DEVELOPMENT OF A HIP ORTHOSIS USING PNEUMATIC ARTIFICIAL MUSCLES TO CONTROL THE JOINT ROTATION

Claysson Bruno Santos Vimieiro
clayssonvimi@yahoo.com.br

Breno Gontijo do Nascimento
brenognascimento@yahoo.com.br

Danilo Alves Pinto Nagem
dapin@ufmg.br

Henrique Resende Martins
henriqueresende@yahoo.com.br

Charles de Oliveira Costa
fisiocharles@yahoo.com.br

Giovanna Mendes Amaral
giovannamaral@yahoo.com.br

Marcos Pinotti
Laboratório de Bioengenharia - Labbio
Departamento de Engenharia Mecânica
Universidade Federal de Minas Gerais – UFMG
Av. Antônio Carlos, 6627 – 31.270-901 – Belo Horizonte, MG - Brasil
pinotti@demec.ufmg.br

Abstract. *Different types of neurological injuries affect a patients walking ability. Rehabilitation Engineering provides equipment and devices to aid these patients to recover the lost movements or to improve their quality of life. The aim of the present study was to develop equipment to assist the lower limb movements for patients with a physical deficiency. An exoskeleton was designed which consists of a hip orthosis equipped with pneumatic artificial muscles. The orthosis was moulded for a patient who had motor deficiency as a result of Poliomielitis. The kinematics and dynamics of the hip and the lower limb were studied to determine the force produced by the artificial muscles in the initial and final positions of the patient's lower limb during walking. A control system for the pneumatic muscle using the remaining myoelectrics signal of the patient's muscle was developed. This signal was obtained by two electrodes and modulated to make the pneumatic muscle control. The exoskeleton reported here has shown to be capable of assisting the hip flexion movement.*

Keywords*: Bioengineering, Rehabilitation, Exoskeleton, Orthosis, Pneumatic Artificial Muscle*

1. Introduction

By using biomechanical analysis, mathematical calculations and kinesiological assessment, it is possible to analyze the force effect, the acceleration and the speed during the human movement and to study the locomotion system's behavior (HALL, 1991). Recent studies show the possibility to reproduce muscle function by employing different systems (pneumatic, hydraulic or electric). The McKibben artificial muscle (Chou and Hannaford, 1996) is a pneumatic system, which can be used to reproduce this function.

The aim of the present work is to develop a hip orthosis using pneumatic artificial muscles.

2. Methods

Pneumatic artificial muscles were developed in the Bioengineering Laboratory at Federal University of Minas Gerias (NAGEM, 2002). These muscles consist of an internal latex bladder surrounded by a braided nylon shell that is attached at either end to fittings. When the internal bladder is pressurized, the high pressure gas pushes against its inner surface and against the external shell, and tends to increase its volume. Due to the braided nylon shell properties, the muscle shortens according to its volume increase and, if it is coupled to a mechanical load, produces tension. The pneumatic muscle employed in the orthosis is shown in Figure 1.

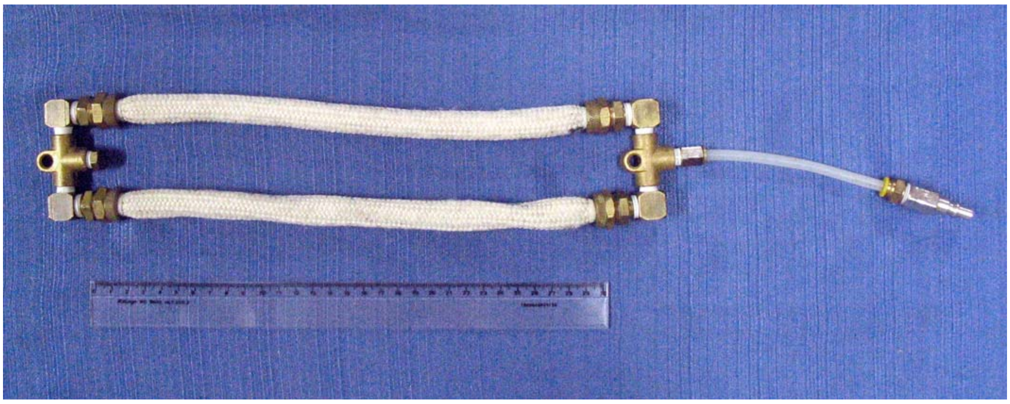

Figure 1 – Pneumatic artificial muscle.

There is a direct relation between the inner pressure, the decrease in length and the imposed load. As the inner pressure rises the length decreases. On the other hand, an increase in load reduces the decrease in length. Figure 2 illustrates a force test for an artificial muscle with diameter 15 mm and length 300 mm. In the test, this muscle was submitted to different loads levels (0 - 200 N), different feeding pressure (0 - 7 Bar) and the decrease in length measured for all the tests.

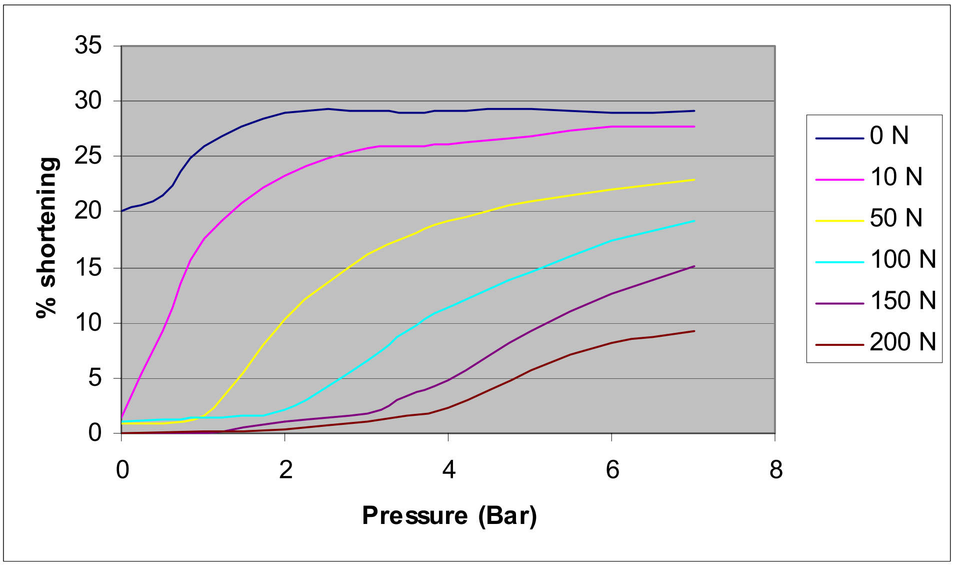

Figure 2 – Shortening percentage characteristics of the artificial muscle in function of the feeding pressure and of the imposed load.

A hip orthosis equipped with pneumatic artificial muscles (Exoskeleton) was designed for a patient with Poliomielitis sequels. Figure 3 illustrates the description of the orthosis.

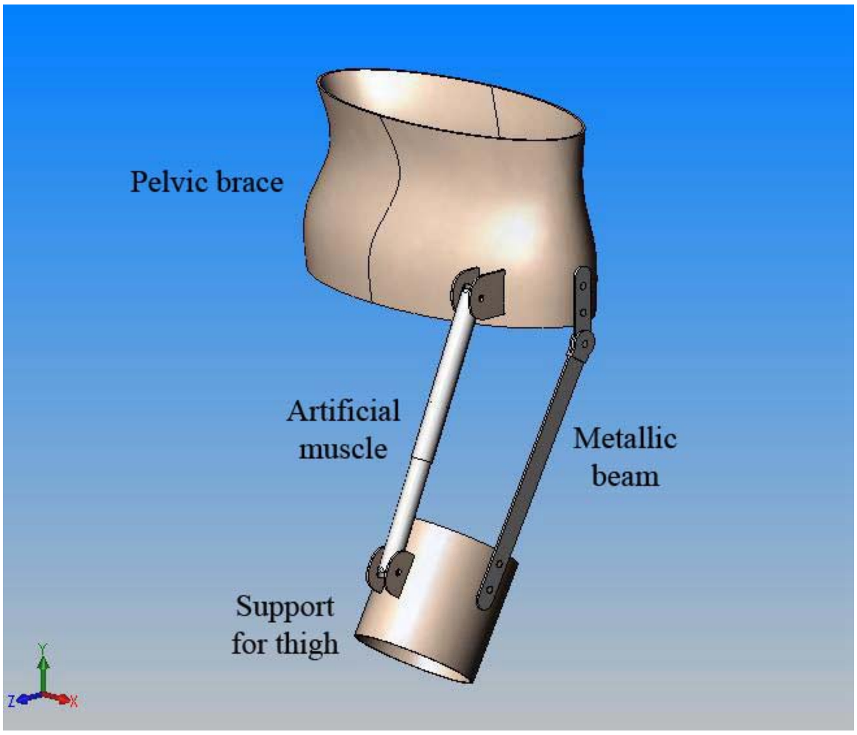

Figure 3 – Project of the orthosis parts with the artificial muscle (Exoskeleton).

The orthosis is composed by a polyethylene pelvic hamper and a polyethylene support for thigh. The pelvic brace, with a bulkhead on the iliac crest, uses the hip to provide stability and must be made in two parts. The front part that involves the region from the xifoide appendix to the upper pubic region and the rear part that involves the region from the thoracic back end until the gluteus maximum. These parts are joined laterally by Velcro ribbons.

The pelvic brace and the support for thigh are connected by a vertical articulated beam. This beam must have a constraint to prevent hip hyper-extension and must be fixed on two points in both extremities, to give rigidity and to prevent rotation on the attachment point. It is manufactured using an aluminum alloy. Figure 4 illustrates the orthosis in exploded view.

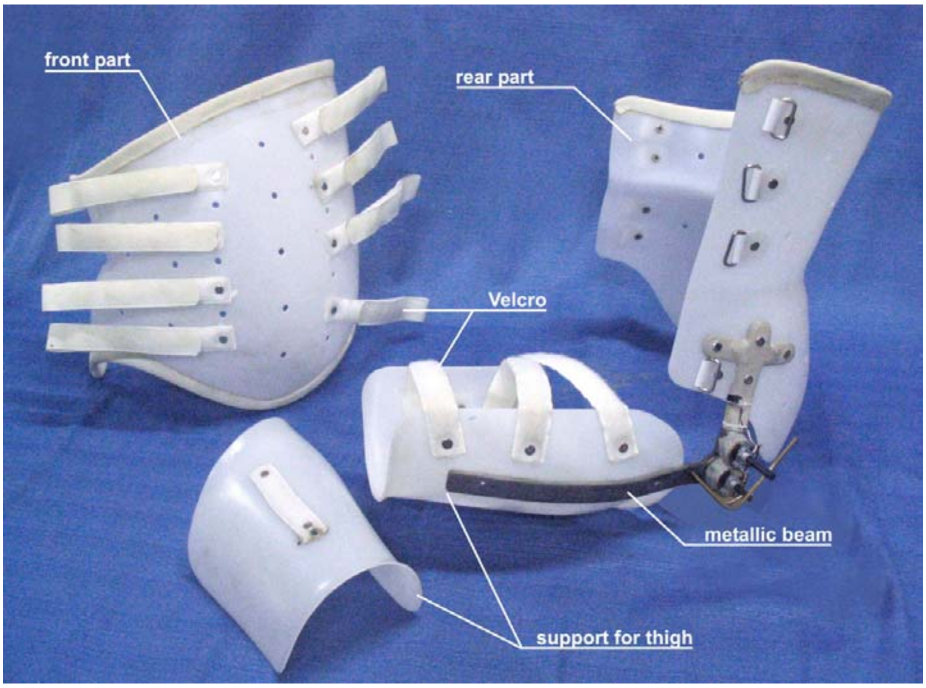

Figure 4 – Exploded view of orthosis.

Kinematic and dynamic calculations had been executed to make possible the exoskeleton movements simulation as a robotic mechanism, and to analyze the artificial muscle position in the orthosis.

An electronic system was implemented to control the pneumatic muscle activation. This system uses the remaining myoelectric signal of the patient's muscle. This signal is collected by amplified electrodes, which detect the potential difference existing between its terminals, when the muscle is activated. This signal is sent to a differential amplifier with a high value of CMRR (Common Mode Rejection Ratio). Then, the remaining signal is submitted to a low pass filter (Nilson and Riedel, 1999) with cut frequency of 500 Hz, because the signals with higher frequencies do not represent myoelectric signals.

After that, the signal is submitted to a new amplification, which is adjusted in accordance with the patient's needs. Then, the signal is demodulated and transformed by a tension comparator into a binary signal (Sedra and Smith, 2000), where binary logic 1 (10 Volts) means "muscle contraction" and binary logic 0 (0 Volts) means "muscle relaxation". Figure 5 illustrates the effect of the modulator and the comparator in the analyzed signal.

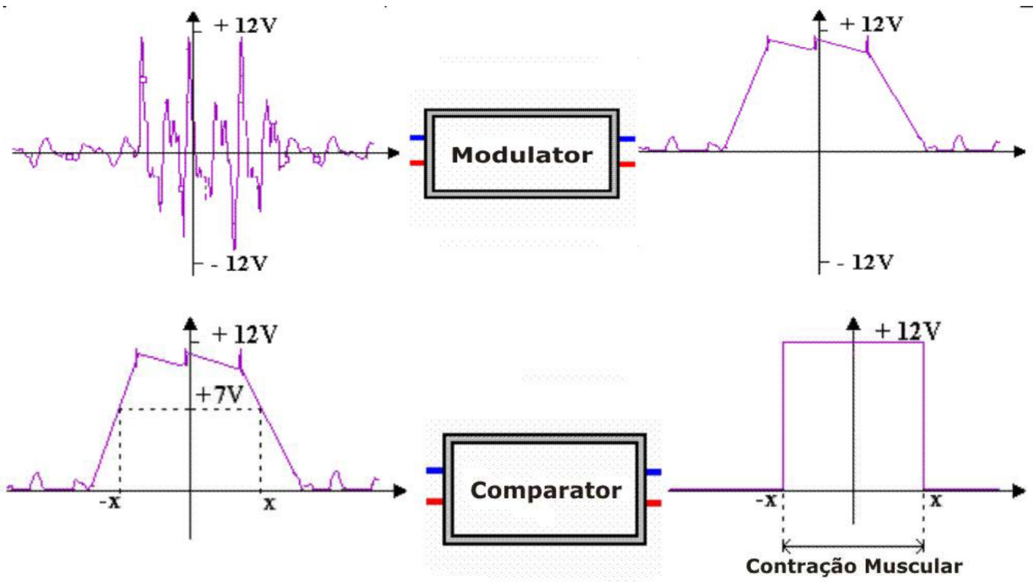

Figure 5 –Myoelectric signal Treatment.

As the power of the myoelectric signal is very low (microwatts), the exiting signal must be amplified by a Darlington amplifier (Sedra and Smith, 2000), for be capable to activate the pneumatic valve that controls the artificial muscle. Figure 6 represents the block diagrams of the electronic circuit that controls the muscle.

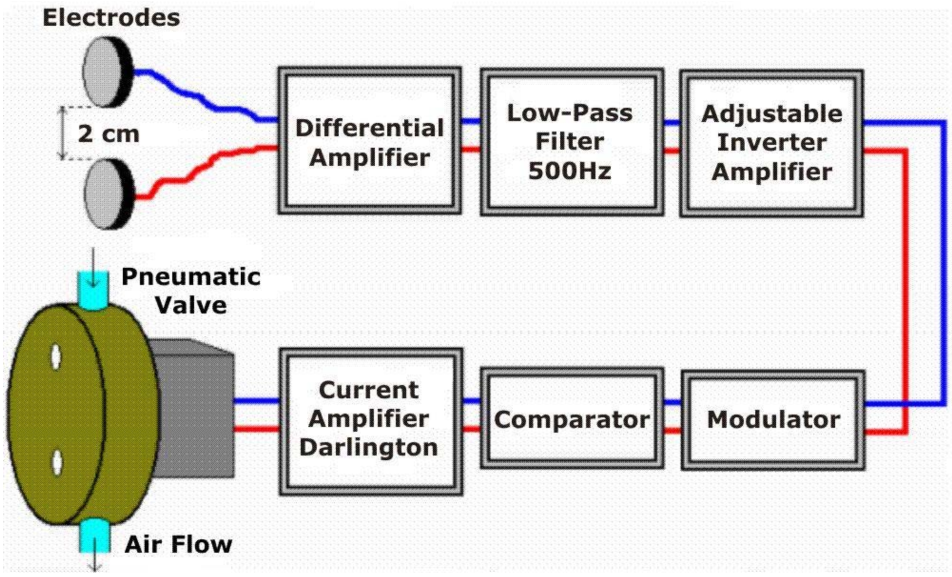

Figure 6 – Blocks Diagram of the electronic circuit.

This control system gives the orthosis a more functional actuation pattern, improving the patient's motion capacity.

3. Results and Discussion

By performing the kinematic calculations, the general transformation matrix could be determined (Equations 1 to 4), making it possible to analyze the exoskeleton position during the gait, by using the joint (hip, knee and ankle) angle values (CRAIG, 1995).

Several parameters were determined by dynamic calculations (inertia coefficients, Coriolis force, centrifugal force, disturbance and gravity terms) which permits the gait movement model construction (CRAIG, 1995).

After application of the muscles, the force produced in the initial and final positions of the patient's lower limb during walking was assessed. For the initial position (Fig. 7) the muscle force required to raise the limb from the floor was 151.5 N.

$$\sum M = 0 \therefore (m \cdot g \cdot sen20^{o}) \cdot x_t - (Fm \cdot sen14^{o}) \cdot x_t = 0 \tag{1}$$

$$F_m = \frac{(10.92 \cdot 9.81 \cdot sen20^{o})}{sen14^{o}} = 151.5N \tag{2}$$

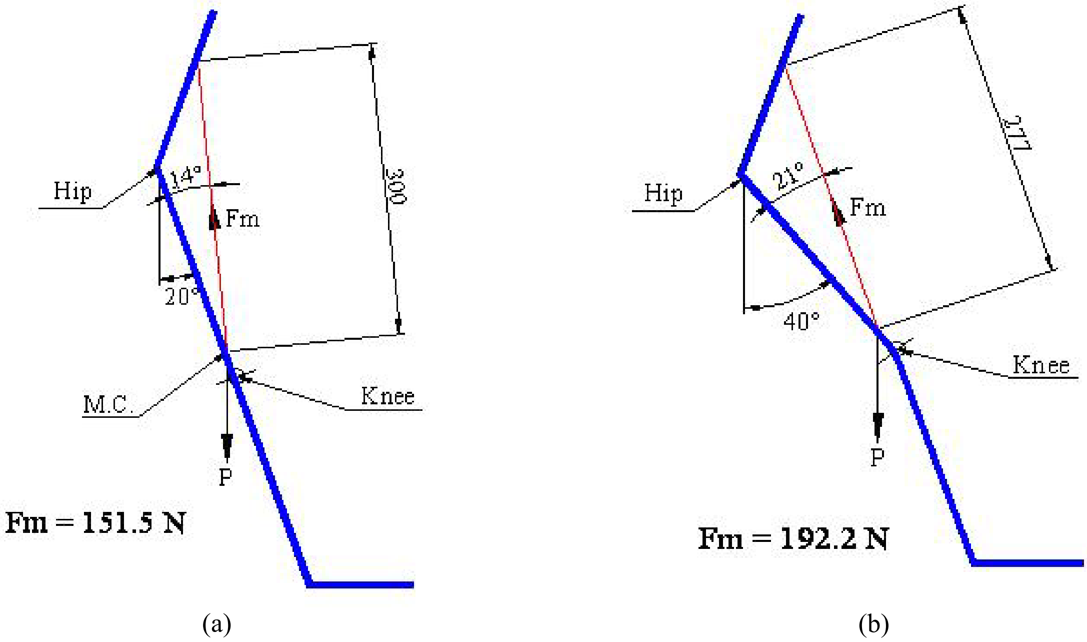

Figure 7 – (a) Initial position of flexion hip in the patient’s gait, (b) Maximum Position of flexion hip in the patient’s gait.

In the final position (Fig. 7b), the muscle force required was 192.2 N.

$$\sum M = 0 \therefore (m \cdot g \cdot sen40^{o}) \cdot x_t - (Fm \cdot sen21^{o}) \cdot x_t = 0 \tag{3}$$

$$F_m = \frac{(10.92 \cdot 9.81 \cdot sen40^{o})}{sen21^{o}} = 192.2N \tag{4}$$

Two artificial muscles working in parallel configuration had been used for the orthosis (Fig. 1). Each muscle was responsible to produce the half of the total force. The braided shell used has a diameter of 15 mm and length of 300 mm. As each muscle is capable to raise 200 N, the two muscles together can raise 400 N. Hence, when the critical situation comes, demanding force of 192.2 N, each muscle will produce 96.1 N.

In the initial position, the muscle has a length of 300 mm and in the final position its length falls to 277 mm. This results in a shortening of 23 mm, which is equivalent of 7.7 % of the muscle total length. Observing the Fig. 2, it is seen that the muscle is capable to raise the patient’s lower limb from the floor during the gait. This movement carried by the orthosis has the function to produce a flexion in the patient's hip in a range of 20º. The complete assembly of the exoskeleton is shown in Figure 8.

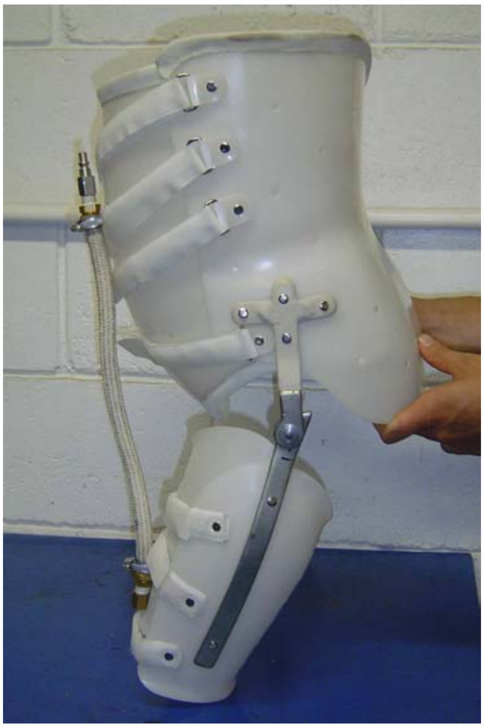

Figure 8 – Final assembly of exoskeleton.

4. Conclusion

The exoskeleton developed could assist in the accomplishment of the hip flexion movement, providing better conditions to develop a standard gait next to the physiological one. The exoskeleton also acts as stabilization mechanism of the trunk and the hip, which could provide greater security for walking activity.

5. Acknowledgements

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7. Responsibility notice