Model Based Open Looped Position Control of PAM Actuator

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***Abstract*—The Pneumatic Artificial Muscle (PAM) has great potential in industrial, robotic and prosthesis applications because of the extreme power to weight ratio, high strength and scalability for different purposes. However it is hard to control without precise modeling because of its high nonlinearity. In this paper we present our more accurate transfer function in comparison with other approaches. Finally we present the design and experimental testing of an open looped position controller for PAM actuator using the inverse of the transfer function.**

I. Introduction

Pneumatic Artificial Muscles (PAMs) are contractile devices operated by pressurized air or hydraulic material.

The McKibben artificial muscle is the most made and common type of these artificial muscles in use.

This 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]. The classification of PAMs and detailed description can be found in reference [7].

Designing an adequate control mechanism for this highly non-linear system needs precise modelling. In our previous study we developed a new, accurate and simple approximation model of PAM in reference [8]. Using this new equation we built an open looped position control of PAM actuator for experimental purposes.

II. Design Of The Transfer Function

In this study we used a McKibben type Festo pneumatic muscle shown in Figure 1.

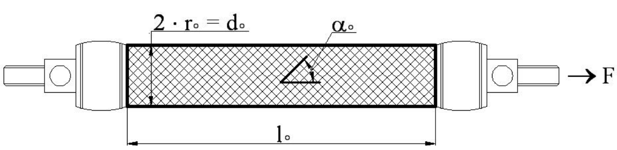

Figure 1. The main parameters of the Festo PAM Fluid muscle

Using these parameters Tondu and Lopez [9] made an approximated equation for static force as shown in equation (1).

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

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

Where: 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.

Kerscher et al. in [10] introduced a better approximation function using 4 new parameters as in equation (2).

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

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

While we first showed in [8] a purely statistical approach for approximating the static load characteristic of a PAM for a given pressure in equation (3) and for all pressures in the generalized equation (4).

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

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

In the same study we also suggested the use of equation (5) as the inverse of equation (4) for an open looped position control system, where the pressure is the function of the desired force and contraction.

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

For the experiments this last equation (5) was used because it is more accurate.

For comparisons of equation (1), (2), and (4) see reference [11].

III. DESIGN OF THE TEST SYSTEM

The experimental test set-up is shown in Figure 2. and the block diagram in Figure 3. The following parts were used: DMSP-20-400N-RM-RM type PAM actuator, 7923 type MOM load cell, LINIMIK MSA 320 incremental encoder, VPPM-6L-L-1-G1/8-0L6H-V1N-S1C1 type proportional pressure regulator, and Motorola MPX5999D pressure sensor.

One side of the muscle was fixed to the load cell, while the other side was attached to a slider that was connected to the load through a flexible wire across a pulley (Figure 3).

The load cell measures the pulling force of the load through the PAM that was distorted by the friction of the pulley. The linear displacement of the actuator was measured by the linear incremental encoder with 0,01 mm resolution.

All sensors were used for only calibration and evaluation purposes. After calibration the inverse function was coded into the control software written in LabVIEW environment (Figure 4). Only three input variables were used: the length of the PAM actuator in millimetre, the pressure of the compressor in Pascal, and the desired position in millimetre.

The inverse function calculates the required pressure for the desired contraction and the given force, which was fixed during the test. The fraction of the predicted pressure and the compressor (maximum) pressure multiplied by 10 gives the regulator signal for the proportional pressure regulator in voltage.

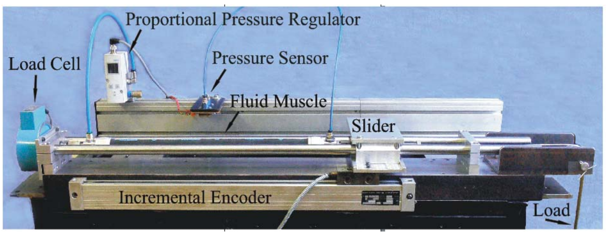

Figure 2. The photo of the experimental set-up

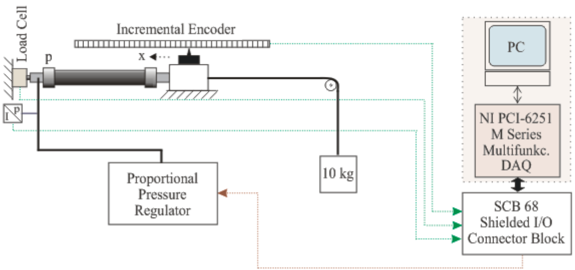

Figure 3. The block diagram of the experimental set-up

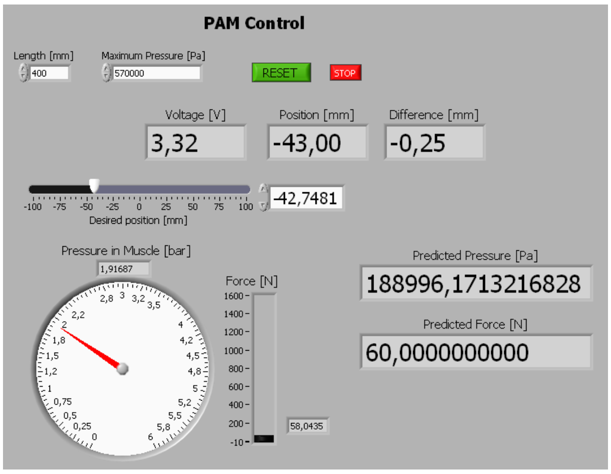

Figure 4. The LabVIEW program for the open looped control

IV. EXPERIMENTAL RESULTS

In this study we used the previously presented PAM module in a working range between 0% and 20% contraction which is recommended by the Festo catalogue [12] as shown in Figure 5.

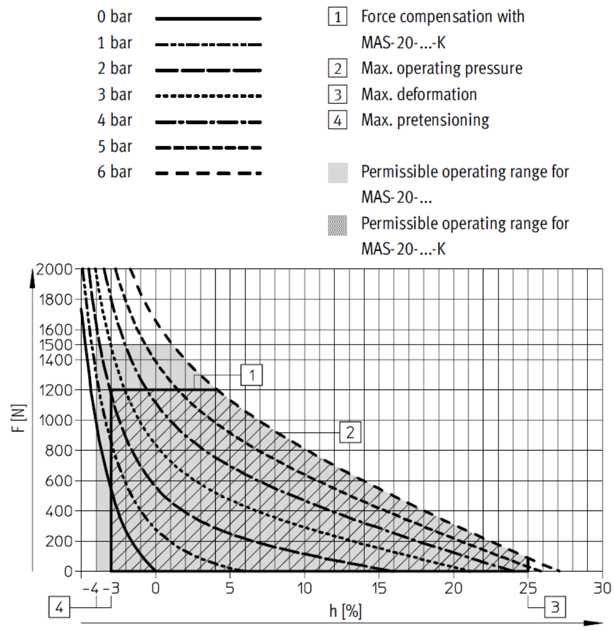

Figure 5. Static correlation between force pressure and contraction of the FESTO-DMSP fluidic muscle

Testing the open looped control set-up we used a 15kg load and the widest possible working range that was calculated as the following. The required holding force for a 15kg weight in theory is 147.15N assuming that the gravity of Earth is 9.81m/s^2 (or N/kg equivalently). However in practice we measured the force between 130N and 180N due to high friction of the pulley. In addition our compressor could produce maximum 5.7bar pressure. Because of these specific circumstances we also set our test range between 0% and 20% contraction as recommended by Festo.

The task of the controller was to set the contraction of the PAM module from 0% to 20% at every percent while lifting the attached load. Given the 400mm muscle length, these percentages meant 0, 4, 8... 80mm.

After repeating the experiments we calculated the average positional error, which is the difference between the desired and measured positions. The average and the standard deviation of the positional error are shown in Figure 6.

The total average of the unsigned average positional errors for the whole range was 0.22%, while narrowing it between 3% and 18% we achieved 0.1% average error. With our 400mm PAM it means 0.89mm average error for the total 80mm range, and 0.4mm for the narrowed 60mm range.

Note that, most of the inaccuracy was due to the pulley friction.

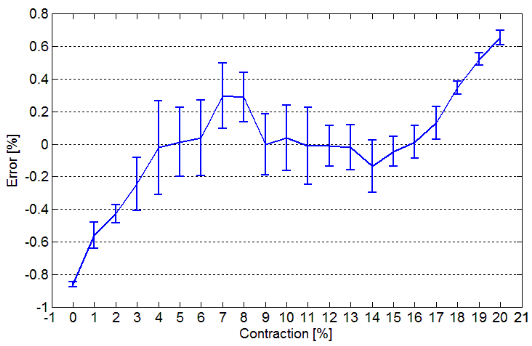

Figure 6. The error function of the open looped system in percentages

V. Conclusions and Future Works

In this study we successfully demonstrated an open looped controller application using our transfer function. This system gives moderate accuracy to control the position of a PAM without the need of any sensors, especially the expensive linear encoder, and even with uncompensated friction. However, the accuracy of the above mentioned system is suitable for solving many real tasks where for example, the required average precision is approximately 2.2mm for 200mm working range. In summary our proof of the concept is simpler, less expensive than closed looped system with built in linear sensor.

Our model is capable of supporting more complex systems, such as model predicted control, or it can further approximate the PAM dynamic properties.

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