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Experimental Investigation of Characteristics of Pneumatic Artificial Muscles

Abstract

The characteristics of pneumatic artificial muscles (PAMs) make them very interesting for the development of robotic and prosthesis applications. The McKibben muscle is the most popular and is made commercially available by different companies.
The aim of this research is to acquire as much information about the pneumatic artificial muscles as we can with our test-bed that was developed by us and to be able to adopt these muscles as a part of prosthesis.

This paper presents the set-up constructed, and then describes some mechanical testing results for the pneumatic artificial muscles.

1. Introduction

PAMs have different names in literature: pneumatic muscle actuator, fluid actuator, fluid-driven actuator, axially actuator, tension actuator, etc. (Daerden 1999, Daerden and Lefeber 2002, Plettenburg 2005, Ramasamy et al. 2005).

The pneumatic artificial muscle consists of rubber tubes and fibers. When the rubber tube is inflated with compressed air, the cross-weave sheath experiences lateral expansion, resulting in axial contractive force and the change of the end point position of pneumatic muscle.

The working principle of the pneumatic artificial muscles is well described in literature Daerden 1999, Tondu and Lopez 2000, Daerden and Lefeber 2002, Balara and Petík 2004, Ramasamy et al. 2005).

Pneumatic muscles have many advantages such as high strength, good power-weight ratio, low price, little maintenance needed, great compliance, compactness, inherent safety and usage in rough environments (Chou and Hannaford 1996, Tondu and Lopez 2000). The most significant problem of PAMs is nonlinearity (Caldwell et al. 1995, Medrano-Cerda et al. 1995).

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 27%.

Materials and methods

A good background of this research can be found in Toman et al. 2008 and Sárosi et al. 2009.

The experimental set-up *(Fig. 1)* consists of a slider mechanism. One side of the muscle is fixed to a load cell, while the other side is attached to the movable frame. The load cell (7923 type from MOM) is a 4 bridge element of strain gauges. It is mounted inline to the PAM on the fixed surface. The load cell measures the force exerted by the PAM. The tests are performed by changing the displacement of this slider. The linear displacement of the

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actuator is measured using a LINIMIK MSA 320 type linear incremental encoder. During each test, frame position, muscle force and applied gauge pressure are recorded.

In the test-bed two fluidic muscles can be mounted. Instead of second PAM a bias spring or an external load can be attached with flexible steel cables, producing the necessary counter force to pull the actuator back when it is not activated. In a spring, the stiffness is constant within a definite field.

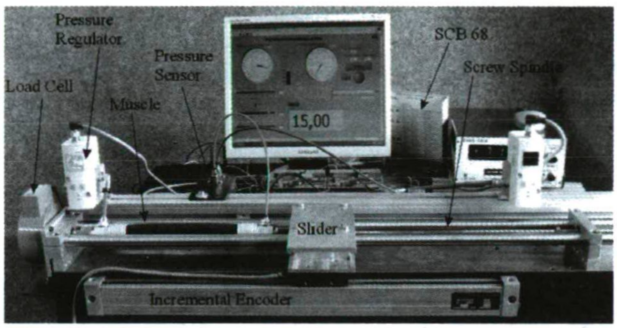

Fig. 1. **Experimental set-up for analysis of the pneumatic artificial muscle (fixed slider position)**
(*Source:* Edited by authors)

The air pressure applied to the actuators can be regulated with two adjustable regulator type Festo VPPM-6L-L-1-G1/8-0L6H-V1N-S1C1. The proportional pressure regulators (PPRs) are controlled by voltage inputs. The main purpose of the PPR is to regulate the pressure entering the PAM. To measure the air pressure, two Motorola MPX5999D pressure sensors were plumbed into the pneumatic circuit. A National Instruments Multi-I/O card (NI 6251) reads the signal of force, pressure sensors and incremental encoder into the PC.

National Instruments LabVIEW is a typical example for high level software, capable of connecting various kinds of DAQ boards with a PC. We used this program to monitor and collect the data imported through the DAQ card. It was also dispatch the control profiles for the PPRs. Fig. 2 shows the environment in LabVIEW.

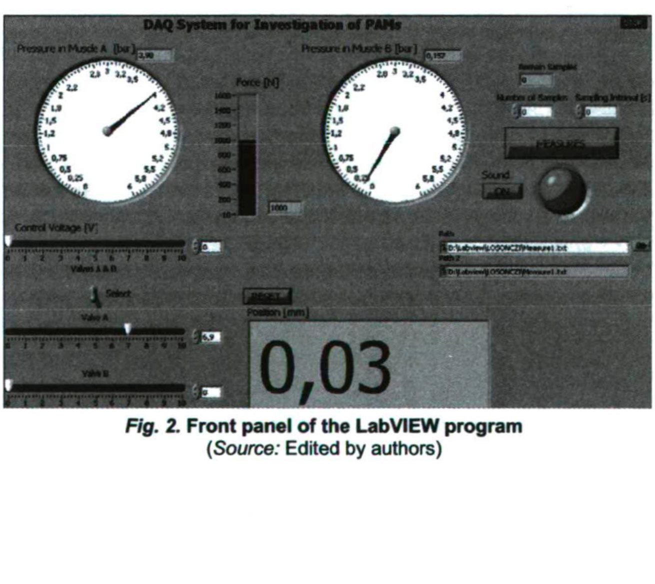

Fig. 2. **Front panel of the LabVIEW program**
(*Source:* Edited by authors)

With the specially constructed dynamic testing machine, we are able to measure the static and dynamic characteristics of several versions of these pneumatic actuators.

Experimental results

The first experiment was done under different constant pressures (0-5,5 bar). *Fig. 3.* shows the relation between tensile force [N] and position [mm] of this 20 mm inner diameter and 200 mm length artificial muscle. Tensile force of artificial muscle is under different constant pressures a function of muscle length and of air pressure. The force always drops from its highest value at full muscle length to zero at full inflation and position.

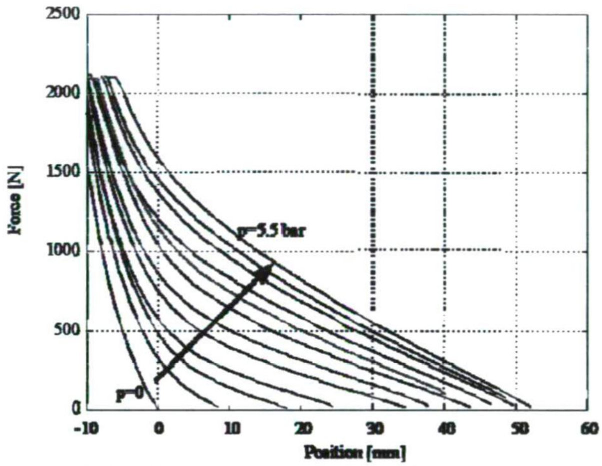

***Fig. 3.* PAM isobaric force-position characteristics**
(*Source:* Edited by authors)

Next, we examined the characteristics of PAMs in antagonistic set-up.

The antagonistic configuration of the actuators causes the active muscle to have to pull against the stiffness of the passive muscle. So, a pair of pneumatic artificial muscle actuators put into antagonism configuration can imitate a biceps-triceps system and emphasize the analogy between this artificial muscle and human skeletal muscle.

In the antagonistic set-up, in the test-bed two muscles were mounted. The characteristics of pneumatic artificial muscles under different constant pressures with antagonistic configuration of PAMs are shown in *Fig. 4,* where x_{max} means the maximum range of motion (±6–10 mm). In an antagonistic set-up without external load, position is determined by the ratio of pressures in both muscles.

Finally, we mounted the PAMs into shorter places than their initial lengths *(Fig. 5). Fig. 6.* shows how to extend the operating range of pneumatic artificial muscles in antagonistic set-up.

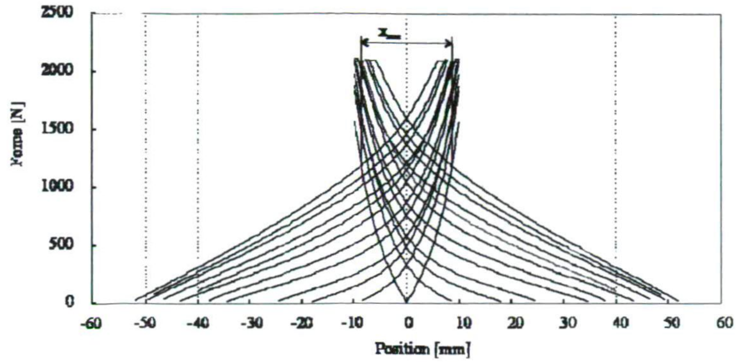

Fig. 4. **PAMs isobaric force-position characteristics in antagonistic configuration**
(*Source:* Edited by authors)

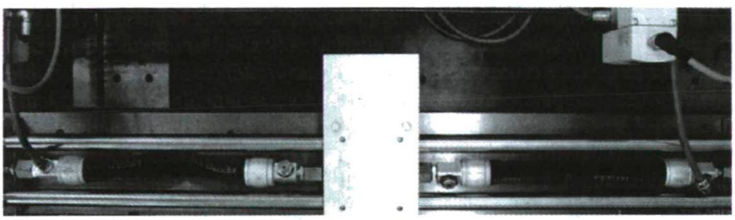

Fig. 5. **Mounting PAMs into shorter places than their initial lengths**
(*Source:* Edited by authors)

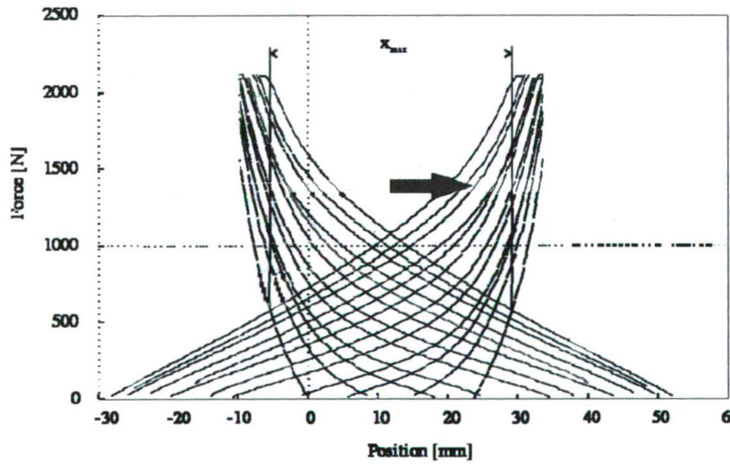

Fig. 6. **Extended operation range of PAMs**
(*Source:* Edited by authors)

Conclusions and future work

This paper presented the mechanical structure of our test-bed that is capable of carrying out several static and dynamic investigations of PAMs. The results are a study on PAMs that have the potential for use in robotic and prosthesis applications. The future work for this project is to show that the fluidic muscle can be used as a good approximation of the biological muscle. These muscles seem a better choice than present day electric or other drives.

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