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STUDY OF THE SELECTED CHARACTERISTIC OF ARTIFICIAL PNEUMATIC MUSCLES

BADANIA WYBRANYCH CHARAKTERYSTYK MUSKUŁÓW PNEUMATYCZNYCH

A b s t r a c t

McKibben pneumatic artificial muscles (PAMs) allow for a proper representation of static and dynamic movement characteristics of biomechanical systems. These actuators have features similar to physiological muscles such as ability to generate high value of force in short time and elastic and damping properties. McKibben muscles have a nonlinear character – the value of a generated force depends not only on the pressure but also on the stroke. In the presented paper, the authors exemplify basic traits of these actuators and present drawn characteristics of a force to stroke at a constant pressure.

Keywords: McKibben artificial pneumatic muscle, biomechanical systems

S t r e s z c z e n i e

Sztuczne muskuły pneumatyczne McKibben umożliwiają dobre odwzorowanie ruchu układów motorycznych istot żywych w układach mechanicznych. Siłowniki te posiadają cechy upodobniające je do mięśni fizjologicznych, m.in. możliwość generowania dużych wartości sił w krótkim czasie oraz korzystne własności sprężyste i tłumiące. Siłowniki te cechują się nieliniowymi charakterystykami pracy, a wartość generowanej przez nie siły zależy nie tylko od ciśnienia, ale również od stopnia ich skrócenia. W prezentowanym artykule przedstawiono budowę oraz podstawowe cechy tych siłowników, a także charakterystyki generowanej siły w funkcji skrócenia mięśnia przy stałym ciśnieniu wyznaczone na skonstruowanym na te potrzeby stanowisku laboratoryjnym.

Słowa kluczowe: sztuczny muskuł pneumatyczny McKibben, układy biomechaniczne

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1. Introduction

Human muscles have the ability to shorten to about 40–50% of the beginning length. The value of the force created by a muscle ranges between 50–110 N/cm^2. The development of biomedical engineering and rehabilitation disciplines have created the need for artificial muscles. They were applied as driving means of mobile anthropomorphic and humanoid robots as well as a drive for artificial limbs. The pneumatic muscle may be classified as an elastic pneumatic pulling unilateral actuator. The dynamic characteristics allow for a very good mapping of a motion for the motoric system of living beings. It was very well presented for the Mowgli robot [1]. Pneumatic muscles were successfully applied in constructions supporting human motoric moving [2]. For the first time, they allowed for obtaining the metabolic cost of the machine closely to a physiological one. The average energy consumption measured for the suit amounted to about 386.7 W, being almost identical to the result of 381.8 W, measured for the control sample without the suit.

The pneumatic muscle is produced in several types, including McKibben or PLAM. In the recent years, the construction of McKibben muscles was enhanced and commercialized e.g. by FESTO, a company which produces Fluidic Muscles [3]. In the production series of FESTO, there are muscles with the pulling force of 630 N, 1500 N and 6000 N [3], and the frequency of up to 150 Hz [4].

2. The construction and operation of the muscle

A radially deformable tube is the most important element of muscle construction. The tube is made of rubber, latex or silicone and it is disposed in a braid made of non-stretchable fibers. A flexible tube is usually made of latex because of the higher fatigue resistance comparing to silicone [5]. Other materials may also be used, however, this element should be made of elastic materials with low Shore's hardness. Polyester braids are most commonly used as an outer sheath. Metallic braids are also used but the higher mass of a muscle and quicker rubbing of the internal elastic cord is the disadvantage of such a solution. The purpose of the braid is to transform radial deformations into axial deformations. In the McKibben PAMs, the braid structure is helical and crossed. It enables the distribution of forces like in a pantograph (Fig. 1).

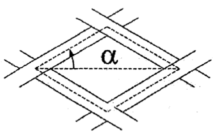

Fig. 1. Structure of a typical braid in McKibben PAM [6]

The capability to activate a large axial force from a relatively small mass and a small cross-section area is a significant advantage of McKibben's PAMs. The peak value of a generated force is almost eight times higher for Fluidic Muscle actuators than for a classic pneumatic actuator with the same cross-section area.

The PAM is activated by compressed air introduced into the muscle's internal space. The pressurized air pushes against the membrane wall and the membrane transmits the generated force to the PAM's braid [7]. This simultaneously results in the swelling and shortening of the PAM. The PAM's shortening and its pulling force are controlled by a pressure value.

The movements performed by PAM, constructed and acting in this way, are smooth and do not show irregularities typical for classic actuators. The design which uses flexible tubes allows for obtaining high elasticity while the contact of the flexible membrane with the braid introduces significant damping properties.

To sum up, the static and dynamic properties of PAM, and especially the ability to generate a large peak force, provide a very good mapping of the biomechanical system work.

3. Operating characteristics of the pneumatic artificial muscle

Fiber braids are arranged diagonally to form a four-bar linkage structure. It allows for converting a radial deformation into the axial one. Although this structure is simple and effective, it introduces some limitations of the actuator. Geometric dependencies make the force generated by the PAM decrease with the increasing of the braid's angle α. Deformations in the radial direction are limited by the geometry of a braid, so the PAM has a relatively small range of shrinkage. The value of the maximum reduction is about 25% of the initial value in the case of McKibben PAMs. The relationship between a generated force and the PAM shrinkage is not linear. It depends on both the degree of the shrinkage as well as the pressure inside the PAM. Typically, the operating characteristics of PAM are defined as a relationship between the force and the percentage shortening at a constant pressure.

This paper describes an investigation of the modified version of McKibben PAMs. These actuators were made as elements of a flexible suit supporting motion motoric (Fig. 2).

Fig. 2. A flexible suit supporting a motion motoric driven by McKibben PAMs

The suit was developed in the AGH University of Science and Technology in the years 2014–2015 [8]. The actuators were completely produced from polymer materials. The flexible membrane was made from a latex tube of 8 mm in diameter and a 2 mm thick wall. The braid was made from a standard polymer braid. The hooks were realized by placing an inactive part of the braid in a latex warp. To increase the flexibility of the actuator, standard metal terminals were replaced by polyethylene ones (one of the terminal was blinded). The connection of the flexible membrane with terminals and the braid was made as pre-stressed ties produced from a nylon-latex composite. It allows for avoiding a quick wipe of the PAM in the place of the polymer-metal contact. The working length of PAM was 33 cm. Muscles were examined on a specially designed test stand (Fig. 3) with one degree of freedom. The stand allows for measuring simultaneously the force, shrinkage and pressure.

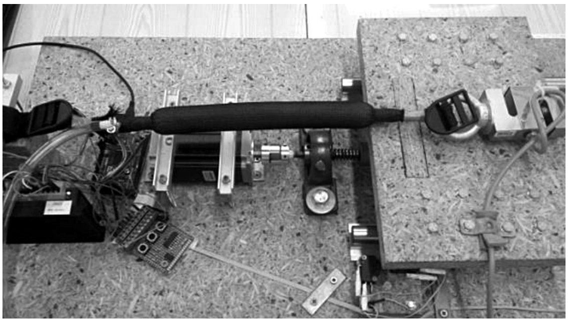

Fig. 3. The test stand for the examination of PAMs

The study was to determine the static characteristics of the actuator. It allows for introducing the relationship between the force and shrinkage into the control model. The control of a force allows subsequently for controlling the torque obtained in the biomechanical system. During the test, the PAM is stretched between the fixed-attachment

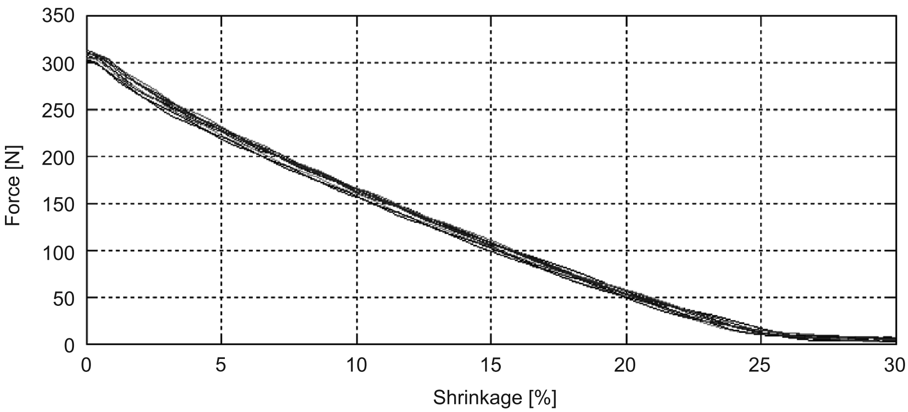

Fig. 4. The relationship between the force and PAM shrinkage obtained for 10 cycles

of the support and the trolley. The trolley is moved by a trapezoidal screw with a stroke of 4 mm while the screw is driven by a stepper motor with a resolution of 400 steps per rotation. The force is measured by a strain gauge with the supply of 10 V. The voltage measurement is made by means of an acquisition card with 16 bit resolution in the range of 0.2 to 0.2 V and a sampling frequency of 100 Hz. The characteristics were achieved by introducing pressure of 4 bar into the PAM and then shortening the PAM's length at a constant speed equal to 10 mm/s.

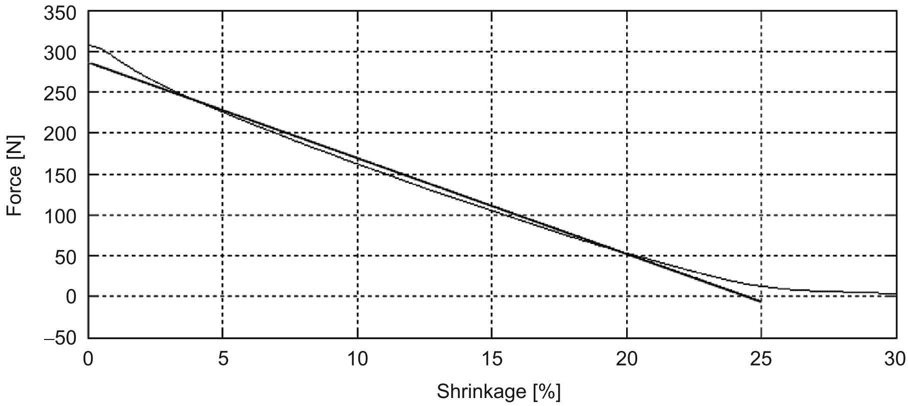

Fig. 5. The linear approximation of the averaged relationship in the range of the shrinkage from 0 to 25% (slope $a = -11.67$, intercept $b = 286.4$)

The obtained characteristics (Fig. 4 and Fig. 5) show a small dispersion. The standard deviation of the shrinkage ranges from 1.34 N to 5.02 N at the assigned value of the force. The average relationship between the force and the shrinkage shows small dynamics of changes in the range of 0–25%. The standard deviation of linear approximation ranges from 1.1 mN up to 11.2 N. The non-linearity is significantly visible in the beginning of the shrinkage range and at 25% of shrinkage, where the plot has a parabolic shape. The modified actuators actively generated a force in the range from 0% up to 26% of shrinkage.

4. Summary

The McKibben artificial pneumatic muscles are an interesting concept of the motion source construction in biomechanical systems. It allows for generating large forces in a short time, which significantly exceeds the capability of conventional actuators. In this paper, the relationships between the force and shrinkage at constant pressure were presented. The obtained characteristics have some non-linearity. The investigation allowed for determining the static characteristics of the actuator. The knowledge of such characteristics makes it possible to introduce a specific relationship between a force and a shrinkage into the control model and – subsequently – to control the force at the variable shrinkage, which derives e.g. from the phase of a movement.

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