ANNALS of Faculty Engineering Hunedoara
– International Journal of Engineering

Tome XII [2014] – Fascicule 4 [November]
ISSN: 1584-2673 [CD-Rom, online]
a free-access multidisciplinary publication
of the Faculty of Engineering Hunedoara

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STUDY ON VISCOELASTIC BEHAVIOUR OF PNEUMATIC MUSCLE ACTUATOR

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Abstract: Pneumatic artificial muscle (PAM) is the less well-known type of pneumatic actuators. It consists of a thin, flexible, tubular membrane with fibre reinforcement and it is operated by pressurized gas, usually air. When the membrane is pressurized, the gas pushes against its inner surface and against the external fibre. Then the PAM expands radially and contracts axially with the result that the volume increases. The force and motion produced by PAM are linear and unidirectional. Similarly to human muscles PAMs are often coupled antagonistically. PAM was originally developed by Garasiev in the 1930's, but the most mentioned muscle was designed by Joseph L. McKibben for use in artificial limbs in the 1950's. There is growing interest in the use of pneumatic artificial muscles for robotic and rehabilitation applications due to their high power to weight ratio, soft and flexible nature and adaptable compliance. To know the optimal usage viscoelastic properties of PAM need to be investigated. In this paper some experiments related to viscoelastic behaviour of PAM are described. For this study a Fluidic Muscle made by Festo Company is selected. Fluidic Muscle is one of the most used and investigated type of PAMs.
Keywords: Pneumatic artificial muscle, Fluidic Muscle, viscoelasticity, hysteresis, creep effect

1. INTRODUCTION

Mechatronic systems are commonly used in industrial environment, robotics, research and education (Csikós 2010, Alexa et al. 2011, Parr 2011, Alexa et al. 2013, Gogolak et al. 2013, Lamár-Neszveda 2013, Tothova-Pitel 2013). Pneumatic artificial muscles have an also wide range of applications, e. g. hand therapy device, lifting device and walking robot (Fig. 1) (Koeneman et al. 2004, Festo 2005, Vanderborght 2007).

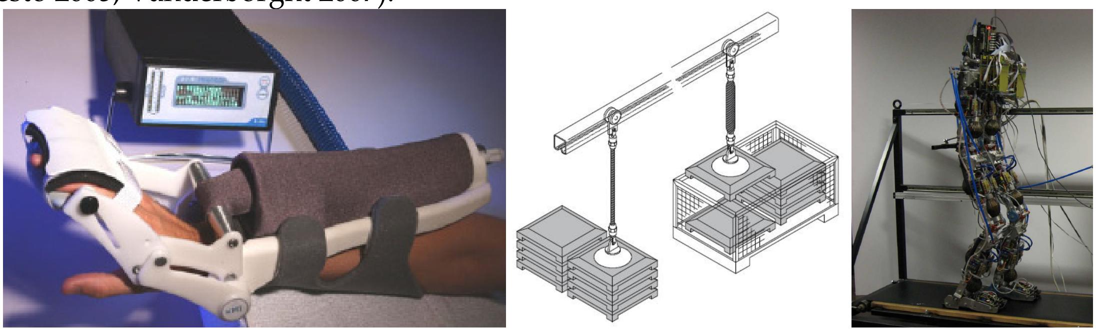

Figure 1. Applications of pneumatic artificial muscles
(Koeneman et al. 2004, Festo 2005, Vanderborght 2007)

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. The most mentioned drawbacks of PAMs are hysteresis, creep, threshold pressure (pressure difference to start deformation), nonlinear and time varying nature and antagonistic configuration to achieve bidirectional motion. The nonlinear behaviour is due to compressibility of air and the viscoelastic material (Lilly 2003, Wickramatunge-Leephakpreeda 2009). Chou and Hannaford (1996) report hysteresis to be substantially due to the friction, which is caused by the contact between the bladder and the shell, between the braided threads and each other, and the shape changing of the bladder. Fluidic

Muscle type DMSP-10-100N-RM-RM produced by Festo Company is selected for this study to illustrate the viscoelastic properties of PAMs.

The layout of this paper is as follows. Section II (Materials and Methods) is devoted to describe the experimental setup and software environment for measuring the force developed by PAM, the pressure inside the muscle and the position of the actuator. Section III (Results and Discussion) describes three experiments related to viscoelasticity. Finally, Section IV (Conclusion and Future Work) gives the consequence and the planned investigations in the future.

2. MATERIALS AND METHODS

The most significant characteristic of PAMs is the force as a function of pressure and contraction (relative displacement). To measure force, pressure and displacement experimental setup and LabVIEW program shown in Fig. 2 were used. It is shown that the Fluidic Muscle was built horizontally into the test bed. One side of the muscle was fixed to a load cell, while the other side is attached to slider moved by a screw spindle. The linear displacement of the actuator at different pressure values was measured using a LINIMIK MSA 320 type linear incremental encoder with 0.01 mm resolution.

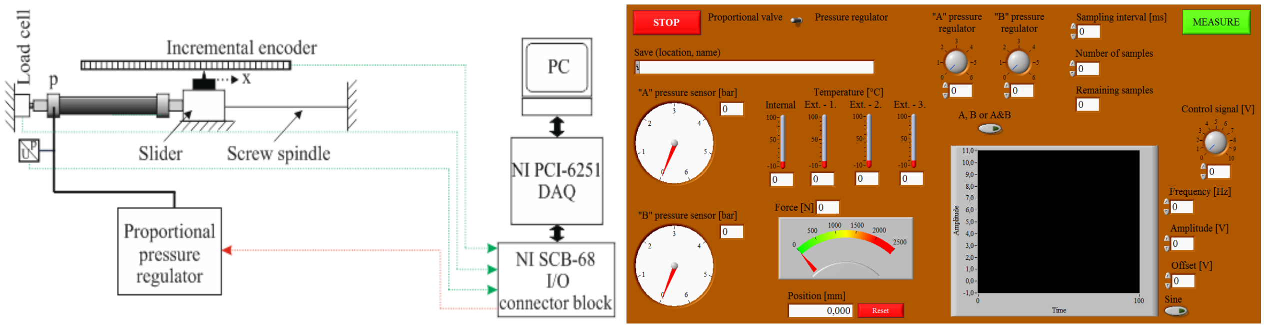

Figure 2. Test bed and front panel of LabVIEW program for measuring force, pressure and displacement

The next investigations were carried out:

- hysteresis loop in the force-contraction relationship,
- how the force changes with time at constant displacement and pressure,
- hysteresis loop in the pressure-contraction relationship.

3. RESULTS AND DISCUSSION

Firstly, the force-contraction functions were measured. The applied pressure was kept at a constant value, while the length of PAM was changed by the screw spindle. This method can be used to substitute the variable mass. As shown in Fig. 3a, the pulling force decreases with increasing contraction. At maximal contraction the volume reaches its maximum value and the force drops to zero. It means that contraction has an upper limit at which there is no force developed by PAM. The characteristic is nonlinear. The hysteresis loop was obtained when the procedure in the opposite direction was repeated. Fig. 3b illustrates the hysteresis loop at a pressure of 600 kPa, while Fig. 4 demonstrates the loops at different pressure values (0-600 kPa).

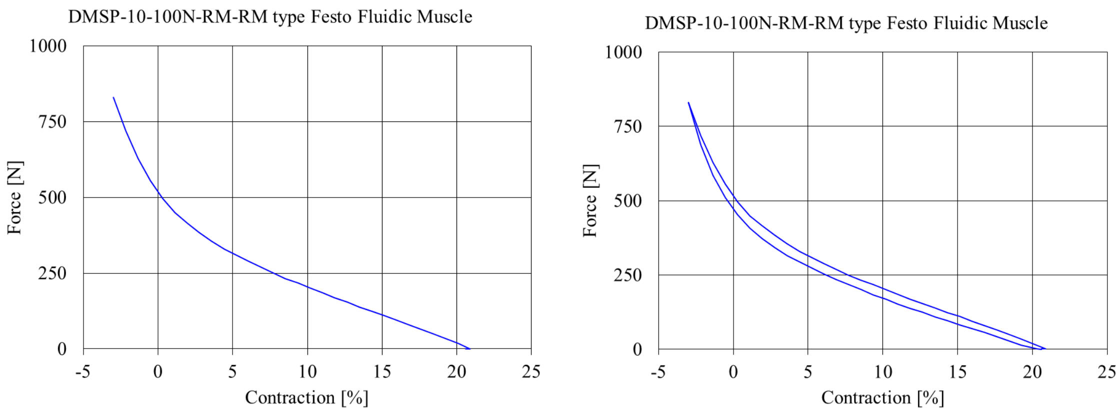

Figure 3. Isobaric force-contraction diagram (a) and hysteresis loop (b) in the force-contraction relationship at a pressure of 600 kPa

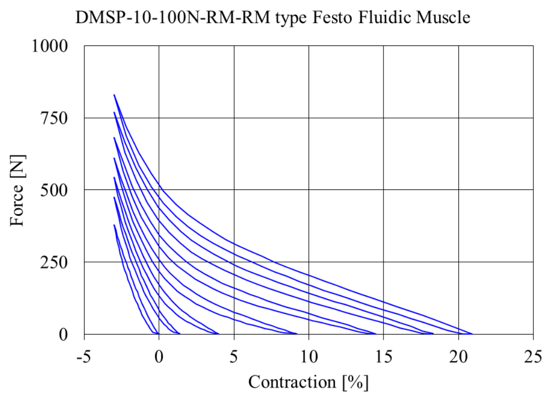

Figure 4. Hysteresis loop in the force-contraction relationship at different pressure values (0-600 kPa)

Next, the creep effect was analysed. In this case the creep means that the force changes with the time. During the investigation the pressure was constant and the muscle was fixed (i.e. the load was constant). Fig. 5 illustrates that the creep test lasted for 300 s at a pressure of 600 kPa and different contraction values (5%, 10% and 15%). It is important to note that at every contraction significant creep was obtained. Enlarging the experimental result at a contraction of 10%, more than 20 N creep was experienced.

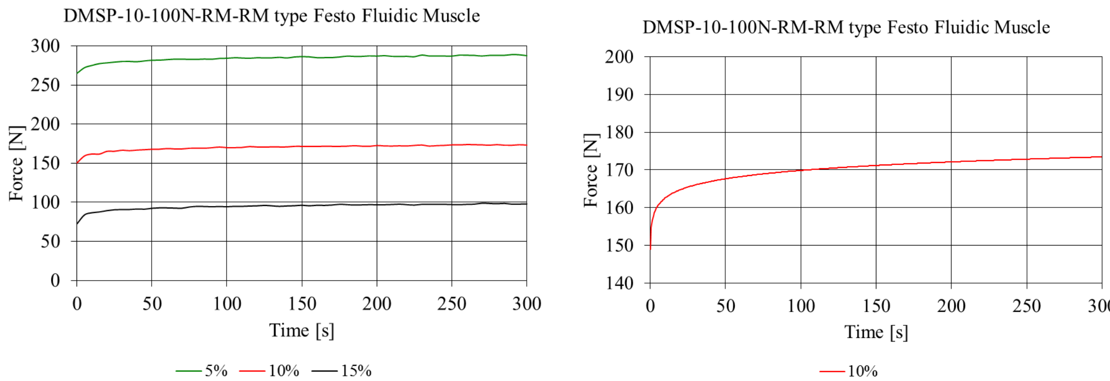

Figure 5. Experienced creep effect at different contraction values (5%, 10% and 15%)

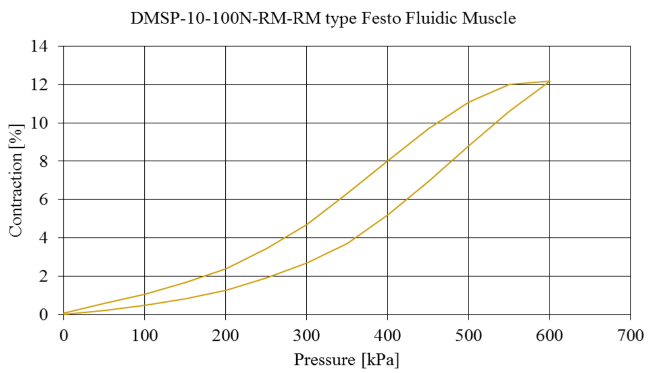

Figure 6. Hysteresis loop in the pressure-contraction relationship

Finally, instead of the screw spindle a load with a mass of 10 kg was attached to the slider. After the muscle has been stretched by the external load the position of slider was set to 0. The position (contraction) was measured while the pressure was changed from 0 to 600 kPa, then from 600 kPa to 0. Similarly to the first experiment, hysteresis loop was acquired. Outcome of this analysis is presented in Fig. 6.

4. CONCLUSION AND FUTURE WORK

In this study viscoelastic properties of pneumatic artificial muscle were investigated. Three experiments related to hysteresis and creep effect show that viscoelasticity cannot be ignored for developing precise applications actuated by PAMs. A static force model has been developed to approximate the force produced by Fluidic Muscle. In the future a dynamic model based on static force model is going to be introduced that is capable of eliminating this drawback of PAMs.

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