STUDIES ON THE APPLICABILITY OF THE PNEUMATIC MUSCLE IN INDUSTRY

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Abstract. The evolution underwent by the technology during the last decade facilitated utilization of pneumatic muscle in many applications, particularly in the field of industrial robots. The pneumatic muscles are lightweight actuators, able to generate high torques at low and moderate speeds, able to be connected to the structure without gearing, having a natural compliance and shock resistance and a possible autonomous operation. The current paper will focus on the pneumatic muscle with it's applicability in the industry .The paper presents also one possible application for pneumatic muscle which is isokinetic equipment designed for therapeutic exercises and it's functionality. The isokinetic equipment allows recovery exercises of the hip and knee joints, the lower limb being immobilized in the device. Completed research has proved that the utilization of such equipments would significantly reduce the period of recovery, the patients resorting to a smaller quantity of pain medication. Although the utilization of pneumatic muscles in industrial applications is still in an early phase, because the relative newness of these components, it is soon to become a feasible alternative for the electro-mechanically actuated systems.

Keywords: pneumatic muscle, actuators, isokinetic equipment

1. Introduction

The current paper will focus on the pneumatic muscle with it's applicability in the industry. Compressed air utilized as source of energy represents one of the most efficient means of actuation and automation of production systems.

The utilization of compressed air in industrial applications has many advantages like: comfortable generation and storage, lack of flammability, minimum risk of explosion, minimum maintenance effort of pneumatic systems, etc. Another important advantage of compressed air is its being a clean, ecological working medium, lending itself to environmentally friendly processes, like those encountered in food, electronics or pharmaceutical industry [1].

Recent research on pneumatic actuation elements led to the conception of a membrane type actuation system, known as *pneumatic muscle* (figure 1).

Figure 1 Pneumatic muscles

Pneumatic actuators are usually used in factory floor automation. Lately, robotics as well is starting to use pneumatics as a main motion power source. One of the major attractions about pneumatics is the low weight and the inherent compliant behaviour of its actuators. Compliance ensures a soft touch and safe interaction. In contrast with pneumatic muscle actuator, hydraulic and electric drives have a very rigid behaviour and can only be made to act in a compliant manner through the use of relatively complex feedback control strategies [2].

2. Pneumatic Muscle

Pneumatic muscles were conceived in 1930 by S. Garasiev a Russian inventor [3]. According to Baldwin [4], J. L. McKibben introduced it as an orthotic actuator in the late 1950's: due to the similarity in length-load curves between this artificial muscle and skeletal muscle, it seemed an ideal choice for this purpose [5, 6].

The Bridgestone rubber company (Japan) commercialized the idea in the 1980s under the name of Rubbertuators and used them to power an industrial use robot arm, Soft Arm.

At the present, McKibben-like muscles are being brought to the market by Festo Ag. & Co.

The pneumatic muscle system is composed

by an inflatable tube, which increases its diameter and decreases its length, proportionally with the action of compressed air. When compressed air is passed into the muscle, which is blocked at one end, the tube inflates, but the action of the enclosing mesh forces the tube to shorten (figure 2). The resultant force is used as a linear actuator. The pneumatic muscle carries out a certain stroke, according to the level of the feed pressure.

In figure 2 is presented the working principle of a pneumatic muscle.

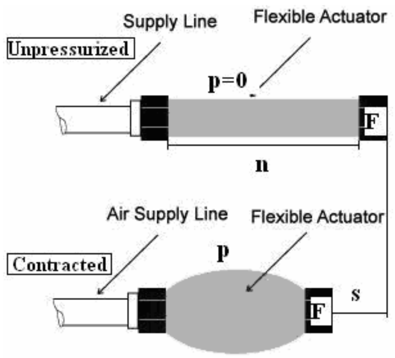

Figure 2. Working principle of a pneumatic muscle

The inflatable tube, contained by the pneumatic muscle can have various lengths and is made from an elastic material, typically neoprene rubber. This tube is wrapped in a multilayer tissue made from nylon, strengthening and protecting it from the influences of the working environment. The enveloping angle of the tissue, denoted by α, is of 25.4º in the relaxed state of the muscle and of 54.7º at maximum contraction. The force developed by pneumatic muscle is given by (1) [5].

$$F = p \cdot \frac{\pi}{4} \cdot d^2 \cdot \left[\frac{3 \cdot \cos^2 \alpha - 1}{1 - \cos^2 \alpha} \right] \quad (1)$$

where p is the working pressure and d the interior diameter of the pneumatic muscle.

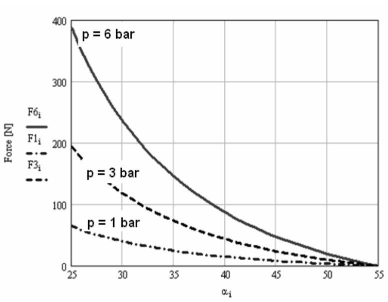

Figure 3. Force versus enveloping angle and working pressure

Upon completion of the maximum stroke, the developed force is equal to zero. Equation (1) allows plotting of the graph featuring the force developed by a pneumatic muscle versus the enveloping angle and feed pressure (figure 3) [6].

3. Applicability

The utilization of muscles in the construction of pneumatic actuation elements has known continued development, particularly in the field of industrial robots [7, 8].

Some examples in this field are the pneumatically actuated arm developed by the American J.L. Mc Kibben, the stepping robot WAP 1 developed by the Waseda University of Tokyo (1969), the pneumatic membranes built by the IAI Research Centre of Karlsruhe, Germany (2002 or the humanoid robot developed by the Festo Company in cooperation with the Technical University of Berlin, Germany.

Pneumatic muscles have been used for a number of years as actuators in robotic systems, usually in those that mimic human actions, where compliance and low power to weight ratio are important. They are most commonly used in systems designed to aid physically handicapped people [9].

Several types of pneumatic actuators—e.g. cylinders, bellows, pneumatic engines and even pneumatic stepper motors—are commonly used to date. Pneumatic muscles represent a good alternative to pneumatic cylinders used in various industrial applications. Figure 4 [10] illustrates a comparison of the forces generated by a pneumatic muscle of 10 mm nominal diameter and the force developed by a pneumatic cylinder of the same diameter.

It can be observed that for identical dimensions (diameters) a pneumatic muscle develops a significantly higher force than a pneumatic cylinder [10].

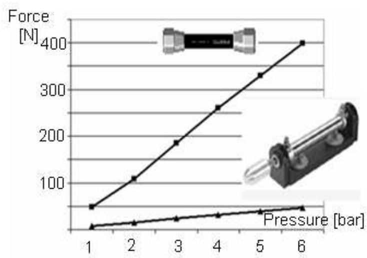

Figure 4. Forces developed by a pneumatic muscle and a pneumatic cylinder

Over the past years, many applications have been found for the pneumatic muscles. Caldwell used 18 small McKibben Muscles to power a dexterous four-fingered manipulator. One full humanoid project is the Shadow Robot Project.

Hannaford built an anthropomorphic arm, having fifteen McKibben Muscles. The Soft Arm, developed by Bridgestone Co. has a shoulder, an upper arm, a lower arm and wrist, and a useful payload of maximum 3 kg.

Yoshinada used hydraulically actuated McKibben Muscles to power an underwater manipulator [2].

4. Pneumatic Muscle Based Isokinetic Equipment

One application for a pneumatic muscle is isokinetic equipment designed for therapeutic exercises.

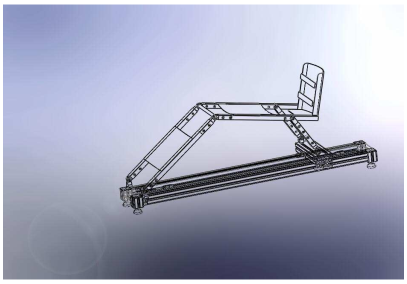

Figure 5. The isokinetic equipment

Figure 6 illustrates the diagram of principle of operating of the equipment.

The equipment allows recovery exercises of the hip and knee joints, the lower limb being immobilized in the device.

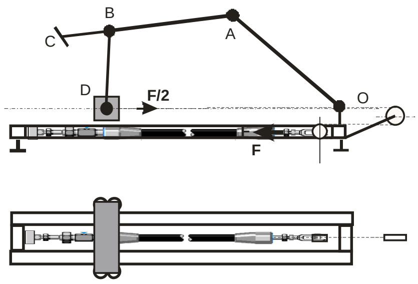

Figure 6. Operating principle of the isokinetic equipment

The pneumatic muscle used in the construction of the equipment is of 20 mm interior diameter and initial length of 750 mm, the maximum possible stroke of the free end of the muscle being of approximately 20% of its length in relaxed state (that is 150 mm). The required value of 300 mm is obtained with a mobile pulley, placed between the muscle and the sliding block in order to amplify the sliding block stroke (figure 7).

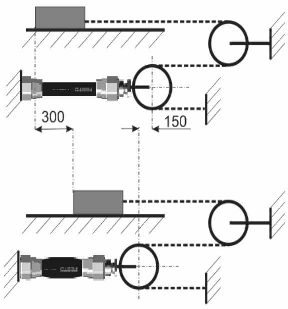

Figure 7. Actuation of the isokinetic equipment

In order to achieve the desired rehabilitation motions, the sliding block is linked to a mechanism with a flexible bar mechanism (figure 8).

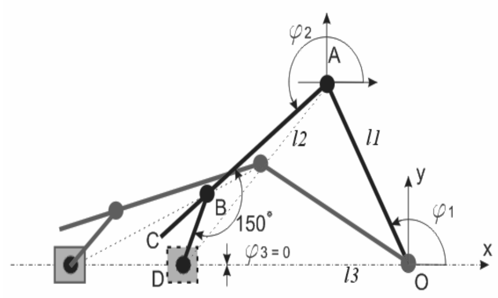

Figure 8. Kinematic diagram of the flexible bar mechanism

The variation limits of the rotation angles of the hip joint φ1 and the knee joint, φ2, respectively, can be calculated, and also the evolution of these angles can be represented for the entire duration of the sliding block double stroke. The input value considered for this purpose is the sliding block travel over a 300 mm distance, the unknowns being the two angles φ1 and φ2. Also known are the lengths of the bars, as follows: l1 = 450 mm; l3 = 600…900 mm. In triangle ABD the length of segment l2 = AD can be calculated as being of 552 mm.

The following equations can be written in triangle OAD:

$$l1 \cdot \cos\varphi 1 + l2 \cdot \cos\varphi 2 + l3 \cdot \cos\varphi 3 = 0 \qquad (2)$$

$$l1 \cdot \sin\varphi 1 + l2 \cdot \sin\varphi 2 + l3 \cdot \sin\varphi 3 = 0 \qquad (3)$$

Upon processing these equations and imposing the condition φ3 = 0, the magnitude of angle φ2 can be computed:

$$\varphi 2 = \pm \arccos\left(\frac{l1^2 - l2^2 - l3^2}{2 \cdot l2 \cdot l3}\right) \qquad (4)$$

followed by the computation of angle φ1:

$$\varphi 1 = -\arcsin\left(\frac{l2}{l1} \cdot \sin \varphi 2\right) \qquad (5)$$

Figure 9 and 10 show the variations of these two angles with the displacement of the sliding block between its extreme limits (-900…-600 mm):

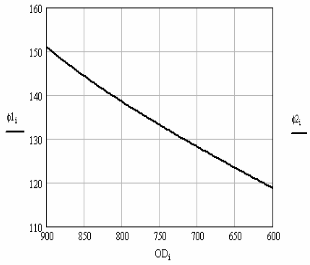

Figure 9. φ1 = f(l3)

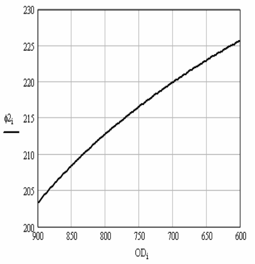

Figure 10. φ2 = f(l3)

As follows from the graphs, the variation limits of the two angles are the following:

- For the hip joint: φ1 = 118.7º … 151.037º;
- For the knee joint: φ2 = 203.347º … 225.754º.

The graphs below (Fig. 11) show the time related evolution of the sliding block speed and of the two angles, considering the stroke length of 300 mm being achieved in 2 seconds.

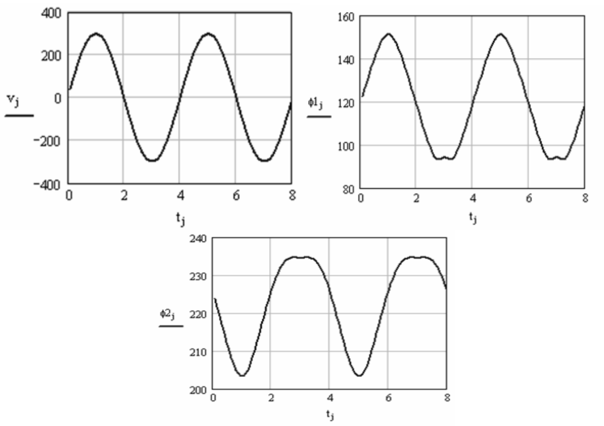

Figure 11.Variation diagrams of velocity and angles φ1 and φ2 versus time

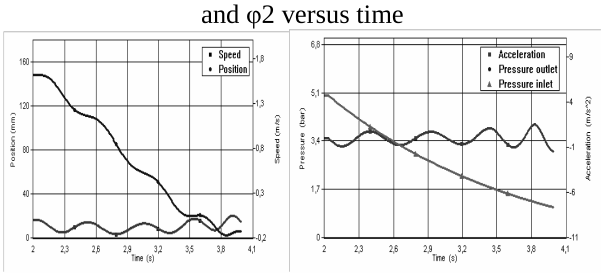

Figure 12. Variation of the muscle position, speed and acceleration versus time

The study of the time related evolution of the actuating pneumatic muscle during its deflation follows from the diagrams presented in figure 12. The variations of speed and acceleration versus time can be observed here, as well as of the position of the free end of the muscle [11].

It can be noticed that the speed of the muscle free end, and implicitly of the sliding block has small variations, thus not being rigorously constant. These variations can however be easily removed by including a throttle in the pneumatic actuation circuit.

4. Conclusions

The pneumatic muscle found its applicability in the industry and that is about to increase in the future, due to the given opportunities, namely ability of realizing delicate handling operations. Because they are lightweight actuators, able to generate high torques at low and moderate speeds, able to be connected to the structure without gearing, having a natural compliance and shock resistance—pneumatic muscles is soon to become a better choice than present day electric or other drives.

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