ANNALS OF THE UNIVERSITY OF ORADEA
FASCICLE OF TEXTILES, LEATHERWORK

ACTUATORS USED FOR ARTIFICIAL MUSCLES

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Abstract: *This work presents aspects regarding the actuators used to create artificial muscles and their operating principles. Actuators perform an action (movement, brightness increase, colour change) based on a stimulus (electrical, mechanical, magnetic or chemical). Actuators can be used to create artificial muscles, stimulating or replacing the functions of human muscles, for robots or medical devices such as prostheses. They can be used to create linear or rotary motion and can be controlled via electrical or hydraulic systems. In terms of artificial muscles, actuators are used to produce the movement or force required to mimic the action of human muscles. In general, the actuators used in artificial muscles must present good precision and be easily controlled. In addition, they must be reliable and able to be integrated into a wide range of devices. While electric motors are the most popular actuator-based systems, hydraulic, pneumatic and piezoelectric actuators are frequently used to create artificial muscles.*

Key words: *actuators, artificial muscles, energy, medical devices*

1. INTRODUCTION

Actuators are essential for complex systems that require the production of motion. They can be defined as controllable execution systems that transform input energy of various origins, electrical, magnetic, thermal, optical or chemical, into mechanical work (a displacement, rotation, force or moment).

Integrating actuators in textiles is a new approach with an incredible potential for developing the textile industry, opening new perspectives for using smart textiles. In general, most actuator-based actuation systems are rigid, heavy, and noisy, features that make them unsuitable for integration into smart textiles, and in addition, they need heavy power supplies that are rarely flexible and lightweight, which affects wearability, it is necessary to create flexible actuators, with reduced mass and dimensions and silent [1, 2].

Based on the characteristics, stimuli-sensitive materials represent an emerging class of materials responding to temperature, pH, light, magnetic fields and can manifest by changing the dimensions, shape, appearance, permeability, electrical conductivity, and mechanical or optical properties [1].

Polymers are among the most used materials for making textile actuators (actuators based on polymers), due to their many advantages compared to actuators based on ceramic or metal materials [2].

To realise artificial muscles, materials or devices (actuators) are used that imitate natural muscles by changing the stiffness, contraction, elongation or reversible rotation under the action of an external stimulus (pressure, electric voltage, temperature) [3]. To create artificial muscles, pneumatic actuators use pressure generated with compressed air to generate mechanical movement, and thermal or piezoelectric actuators use electrical energy to generate movement.

2. ARTIFICIAL MUSCLES

2.1. Artificial pneumatic muscles

Pneumatic artificial muscles (PAMs) are actuated by air pressure and contract when air pressure increases. These actuators are made of membrane covered with a structure made by interlacing some filaments. As the soft membrane is pressurized, the volume increases, expanding in the radial direction and contracting in the axial direction [4].

The working mechanism of PAMs can be described in two categories which are:

- under a constant load and with variable pressure;
- with constant pressure and a variable load.

Soft pneumatic actuators define the field of robotics that deals with intrinsically soft or extensible materials used to construct robot bodies and actuators, as a possibility to create robots with new capabilities.

Unlike common actuators used in industry, which are based on rigid materials and perform one or several operations efficiently, soft pneumatic actuators are flexible.

These actuators are particularly interesting in narrow spaces, as they can adapt their shapes accordingly.

The first pneumatic muscle patented by A.H. Morin in 1953 was made of textile threads integrated into a cylindrical rubber tube [5]. The most common muscles of this kind are known as McKibben [6].

The McKibben's muscle is a simple structure consisting of an internal elastic tube surrounded by a braided sleeve. The tube provides gas-tightness during the deformation that occurs when the muscle is supplied with compressed air introduced into the tube, while the braid controls the expansion of the tube, allowing the radius to increase and thus produce an axial contraction to the actuator.

Figure 1 shows the McKibben muscle in a relaxed state (figure 1.a. the diameter of the elastic tube is minimum) and in a tense-deformed state by introducing compressed air (figure 1.b. the diameter of the elastic tube is maximum). The braided wire structure in which the elastic tube is wrapped exerts control over its expansion.

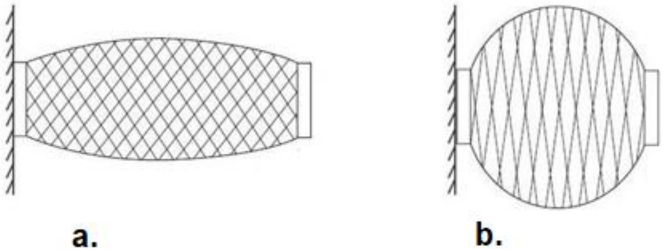

Fig. 1: Deformation depending on the pitch angle of the wires and their density [7]

Since the first pneumatic muscles were developed, medical rehabilitation equipment based on artificial muscles is considered an important application. Essentially, the pneumatic actuator-based artificial muscle can produce force and perform the movement as it contracts, with an action similar to that of natural muscles. Consequently, these pneumatic actuators can be effectively used as substitutes for natural muscles or for actuating robots.

In the field of medical recovery, pneumatic actuators have the following applications:

- External devices applied to the upper and lower limbs (active exoskeletons);
- Active clothing operated by pneumatic devices;
- Inflatable massage balloons.

Soft actuators can be integrated into rehabilitation equipment, having the following applications:

- Artificial muscles made of elastic, gas-tight tubes and fabric or braid to limit the degree of expansion of the elastic tube;
- Interwoven fluidic muscles, based on the use of high resistance placed sheaths. They can produce medium/high forces;
- Actuators with large deformation, which present a particular geometry and are used when large movements are required;
- Soft pressure actuators consist of several chambers side by side and are used to transmit pressure forces that differ from area to area.

2.2. Other types of actuators used for artificial muscles

The pleated pneumatic artificial muscle developed by Daerden [7] is a membrane rearrangement actuator, meaning that the membrane surface is rearranged as it is inflated and no material tension is involved. The membrane of this actuator has a number of longitudinal folds that unfold when the muscle is inflated, allowing the membrane to expand and the actuator to contract. The performance of this actuator depends on the muscle length-to-radius ratio [7].

The Yarlott muscle is an elastomeric balloon reinforced with a series of cables running axially and connected to end fittings. When fully inflated, the muscle takes on a spherical shape.

The Kukolj muscle is similar to the McKibben's muscle, except that in the unloaded one the condition is that there is a space between the inner and outer membrane. For this actuator, the initial working condition is that when the load is applied, the inner membrane is fully extended and contraction occurs when the muscle is inflated. The advantage of this design over the McKibben's muscle is that it prevents the membrane from buckling near its ends [7].

Straight fiber muscle. Many types of pneumatic muscles have longitudinal fibers that connect end fittings. The fittings move towards each other when a deformable interior element is inflated. Through insertion, unilobed or multilobed muscles can be produced with circumferential stiffening rings at certain sections [7].

Paynter hyperboloid muscle. Another variation of the fiber arrangement is used by Paynter, who constructed an actuator whose membrane is shaped like a hyperboloid of revolution. The membrane is closed by a sleeve of inextensible, flexible wires that, in the initial state of the actuator, run in straight lines but form an angle to the axial direction. At full contraction, the actuator expands into an almost spherical shape [7].

3. CONCLUSIONS

The integration of materials with an acting role in textiles is a new approach with incredible potential for the development of the textile industry, bringing significant improvements in the performance of textiles. However, the downside is that most actuation technologies are hard, non-compliant, have robust operating systems, are heavy and make noise, characteristics that make them unsuitable for assembly into smart textiles. In addition, actuators require heavy power supplies that are rarely flexible and lightweight, severely affecting the usability. With the advancement of wearable devices, there is a need for soft, compliant, lightweight and quiet actuators. Moreover, polymer-based coatings and textile materials can be used as actuation materials. Many actuator models with different actuation mechanisms contain or are made of distinct textile elements. Most types of artificial muscles are based on pneumatic actuators or soft actuators. Developing materials for preparing actuation materials is an important step that enables their application, especially in smart textiles.

Although the recent development of smart textiles appears extremely promising, challenges still remain to improve their properties and performance to become suitable for practical and commercial applications.

ACKNOWLEDGEMENTS

This work was carried out through the Core Programme within the National Research Development and Innovation Plan 2022-2027, carried out with the support of MCID, project no. 6N/2023, PN 23 26 01 03, project title "Materiale electroconductive pe baza de metalizari multistrat pentru sisteme termoelectrice, ecranare electromagnetica si senzori biomedicali integrati in sisteme IoT (3D-WearIoT)"

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