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MODEL AND EXPERIMENTAL RESEARCH OF PNEUMATIC ARTIFICIAL MUSCLES

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Abstract: *Pneumatic artificial muscles (PAM) have similar properties as biological muscles. This fact was one of the main reasons of applying them as executive elements in robotics. This paper presents the results of model and experimental research and describes the test stand as well as the method of determining dynamic characteristics of pneumatic muscles. The authors described the methods of experimental research for the construction of the pneumatic muscle developed by them together with its mathematical model taking account of the nonlinear force dependable on the pressure and deformation.*

Keywords: pneumatic muscle, DELTA parallel manipulator, muscular driving system, energy saving muscle

1. Introduction

At present there are many types of actuators which might be applied as pneumatical artificial muscles. Due to their peculiar properties muscle actuators in comparison with traditional pneumatical actuators are applied as driving elements in mobile robots (for moving artificial limbs) (Takosoglu, et al., 2014), anthropomorphic, bionic and humanoid robots (in jumping and walking robots), physiotherapist manipulators (to ensure repetitive motion) as well as in the automation of production processes and metrology. Pneumatic artificial muscles PAM, due to the way they operate, might be regarded as single-acting pneumatic actuators. The first studies on PAM were conducted by Garasiew, a Russian researcher, in 1930. Due to the absence of proper technologies and materials, mass production of pneumatic muscles was restricted. In 1950 Joseph L. McKibben was the first person who designed an artificial muscle which could be applied in medicine. Pneumatic muscle actuators are constructed in a different way and thus, their characteristics vary. Two construction types of pneumatic muscles are the most common. Usually, a rubber membrane is entwined with an elastic mesh with specific geometrical dimensions and elastic properties or the mesh might be vulcanized with rubber. The mesh is attached at the ends of the muscle actuator and creates a kind of artificial tendons. The force generated by the pneumatic muscle depends on the air pressure (Blasiak, et al., 2014; Blasiak, et al.), its initial length, the degree of shortening as well as its material properties (Bochnia, 2017; Bochnia and Blasiak, 2016). When increasing the air pressure, the circumference increases and simultaneously, the muscle length decreases. As a result, the muscle is contracted and new axial pulling force is generated. In the initial phase of muscle shortening, the greatest force is created which decreases to zero with its maximum shortening (only in the case of constant pressure). By regulating the pressure, it is possible to control the transmitted force and the degree of pneumatic shortening of the muscle actuator.

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2. Methods

A pneumatic artificial muscle reflects the operation of a natural skeletal muscle. A physical model of PMA was presented in Fig. 1 (More and Liska, 2013 - 2013; Ranjan, et al., 2012).

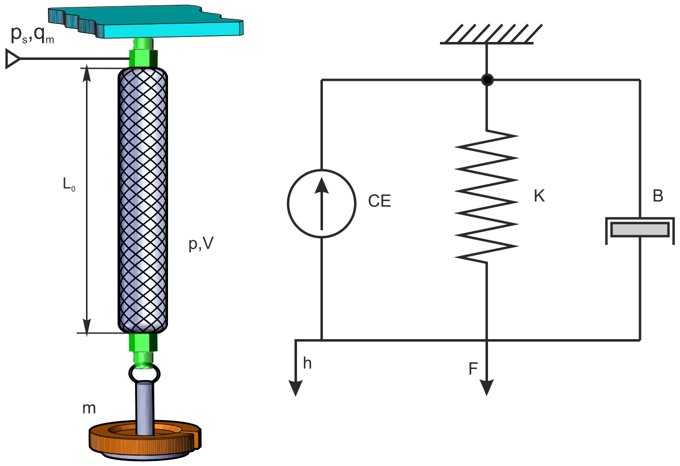

Fig. 1: Biomimetic model of PMA.

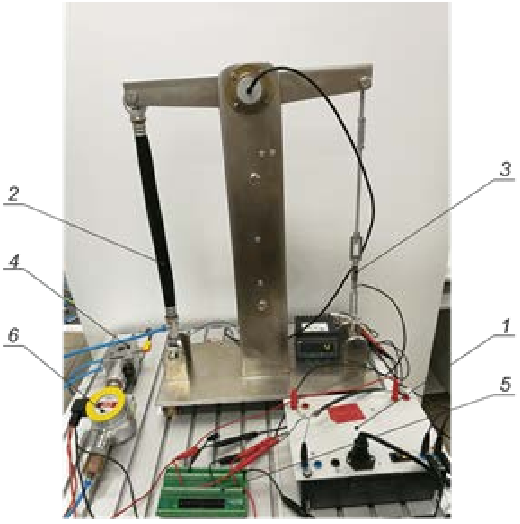

Fig. 2: A general view of the test stand: 1 – power supply, 2 – pneumatic muscle, 3 – force transducer, 4 – proportional pressure valve, 5 – electronic panel, 6 – pressure transmitter.

While determining the characteristics, a biomimetic model of the pneumatic muscle actuator was applied.

2.1. Mathematical model

For the case of attaching the pneumatic muscle in a similar way as in the test stand (see Fig. 1), its equation of motion might be recorded in the following form (Dindorf, et al., 2017; Kang, et al., 2009 - 2009):

$$m\ddot{h} = -B\dot{h} - K\,h + F_{CE} \tag{1}$$

where: h – the muscle contraction described with the dependency (2),

$$h = \frac{L_0 - L}{L_0} \tag{2}$$

L_0 – initial muscle length, L – final muscle length, m – mass load, B – damping element coefficient K – elastic element coefficient, F_{CE} –, contraction force of the muscle actuator. The equation was solved numerically or analytically, as in: (Blasiak and Blasiak, 2017). The theoretical contraction force generated in the PAM depends on the geometrical and material parameters of the inner pipe and the outer braid, as well as on the air pressure p. This theoretical force might be described as well in accordance with the dependency:

$$F_{CE} = A_0\, p\left(a_0\left(1-h\right)^2 - b_0\right) \tag{3}$$

where $a_0, b_0 -$ constant coefficients describing the geometrical dependencies of the muscle braid for the initial state:

$$a_0 = \frac{3}{\tan^2\left(\theta_0\right)},\ b_0 = \frac{1}{\sin^2\left(\theta_0\right)} \text{ and } A_0 = \frac{\pi D_0^2}{4} \tag{4}$$

$D_0 -$ is the initial diameter of the muscle actuator.

The difference between theoretical force and experimental force for similar pressure is correlated with the k_p coefficient.

$$F_{CE} = A_0\, p\left(a_0\left(1-h\,k_p\right)^2 - b_0\,k_s^2\right) \tag{5}$$

$$k_s = \frac{S(p)}{S_0},\ D_0 = \frac{S_0 \sin(\theta_0)}{n\,\pi} \tag{6}$$

Where n – numbers of turns of thread.

The extended PMA model should take into account the real material properties of rubber bladder and a braided shell including bladder thickness, bladder thickness variation, non-linear elastic energy storage of the bladder, friction-induced hysteresis and relaxation of used materials.

2.2. Test stand

In order to determine the experimental characteristics of the pneumatic muscles, a test stand was designed, Fig. 2 presents a general view of the test stand.

The values of the contraction force of the pneumatic muscle depend on the pressure changes in the supply system. The authors used for this purpose a proportional flow valve MNR: R414002009, i.e. a 5/3 valve (a five way three-position valve). The characteristics describing the changes of the measurement data: pressure and force as a function of time were presented in Fig. 3.

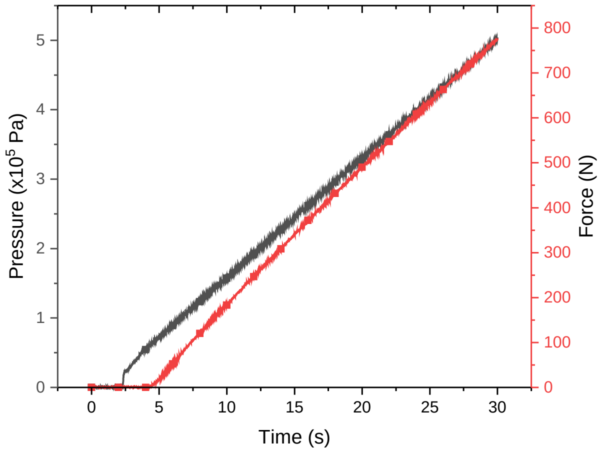

Fig. 3: Pressure and force depending on the time.

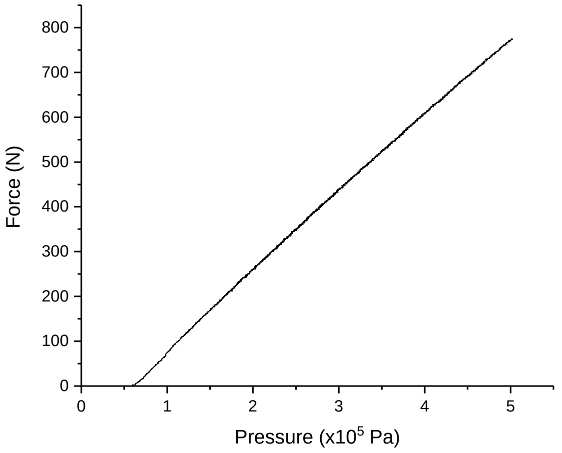

Fig. 4: Force depending on the pressure.

Figure 4 shows the variation of the pulling force of the PMA depending on the supply pressure value. The increase of the pulling force occurs after exceeding the pressure value of $0.6\cdot10^5\,(Pa)$.

3. Conclusions

This paper presents the biomimetic model of the pneumatic muscle. The authors presented as well the test stand used in order to determine the characteristics of changes occurring with muscle contractions depending on the given supply pressure as well as the results of the experimental research. The supply pressure value of the muscle was controlled with the use of a proportional flow valve. The results obtained on the basis of the mathematical model as well as the test stand research were compared. The examination made it possible to determine the range of contraction force of the pneumatic muscle. It is particularly important when muscle driving systems are designed to be used i.a. in DELTA parallel manipulators. Such solutions were applied in some processes of production automation for presenting, palletizing or segregating. A special case of applying muscle systems is their use in manipulators in the rehabilitation of patients who suffer from dysfunctions of motor organs.

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The pneumatic muscle is protected with the patent application no. A1 415198

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