cdot p + a_2) \cdot \exp^{a_3 \cdot \kappa} + a_4 \cdot \kappa \cdot p + a_5 \cdot p + a_6 \qquad (1)$$

where p is the applied pressure, κ is the contraction (relative displacement), a_1, a_2, a_3, a_4, a_5 and a_6 unknown parameters. The unknown parameters of equation 1 were found using least squares method by Microsoft Excel Solver. To describe the nature and strength of the relationship between the measured and calculated results, regression and correlation analysis were used.

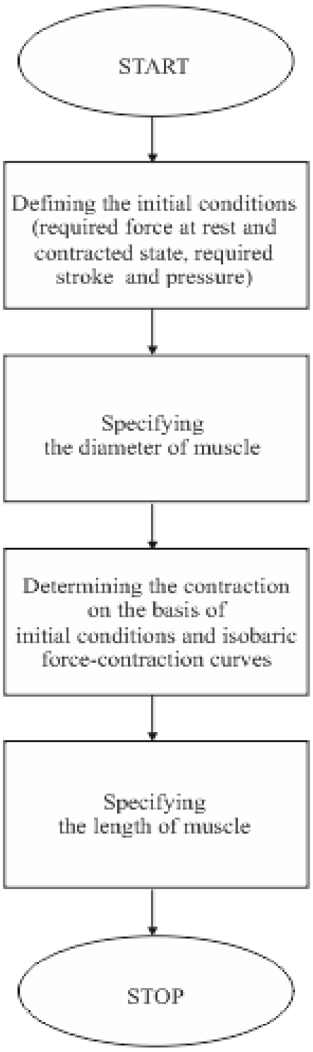

Figure 2. Flow chart of solution

RESULTS AND DISCUSSION

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 (Figure 3).

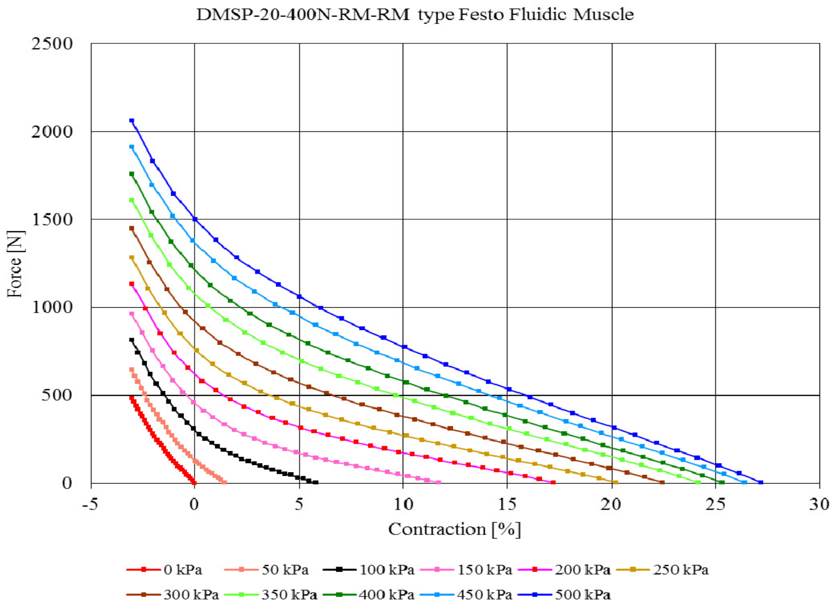

Figure 3. Isobaric force-contraction curves (measured)

To approximate the measured force generated by Fluidic Muscle type DMSP-20-400N-RM-RM equation 1 was used (Figure 4). Values of the unknown parameters of equation 1 are shown in Table 1.

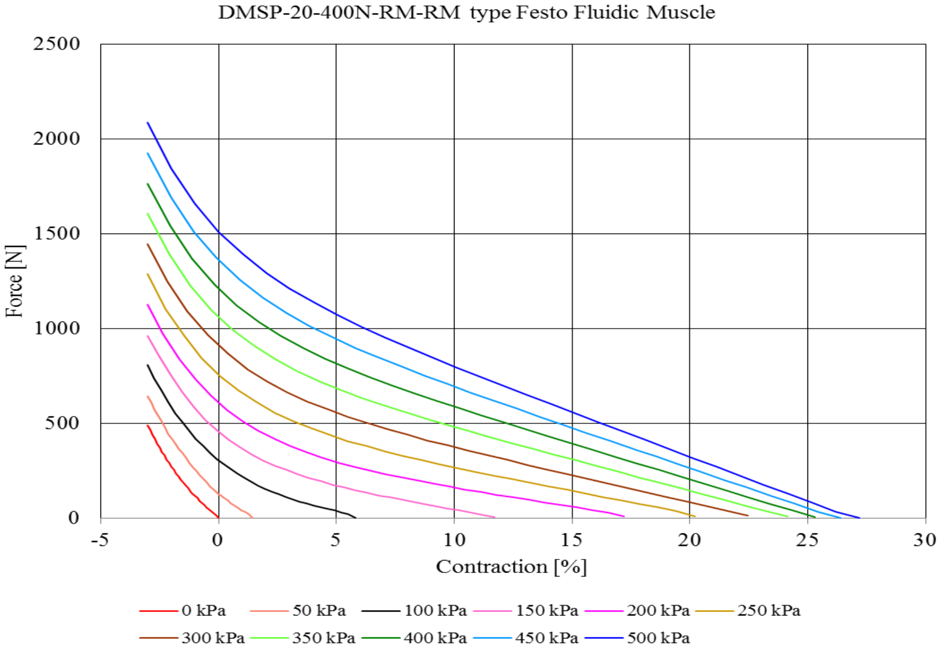

Figure 4. Isobaric force-contraction curves (calculated using equation 1)

Table 1. Values of the unknown parameters of equation 1

Parameters	Values
a_1	-5,90740254
a_2	280,5263678
a_3	-0,33374175
a_4	-9,38346682
a_5	307,2595996
a_6	-274,484755

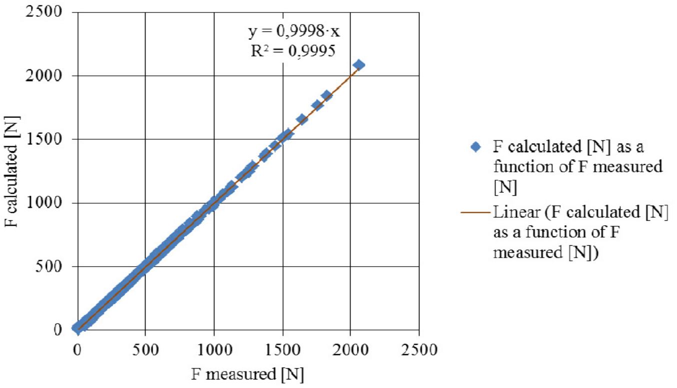

Figure 5. Result of regression and correlation analysis

$R^2 = 0.9995 \rightarrow R = 0.9997$ correlation coefficient approaches the maximum (strongest, R = 1) correlation (Figure 5).

Consequently, equation 1 is capable of making accurate and reliable predictions of static force and it can be used to size the muscle.

Firstly, a constant load of 50 kg is to be lifted from a supporting surface for a distance of 50 mm. Initial conditions:

- ☐ *required force at rest: 0 N,*
- ☐ *required stroke: 50 mm and*
- ☐ *required force in contracted state: 500 N.*

The required force in contracted state (500 N) determinates the muscle diameter: 20 mm or 40 mm [4]. For this study a Fluidic Muscle with inner diameter of 20 mm was selected.

On the basis of Figure 4, if the operating pressure is 4.5 bar, then 14.5 % contraction and 50 mm distance specify the nominal length: 50 mm/0.145 = 345 mm. If the operating pressure is 4 bar only, the same stroke is obtained with 12.5 % contraction and 400 mm muscle length. The life cycle of Fluidic Muscles depends on applied pressure, contraction and temperature. The lower contraction and pressure are more favourable.

If the distance is constant (50 mm) using DMSP-20-400N-RM-RM type Fluidic Muscle, but load of 30 kg and 70 kg must be lifted, operating pressure needs to be 300 kPa and 500 kPa, respectively. Secondly, if the operating pressure is constant (400 kPa), then load of 30 kg, 50 kg and 70 kg can be lifted with 17.5 %, 12.5 % and 7.5 % contraction using DMSP-20-400N-RM-RM type Fluidic Muscle.

Finally, the load is constant (50 kg) and the operating pressure to be 300 kPa, 400 kPa and 500 kPa. Then 6.5 %, 12.5 % and 16.5 % contraction are needed using DMSP-20-400N-RM-RM type Fluidic Muscle.

CONCLUSIONS

In this work - on the basis of a simple example - was proven that static force model of Fluidic Muscle can be used for precise approximation (R = 0.9997 correlation coefficient) and with the help of it the size of the Fluidic Muscle can be found. The behaviour of pneumatic artificial muscles in operation can be described by dynamic model, therefore we plan to develop a new model for it.

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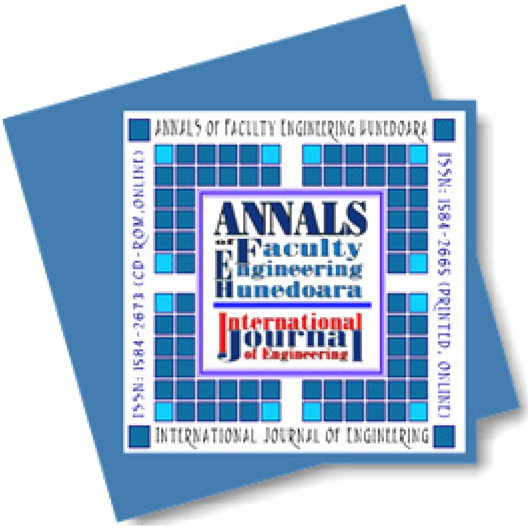

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