CONSTRUCTION AND DYNAMIC PERFORMANCE OF A PNEUMATIC MUSCLE ACTUATED TRANSLATION MODULE FOR ROBOTIC ARMS DESIGNED FOR WHEELCHAIRS

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Abstract: *Pneumatic muscle actuated translation modules represent an innovative solution for systems designed for wheelchairs endowed with robotic arms. Pneumatic muscle actuated robotic arms are intended to increase the degree of autonomy of persons with impairments of the lower and upper limbs. The paper presents in detail the construction of such a translation module, as well as its dynamic performance. Based on the obtained experimental results the dependencies of the stroke lengths achievable by means of pneumatic muscles on air feed pressure and load are highlighted. The developed empirical model gives a concrete and effective description facilitating the understanding of the mechanical behaviour of the pneumatic muscle, in view of optimal design and utilization.*

Key words: *pneumatic muscles, robotic arm, wheelchair, translation module.*

1. INTRODUCTION

Worldwide an increasing trend of the number of physically challenged persons can be observed. With the aggravation of the physical disabilities, these persons increasingly lose their autonomy and need to rely on the support of caregivers and medical assistance in the solving of everyday tasks. A modality of avoiding such situations is the implementation of new technologies in the care giving process.

In order to meet the option of disabled persons to increase their autonomy in everyday domestic and professional life by deploying modern rehabilitation equipment, the last three decades have seen intensive scientific research oriented towards developing, improving and implementing robots in the field of physical rehabilitation, medical assistance and support in the conducting of professional activities [3, 5, and 6].

The increase of the degree of autonomy of persons with locomotion disabilities is achieved mainly by the use of wheelchairs. Depending on the specific handicap, these chairs can be endowed with robotic arms facilitating certain actions desired by the user. The robotic arms (one or two) are placed on the back of the chair or on its sides.

An example of such a robot is the JACO, made by the Canadian firm Kinova [7], that develops technologically advanced products to enable people with disabilities to live a more normal and independent life (Fig. 1). Kinova also adapts technologies from other industries such as aerospace, to provide concrete and practical solutions for those who suffer from mobility impairment.

Fig. 1. Robotic arm on a wheelchair (JACO).

JACO is a lightweight, very quiet, discreet, safe, and waterproof robotic arm that attaches to any powered wheelchair. It can be installed also on a bed or a desk. Its multifunctional hand works as an extension of a human arm in order to assist the patient in conducting everyday activities. JACO, and generally wheelchair mounted manipulators have the highest degree of flexibility in relation to their applicability. They facilitate the gripping of objects located randomly in space, they are instrumental in opening doors, drawers, taps, or can conduct easy manipulation tasks like pouring drink in a glass and raising it to the patient's mouth (Fig. 2).

Fig. 2. Examples of simple gripping and manipulation tasks.

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Fig. 3. Robotic arm developed by the Fraunhofer Institute.

Many researchers around the world have tried to build robotic devices able to help people with paralysis. At present, European researchers have developed a robotic control system based on electroencephalogram (EEG). The patients using the Brain2Robot system might regain some of their lost autonomy. The users will control the robotic arm with their thoughts. To control the robotic arm, the Brain-Computer Interface (BCI) developed at one Fraunhofer Institute in Germany is combined with an eye tracker (Fig. 3). The signals are sent to a computer which performs the main learning task. According to the researchers, the robotic arm could become commercially available in a few years [8].

Until recently the actuation of robotic systems was ensured in most cases by electric motors. Pneumatic actuation was generally avoided, because of issues related to control and compliance. Certain advantages of this type of drive, however, like the compactness of the actuators, the favourable power to weight ratio, reduced costs, easy maintenance, clean operation have determined its increased deployment in robotics, over the last years.

Research conducted over the last years at the Transilvania University of Braşov has revealed the benefits of deploying pneumatic muscles in robotics. This paper discusses the application of pneumatic muscles as actuators of robotic manipulation arms destined for the rehabilitation of disabled persons.

2. CONSTRUCTION OF THE ROBOTIC ARM

Pneumatic muscle actuated robotic arms involving an extremely light construction and increased flexibility meet the safety demands of equipment operating in the immediate vicinity of humans or in narrow spaces. The robotic arm proposed in this paper includes a rotation and a translation module, both pneumatically actuated by artificial muscles. The solution of implementing this type of actuators was selected due to their improved performance versus pneumatic cylinders. Thus pneumatic muscles are about eight times lighter and develop a force about ten times greater, at the same interior diameter [4].

Pneumatic muscles allow very slow motions, of small amplitude, completely stick-slip free, hence their dynamic behaviour being superior to that of pneumatic cylinders.

The pneumatic muscle is system involving a contracting membrane, which upon being fed compressed air increases its diameter while decreasing its length (Fig. 4). Thus the pneumatic muscle achieves a certain stroke, depending on the level of the feeding pressure. The operational behaviour of such a system is similar to that of a human muscle.

Fig. 4. Operational principle of pneumatic muscles.

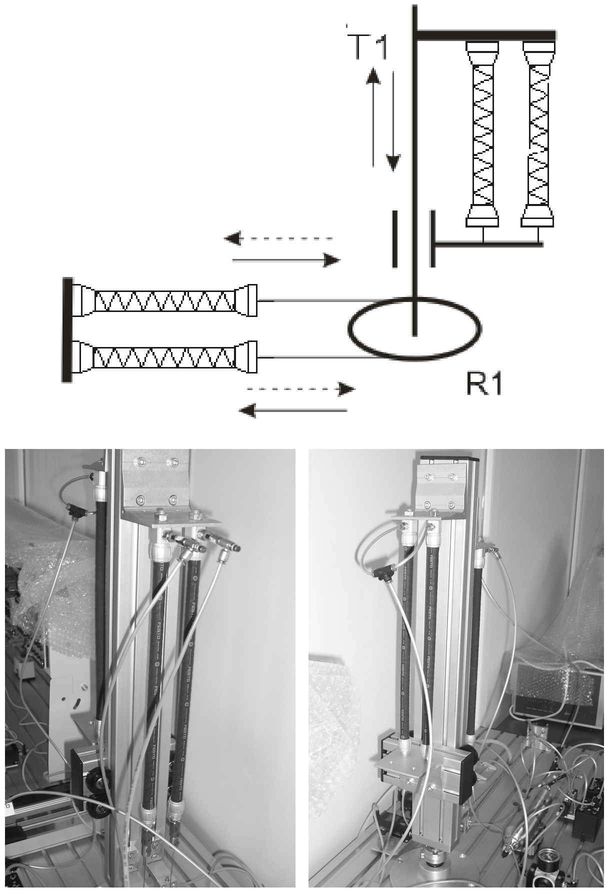


Fig. 5. Kinematic diagram and construction of the robotic system.

Figure 5 shows the kinematic diagram and the structure of the proposed robotic arm [1 and 2]. The designed structure ensures two degrees of freedom (rotation and translation), all movements being obtained by means of two pairs of pneumatic muscles.

The four utilized pneumatic muscles are each of 300 mm length and 10 mm interior diameter. The achievable stroke depends on the level of the feeding pressure, and is of maximum 60 mm.

3. CONSTRUCTION AND PERFORMANCE OF THE TRANSLATION MODULE

The vertical translation motion of the robotic arm is obtained by means of a pair of pneumatic muscles working synchronously. The superior ends of the muscles are attached to the mechanical structure of the robotic arm, while the free ends are attached to a slide that can glide along a vertical guide. Figure 6 shows the construction of the translation module.

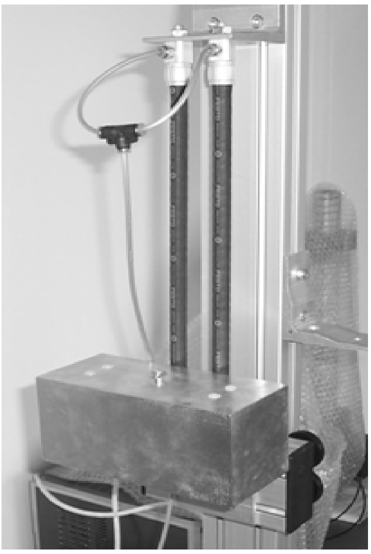


Fig. 6. Construction of the translation module.

The two muscles work simultaneously upon being fed compressed air. By feeding compressed air to the muscles they decrease their initial (resting) length by up to 60 mm, thus setting a vertically gliding slide into motion. The gliding of the slide along the standardized profile is ensured by two pairs of rollers.

Experimental research on the performance of this module was oriented towards determining the positioning precision of the mobile slide at various levels of the feeding pressure. The conducted experiments included loading the slide with five different weights, namely of 10 N, 34 N, 74 N, 98 N and 122 N, respectively. The measurements consisted of determining the contraction ΔL of the two muscles, upon being fed compressed air (inflated) as well as upon releasing air (deflated).

Based on the results obtained by measuring in both the inflation and deflation phase of the muscles, the characteristic curves of Figs. 7 and 8 could be plotted. It can be noticed that with the increase of pressure the contraction (ΔLu – for inflation and ΔLd – for deflation) of the muscles grows, reaching a deformation of 13% to 16% of the initial muscle length, for a feeding pressure of 6 bar. As the weight attached to the gliding slide increases, the axial contraction of the muscles is smaller.

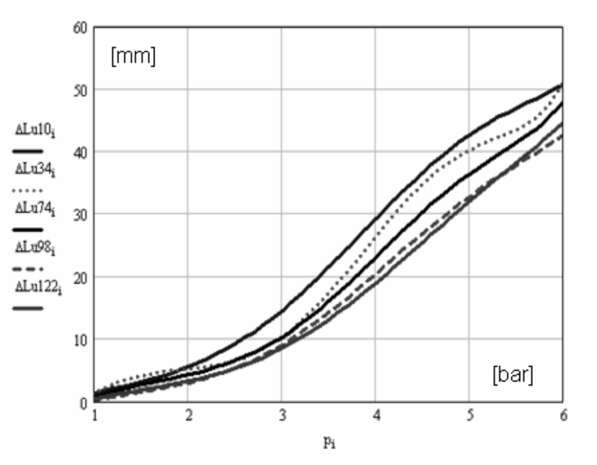


Fig. 7. Magnitude of muscle contraction at inflation.

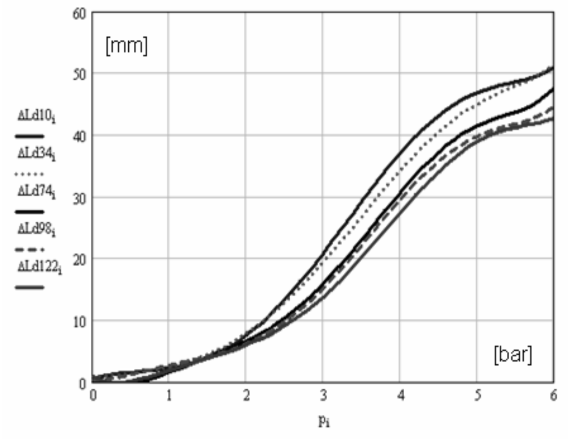


Fig. 8. Magnitude of muscle contraction at deflation.

Fig. 9 presents the evolution of the axial contraction of the two muscles versus the pressure of the fed air, for two values of attached weights (10 and 98 N). The occurrence of a hysteresis phenomenon can be noticed, characterized by a delay (a lag) in the muscles regaining their initial form upon deflation. The maximum difference of muscle contractions in inflating-deflating, for the same value of the feeding pressure is of about 7 mm for a load of 10 N, and of 10 mm for a load of 98 N, respectively. These experimentally determined values imply, for the two values of the attached weights, a difference of the relative deformation of the muscles in inflating and deflating, respectively, namely $\Delta L/L_0 \cdot 100$, ranging between 2.3 % and 3.3 %.

The hysteresis phenomenon can be explained by the friction between the exterior wall of the muscle elastic tube and the mesh enveloping it. The occurrence of hysteresis represents a major disadvantage to the utilization of pneumatic muscles in applications requiring high precision motions.

The measurements allowed the determination of two equations for computing the axial contraction of the pneumatic muscles, contraction expressed as $\Delta L = f(p, F)$:

- In the case of muscle inflation:

$$\Delta L(p,F) \;=\; 1.251 \cdot p^{2.481} \cdot F^{-0.185}. \tag{1}$$

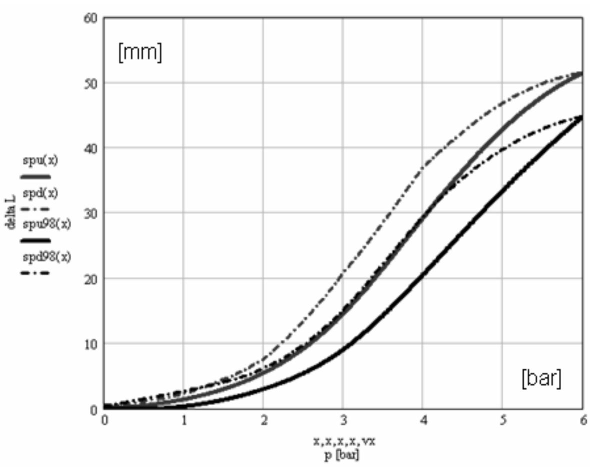
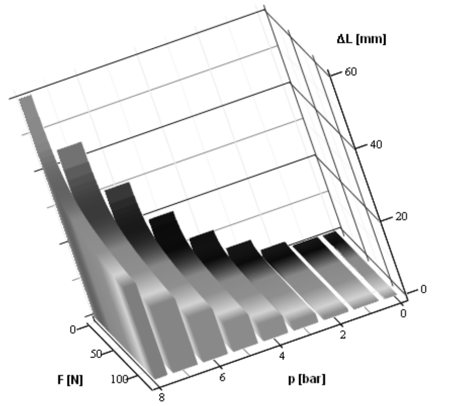


Fig. 9. The hysteresis phenomenon of the pneumatic muscles.

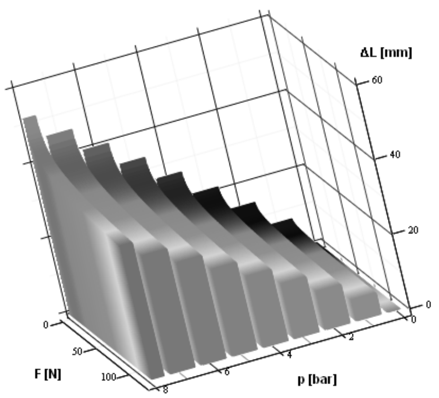
- In the case of muscle deflation:

$$\Delta L(p,F) \;=\; 12.006 \cdot p^{0.93} \cdot F^{-0.08} + 0.5. \qquad (2)$$

Figure 10 presents the evolution of the axial contraction ΔL versus feeding air pressure p and the load F attached to the slide of the translation module.



a



b

Fig. 10. $\Delta L = f(p, F)$: *a* − inflation of the pneumatic muscles; *b* − deflation of the pneumatic muscles.

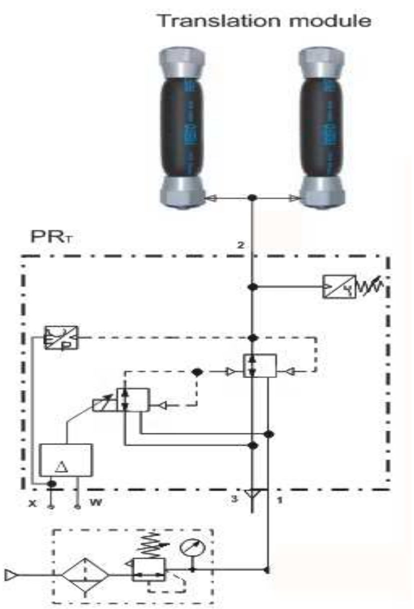


Fig. 11. Pneumatic actuation diagram.

Equation (2) together with the graph describing muscle behaviour at deflation reveal that for air pressure of zero bar, the pneumatic actuator does no resume its resting length L_o. A remnant contraction of 0.5 mm is noticed, that disappears after a longer period of time.

The motion of the two pneumatic muscles is achieved according to the schematic in Fig. 11. The synchronous displacement of the two muscles is obtained by means of a proportional pressure regulator PR_T. This has an integrated sensor that measures the level of the pressure at the exit orifice. The role of the embedded electronic module is to actuate the regulator until the measured value of the output pressure is equal to its preset level. The adjustment of the output pressure is proportional to an electric control value.

4. CONCLUSIONS

The paper presents the mechanical structure and the actuation system of a translation module developed for robotic manipulation systems, useful in rehabilitation activities of disabled persons. The actuation of this module by means of pneumatic muscles reveals that these actuators, still insufficiently known and used, have numerous advantages but also disadvantages related to their operational behaviour. The main advantages include the reduce weight of the muscles compared to that of cylinders and the absence of stick-slip, while the major disadvantage is the occurrence of hysteresis. A detailed knowledge of pneumatic muscles will allow their future replacing simple action cylinders in an increasing number of applications.

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