Annals of the Academy of Romanian Scientists
Series on Engineering Sciences
ISSN 2066 – 8570 Volume **5**, Number **1/2013**

APPLICATIONS OF PNEUMATIC MUSCLES DEVELOPED AT THE FESTO REGIONAL RESEARCH AND TRAINING CENTRE OF BRAŞOV

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Abstract. *Compressed air is one of the most important sources of energy in industry, pneumatic actuations tending to hold an increasing share in the conception of modern industrial systems. At present, due to the development of new pneumatic components and systems assemblies of high complexity can be achieved, many of them with applicability in robotics. Such a component is the pneumatic muscle, increasingly deployed in actuation systems, particularly in the field of industrial robots. The paper presents some of the results of research conducted at the Festo Regional Research and Training Centre (FRRTC) at Transilvania University of Braşov.*

Keywords: Pneumatic muscle, robotics, pneumatic drives

1. Introduction

Compressed air is one of the most efficient means of actuation and automation of manufacturing systems. Its deployment in actuations goes back as far as 2300 years, and at present knows a strong trend of implementing in an increasing number of industrial applications.

The continued development of pneumatic actuations has evolved from utilisation of individual components to that of complex automation systems. The developed systems included in addition to classical pneumatic structures also mechanical, electronic and sensorial elements. Figure 1 presents the evolution in time of pneumatic automation constructive solutions [1].

The increasing range of compressed air industrial applications is due to its advantages, like easy generation and storage, nonflammability and minimum explosion risk, low-maintenance efforts, etc. Another important advantage offered by compressed air is the clean working environment, rendering it eligible for environment-friendly processes, as *e.g.* those in food, electronics or pharmaceutical industry.

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Pneumatics Pneumatics & mechanics Pneumatics & electronics Pneumatics & sensors

Fig. 1. Evolution of pneumatic actuation systems.

At present, the development of new pneumatic components and systems allows the achievement of highly complex assemblies, many with applicability in robotics. Figure 2 presents a number of such examples [2].

Fig. 2. Complex systems including significant pneumatic actuation.

2. Actuations based on pneumatic muscles

Relatively recent research in the field of pneumatic actuation elements yielded the conception of a membrane-type actuation system, known as *pneumatic muscle*. Utilisation of pneumatic muscles for the construction of pneumatic actuations has known continuous development particularly in the field of industrial robots. In this sense worth mentioning are the 2-arm humanoid robot developed by Festo Co. Germany in cooperation with the Technical University of Berlin, called Zar-X (Zwe-Arm-Roboter), Airic's Arm developed by Festo Co. or the hand conceived by Shadow Robot Company, USA [3,4].

Fig. 3. Applications of pneumatic muscles in robotics

The above presented systems, created over the years, illustrate the rapid development of artificial pneumatic muscles, as actuators with multiple application possibilities in various fields of activity.

The pneumatic muscle is defined as an elastic system based on a contracting membrane, which under the action of compressed air increases its diameter and decreases its initial length. Artificial muscles present a number of characteristics that render them extremely useful for robotised applications, like small overall dimensions, impact shock damping capacity, easy connectivity, high energy efficiency, a contracting force similar to that generated by biological muscles, etc. Figure 4 shows the schematic describing the functional principle of pneumatic muscles.

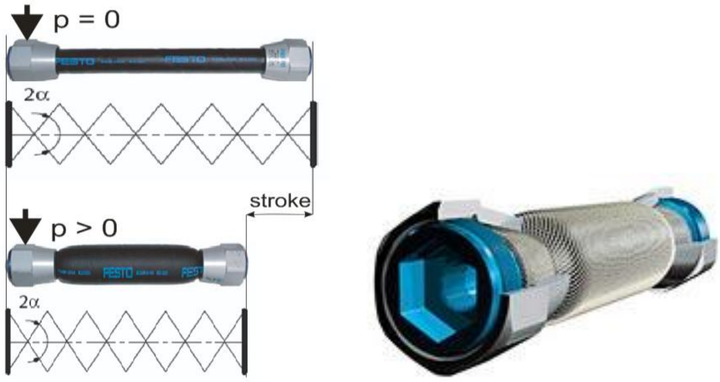

Fig. 4. Operational principle of pneumatic muscles.

The main component of a pneumatic muscle is a flexible tube covered by a sealed envelope made from non-elastic fibres forming a diamond pattern, thus achieving a 3D mesh. When the artificial pneumatic muscle is fed compressed air it deforms longitudinally generating a traction force of a magnitude depending on the working pressure. Pneumatic muscles operate similarly to mechanical springs, meaning that the initial developed force is maximal, and decreases towards zero as deformation increases.

Inflation under the action of compressed air causes a shortening of the muscle while its diameter increases, as illustrated in figure 4. The difference in length between the unloaded state of the muscle and any state reached consequently to the feeding of compressed air represents the stroke.

3. Applications of pneumatic muscles at FRRTC

The Festo Regional Research and Training Centre (FRRTC) was established in 2006 within Transilvania University of Braşov with the main scope of facilitating scientific research and technological development in the field of fluidic automation. Further, the Centre caters to training needs of technical staff from local and regional industry following the Festo model first implemented in Western Europe and also has the role of promoting fluidic automation systems on Central Romania marketplace via specialist courses and seminars.

Among the research-development-innovation activities at FRRTC special emphasis comes to the utilisation of pneumatic muscles in robotic systems, and to study concerning their operational behaviour. Some of the results are further on presented in this paper.

3.1. Rotation-translation system for industrial robot joints

The rotation-translation system actuated by pneumatic muscles presented in figure 5 is part of the construction of a robot arm mounted on a wheelchair [5, 6]. Manipulators mounted on wheelchairs have a high degree of flexibility as to their applicability; they are designed in order to pick up objects randomly positioned in space, to turn taps or carry out simple manipulation tasks like pouring liquids into a glass and lifting that glass to the patient's mouth.

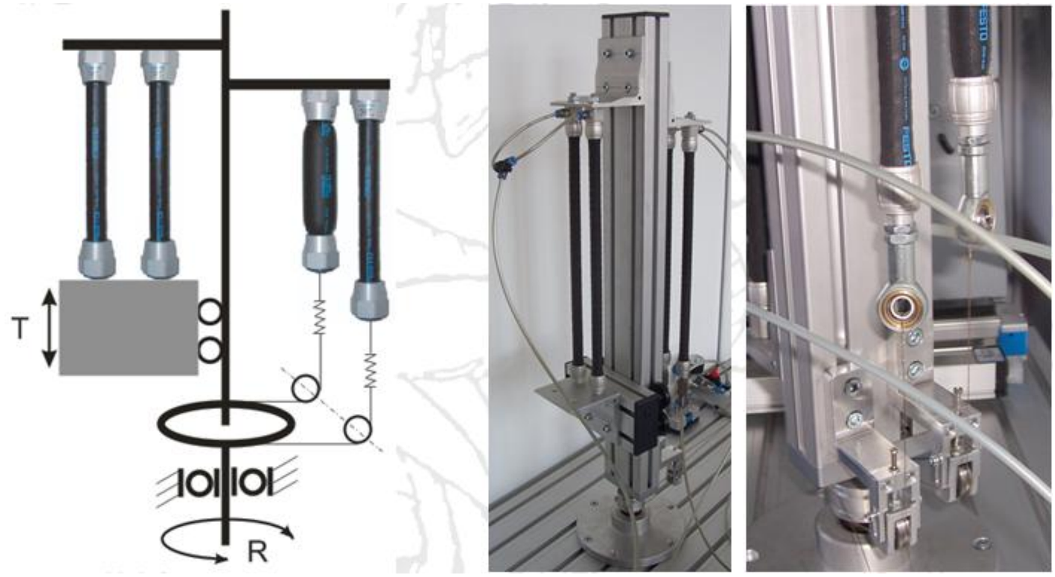

Fig. 5. Rotation-translation system actuated by pneumatic muscles.

The rotation-translation system is actuated by two pairs of pneumatic muscles. The first pair, designed for generating rotation, is based on the principle of counter-time feeding of the two actuators, while the muscles designed for generating translation motion are fed synchronously.

Generation of rotation is based on a bionic solution, where, unlike other systems, the two actuators (pneumatic muscles) rotate together with the element set into motion. The two pneumatic muscles are designed such as, upon being actuated counter-time, to generate a ± 45º rotation, as well as the balance of a certain intermediary position of the actuated system. The rotation of the entire robotic system is quite similar to motions caused by human muscles based on the agonist-antagonist principle, as follows from Figure 6.

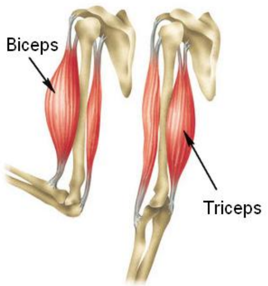

Fig. 6. Human arm.

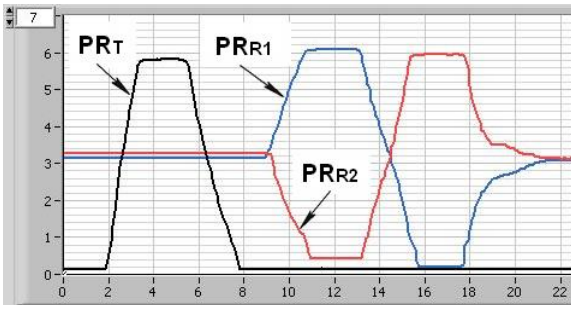

Fig. 7. Variation curves of pressure vs. time.

Figure 7 shows the curves obtained by testing the rotation-translation system at an air pressure of 6 bar. In the case of rotation, initially the two muscles are simultaneously fed compressed air until half of the maximum working pressure ($p_0 \approx 3$ bar) is reached. Then, as illustrated in figure 7, while one of the muscles is further fed compressed air (curve PR_{R1}), the other one is deflated (curve PR_{R2}) and vice-versa. Curve PR_T describes the evolution of the compressed air pressure fed to the muscles in order to generate the translation motion.

3.2. Pneumatic muscle actuated rehabilitation equipment of lower limb bearing joints

Utilisation of pneumatic actuators for bearing joint rehabilitation equipment is a novelty, the only known achievement of this type being that of the Friedrich Wilhelm Bessel Institute of Bremen, Germany. This equipment is based on the principle of joint bars with rotating pneumatic actuators, attached to the joints to be rehabilitated (hip or knee) [7].

The rehabilitation equipment developed at FRRTC Braşov, actuated by a linear pneumatic muscle is conceived for the rehabilitation of hip, knee and ankle by continuous passive motion [8]. Figure 8 a and b presents the kinematic diagram underlying this equipment, the structure of the positioning system, as well as an image of the actuation mechanism (the cover has been removed).

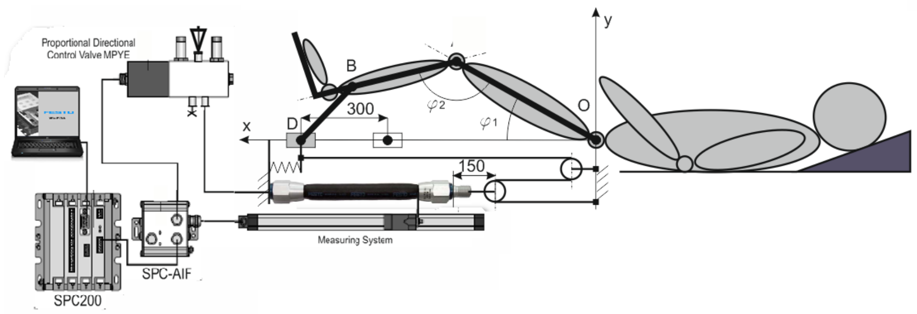

Fig. 8.a. Rehabilitation equipment of bearing joints

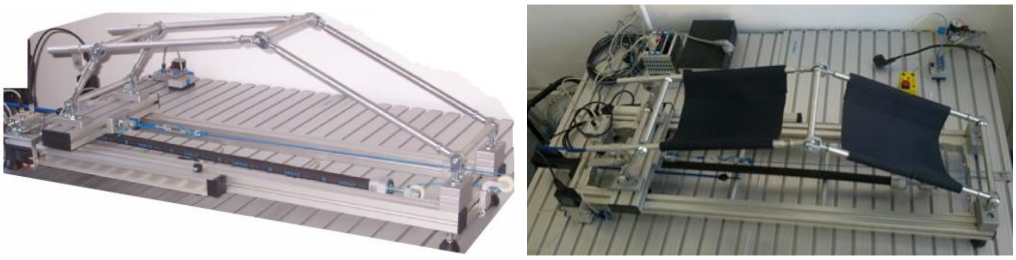

Fig. 8.b. Rehabilitation equipment of bearing joints

Continuous passive motion is generated by a single pneumatic muscle that moves a slide along a stroke up to 300 mm. In order to carry out rehabilitation motions the patient places the disabled leg on a holder mounted on a bar mechanism, linked to the sliding block.

The construction of the mechanism includes a Festo pneumatic muscle of 20 mm interior diameter and an initial length of 750 mm. As the maximum possible stroke of the muscle free end is of about 20% of its initial, relaxed length (that is 150 mm), a mobile pulley mechanism was placed between muscle and slide in order to amplify the stroke to the required value.

The positioning system used for this application offers flexibility, adaptable speed and sufficient accuracy for concrete functional requirements. Such a system is recommended for pneumatic axes requiring more than two stops, as well as temporizations/delays of various durations.

The positioning system includes the following components: the pneumatic muscle actuated by a proportional directional control valve; a resistive position transducer attached to the slide; an SPC 200 controller for programming and saving the working positions, the types of motion and their sequence (programming, operation and diagnosis of the controller are achieved by WinPISA software); electronic elements for transmission of information from the transducer to the controller and of the commands issued by the controller to the proportional valve (electronic elements included by the SPC-AIF interface).

The control variable is a displacement related to the origin of the system and measured by a displacement transducer. The device allows the programming of single or multiple cycles of exercises, depending on the degree of recovery of the affected joints.

3.3. Pneumatic muscle actuated gripping systems

In robotics gripping entails contact between the robot's effector (the gripper) and the body to be manipulated. Grippers are those components of robotic systems that facilitate temporary contact with the manipulated object, ensuring its position and orientation during transport and assembly.

Most gripping systems mounted on robots are two finger mechanisms, used for both manipulation and assembling. Two-finger grippers are most frequently used due the simplicity of configuring object gripping, of the mounting and deployment characteristics.

Further on two variants of non-anthropomorphic grippers are presented as applications of pneumatic muscles, designed and developed by the members of the research team [9]. In the first constructive variant (Fig. 9) the actuation element of the fingers is a transversally positioned pneumatic muscle, controlled by a 5/3 proportional valve. The finger carry out a linear motion of maximum 5 mm stroke, and develop a force of 50 N.

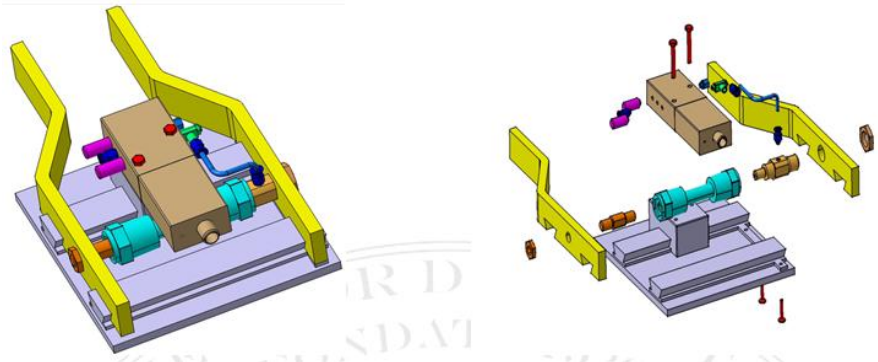

Fig. 9. Constructive variant with a transversally mounted muscle.

It can be noticed that the same casing includes both the actuating elements of the two gripper fingers and the control valve of the pneumatic valve. This yields a light and compact structure, easily placed within a robotised system.

A second constructive solution includes a pneumatic muscle actuating two rotating fingers. While the structure is slightly longer than the previous one, it is similarly light.

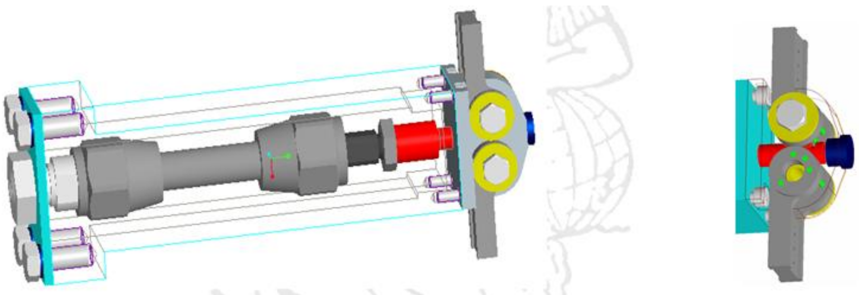

Fig. 10. Constructive variant with rotating fingers.

Both constructive variants use the same type of pneumatic muscle, of 10 mm diameter and 40 mm length.

Conclusions

The utilisation of pneumatic muscles for the actuation of mechanical systems knows an increasingly larger development in industry. In this context in-depth research concerning the performances and behaviour of pneumatic muscle is called for. A detailed knowledge of pneumatic muscles will allow their replacing cylinders with simple action in an increasing number of applications.

Ensuring the driving of systems by pneumatic muscles proves that these actuators, yet insufficiently known and deployed, offer numerous advantages related to dynamic behaviour as well as to involved costs.

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