CHARACTERISTICS OF THE PNEUMATIC ARTIFICIAL MUSCLES

J. Sárosi[1], J. Gyeviki[1], T. Endrődy[1], G. Szabó[1] and P. Szendrő[2]

[1]*Department of Technical and Process Engineering, University of Szeged*
Mars tér 7., Szeged, H-6724, Hungary
Tel.:+36 62 546-000, E-mail: sarosi@mk.u-szeged.hu

[2]*Institute of Mechanics and Machinery, Szent István University*
Páter K. u. 1., Gödöllő, H-2103, Hungary
Tel.:+36 28 522-000, E-mail: Szendro.Peter@gek.szie.hu

Abstract: We can see several types of pneumatic actuators in industrial environment. The newest and most promising type of them is the pneumatic artificial muscle (PAM). Braided pneumatic actuator was invented by Dr. Joseph L. McKibben to help the movement of polio patients in 1950s. Different designs have been developed. The McKibben muscle is the most popular and is made commercially available by different companies. In this paper we present some important characteristics of PAMs in constant pressure.

Keywords: pneumatic artificial muscle, test-bed, isobaric force-position diagrams, LabVIEW environment

INTRODUCTION

Pneumatic artificial muscle is a membrane that will expand radially and contract axially when inflated, while generating high pulling forces along the longitudinal axis.

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 working principle of the pneumatic artificial muscles is well described in literature (Caldwell, Razak and Goodwin, 1993, Daerden, 1999, Tondu and Lopez, 2000, Daerden and Lefeber, 2002, Balara and Petík, 2004).

There are a lot of advantages of artificial muscles like the 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 main disadvantage of these muscles is that their dynamic behavior is highly nonlinear (Caldwell, Medrano-Cerda and Goodwin, 1995, Medrano-Cerda, Bowler and Caldwell, 1995, Situm and Herceg, 2008).

This work is one of the first fundamental steps of a wider project, aimed at studying the humanoid robot.

MATERIALS AND METHODS

A good background of this research can be found in Tomán et al., 2008.

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 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 muscle can mounted. Instead of second PAM a bias spring or an external load can attached with a 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.

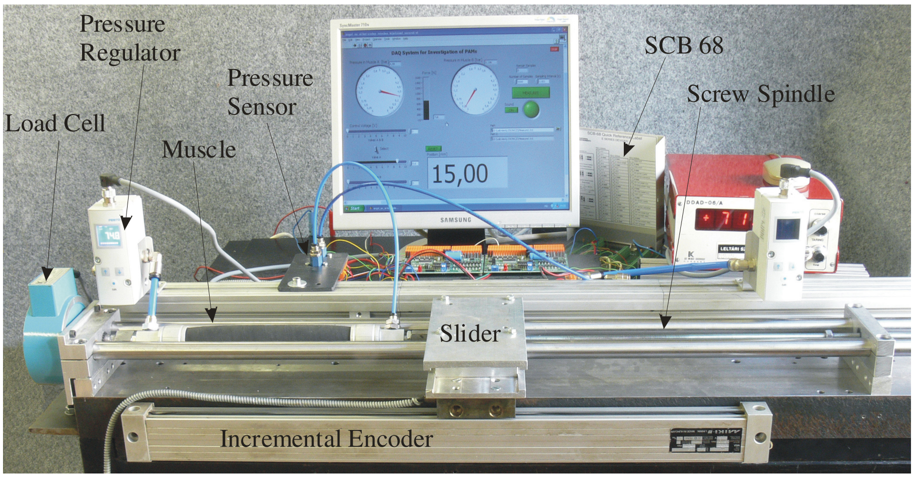
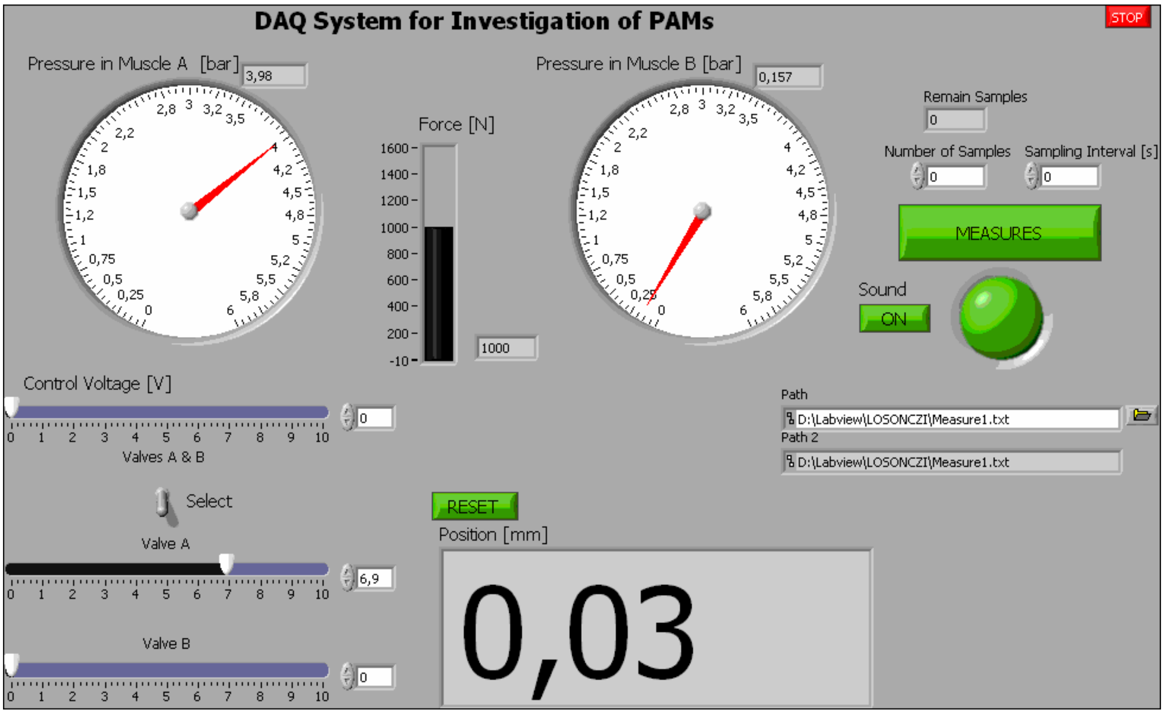


Fig. 1. Experimental set-up for analysis of the pneumatic artificial muscle (fixed slider position)

The air pressure applied to the actuators can 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.



DAQ System for Investigation of PAMs

Pressure in Muscle A [bar] 3,98
Pressure in Muscle B [bar] 0,157
Force [N] 1000
Remain Samples 0
Number of Samples 0
Sampling Interval [s] 0
Sound ON
Control Voltage [V] 0
Valves A & B
Valve A 6,9
Valve B 0
Path D:\Labview\LOSONCZI\Measure1.txt
Path 2 D:\Labview\LOSONCZI\Measure1.txt
Position [mm] 0,03

Fig. 2. Front panel of the LabVIEW program

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 on the pressure of 5,5 bar with DMSP-20-200N-RM-RM type fluidic muscle (from Festo) (Fig. 1.). Fig. 3. shows the relation between tensile force [N] and position [mm] of this 20 mm diameter and 200 mm length artificial muscle.

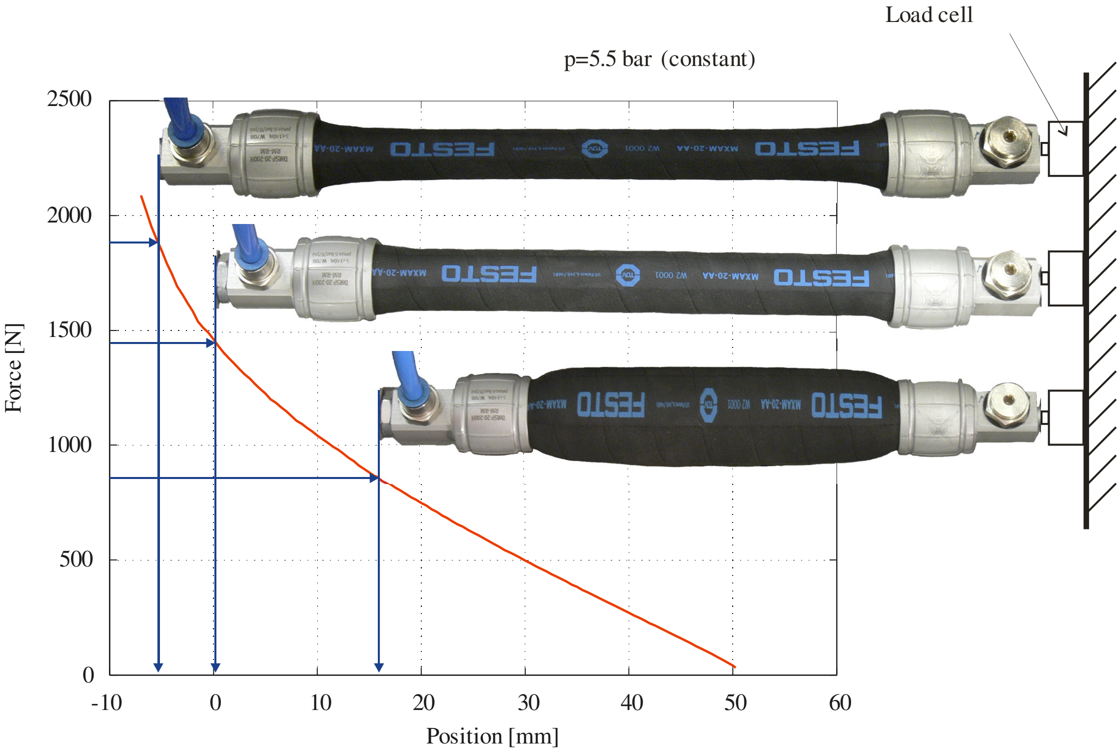


Fig. 3. PAM isobaric force-position characteristic

Length of artificial muscle in constant pressure depends on force. This force decreases with increasing position of the muscle and the muscle inflates. There is a point (maximum position (50 mm)) where the volume reaches its maximum value, the length its minimal value (150 mm) and the force drops to zero. The characteristic is nonlinear.

Secondly, we repeated the previous experiment in different constant pressures (0-5,5 bar): length of artificial muscle in different constant pressures depends on force, too. Tensile force of artificial muscle is in 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. The characteristics (Fig. 4.) are similar to Fig. 3., nonlinear.

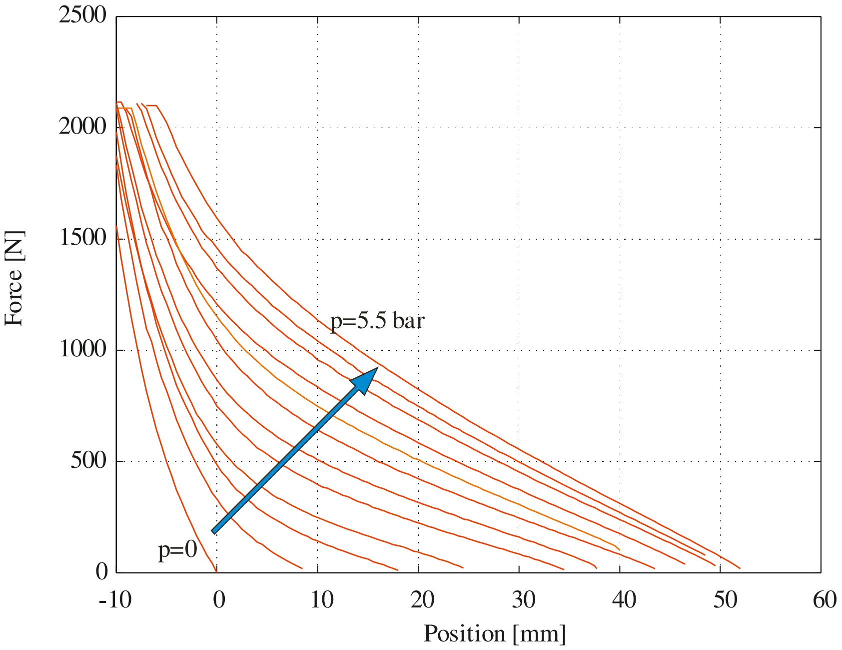


Fig. 4. PAM isobaric force-position characteristics

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

Pneumatic artificial muscles show similarity to biological muscles. The pneumatic artificial muscles are one-way acting, we need two ones to generate bidirectional motion: one of them moves the load, the other one will act as a brake to stop the load at its desired 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 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 DMSP-20-200N-RM-RM type fluidic muscles were mounted (Fig. 5.).

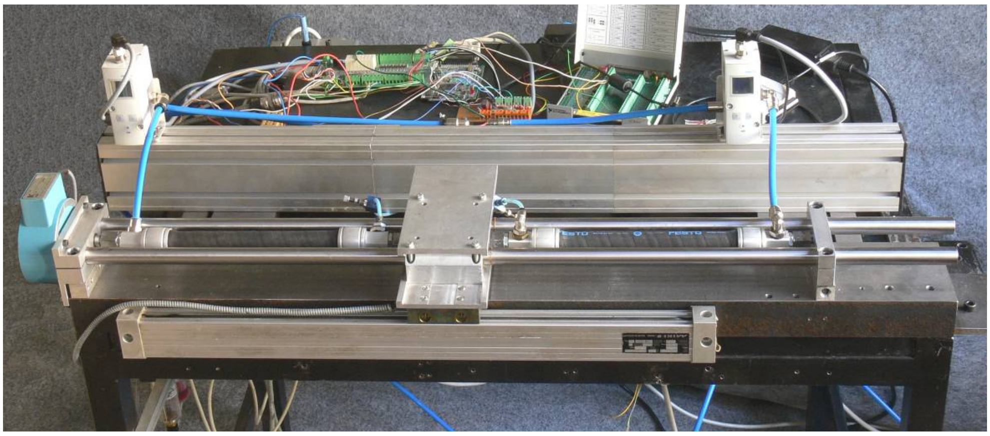


Fig. 5. Experimental set-up for analysis of the pneumatic artificial muscles (antagonistic configuration)

The characteristics of pneumatic artificial muscles in different constant pressure with antagonistic configuration of PAMs are shown in Fig. 6., 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.

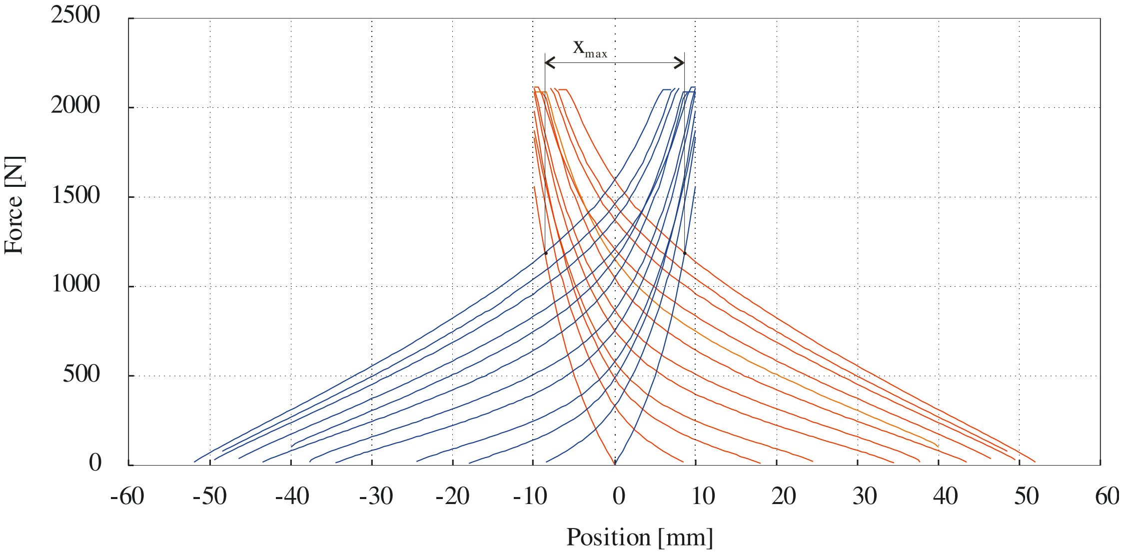


Fig. 6. PAMs isobaric force-position characteristics in antagonistic configuration

Finally, we determined the characteristics of pneumatic artificial muscle in antagonistic set-up with return spring. In this antagonistic set-up, in the test-bed a DMSP-20-200N-RM-RM type fluidic muscle and a spring were mounted (Fig. 7.). The role of return spring is acting against the force of PAM.

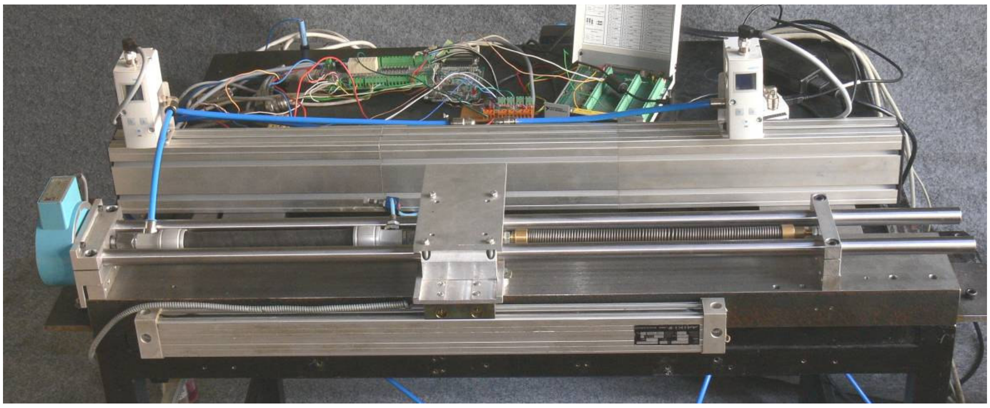


Fig. 7. Experimental set-up for analysis of one muscle and one spring

Fig. 8. shows the characteristics of pneumatic artificial muscle together with the characteristic of return spring: nonlinear characteristics of PAM and linear characteristic of spring. The balance between forces of pneumatic muscle and spring is reached in points of intersection.

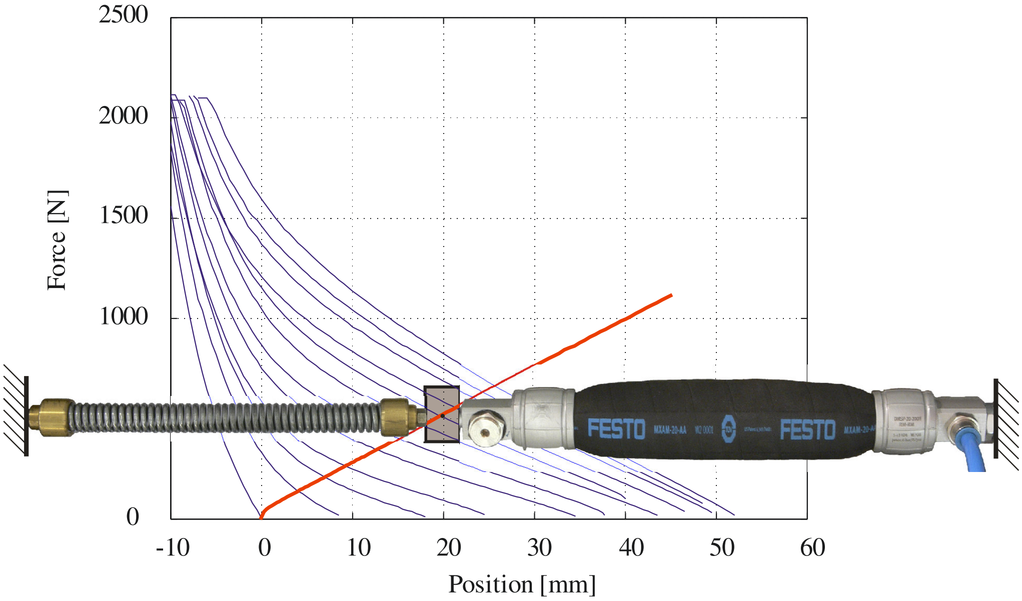


Fig. 8. PAM isobaric force-position characteristics in antagonistic configuration with return spring

CONCLUSIONS

The pneumatic artificial muscle is a pneumatic device characterized by its high level of functional analogy with human skeletal muscle.

With the help of this test-bed we can carry out several static and dynamic investigations. Based on the laboratory measurements, experiences and know-how resulting from these tests will pass a lot of information about the behavior and influence of pneumatic artificial muscle in prostheses. Muscles seem a better choice than present day electric or other drives.

The future work for this project is to show that the fluidic muscle can be used as a good approximation of the biological muscle.

REFERENCES

Balara, M. and Petík, A. (2004), The properties of the actuators with pneumatic artificial muscles, Journal of Cybernetics and Informatics, Volume 4, pp. 1-15.

Caldwell, D. G., Razak, A. and Goodwin, M. J. (1993), Braided pneumatic muscle actuators, Proceedings of the IFAC Conference on Intelligent Autonomous Vehicles, Southampton, United Kingdom, 18-21 April, 1993, pp. 507-512.

Caldwell, D. G., Medrano-Cerda, G. A. and Goodwin M. (1995), Control of pneumatic muscle actuators, IEEE Control System Magazine, Volume 15 (1), pp. 40-48.

Chou, C. P. and Hannaford, B. (1996), Measurement and modeling of McKibben pneumatic artificial muscles, IEEE Transactions on Robotics and Automation, Volume 12 (1), pp. 90-102.

Daerden, F. (1999), Conception and realization of pleated artificial muscles and their use as compliant actuation elements, PhD Dissertation, Vrije Universiteit Brussel, Faculteit Toegepaste Wetenschappen Vakgroep Werktuigkunde, pp. 5-33.

Daerden, F. and Lefeber, D. (2002), Pneumatic artificial muscles: actuator for robotics and automation, European Journal of Mechanical and Environmental Engineering, Volume 47, pp. 10-21.

Medrano-Cerda, G. A., Bowler, C. J., Caldwell, D. G. (1995), Adaptive position control of antagonistic pneumatic muscle actuators, International Conference on Intelligent Robots and Systems, Pittsburgh, PA, USA, 5-9 August, 1995, pp. 378-383.

Plettenburg, D. H. (2005), Pneumatic actuators: comparison of energy-to-mass ratio's, Proceedings of the 2005 IEEE, 9th International Conference on Rehabilitation Robotics, Chicago, Illinois, USA, 28 June-1 July, 2005, pp. 545-549.

Ramasamy, R., Juhari, M. R., Mamat, M. R., Yaacob, S., Mohd Nasir, N. F. and Sugisaka, M. (2005), An application of finite element modeling to pneumatic artificial muscle, American Journal of Applied Sciences, Volume 2 (11), pp. 1504-1508.

Situm, Z. and Herceg, Z. (2008), Design and control of a manipulator arm driven by pneumatic muscle actuators, 16th Mediterranean Conference on Control and Automation, Ajaccio, France, 25-27 June, 2008, pp. 926-931.

Tomán, P., Gyeviki, J., Endrődy, T., Sárosi, J. and Véha, A. (2008), Design and fabrication of a test-bed aimed for experiment with pneumatic artificial muscle, International Conference on Science and Technique in the Agri-food Business, Szeged, Hungary, 5-6 November, 2008, pp. 361-367.

Tondu, B. and Lopez, P. (2000), Modeling and control of McKibben artificial muscle robot actuator, IEEE Control System Magazine, Volume 20, pp. 15-38.