PNEUMATIC MUSCLE ACTUATED EQUIPMENT FOR THE PASSIVE EXERCISING OF INFERIOR LIMB BEARING JOINTS

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Abstract: - Applying passive exercising as part of the recovery programme of patients with post-traumatic disabilities of the bearing joints of the inferior limbs requires the development of new high performance equipment. The paper discusses a study of the kinematics, construction and actuation of a novel, pneumatic muscle actuated rehabilitation system for continuous passive motion. The utilized energy source is compressed air ensuring complete absorption of the end of stroke shocks, thus minimizing user discomfort.

Keywords: - equipment, passive exercising, bearing joints, pneumatic muscle

1. Introduction

The recovery of patients suffering from post-traumatic dysfunctions of the inferior limb bearing joints (Fig. 1) can be achieved by applying *continuous passive* rehabilitation *motions*, that is by *passive exercising*. A full and swift recovery of dysfunctional joints can be obtained by means of equipment specially developed for passive exercising, currently the subject of numerous ongoing researches worldwide.

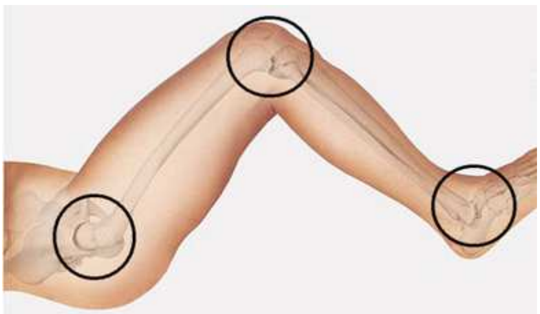

Figure 1. Bearing joints of the inferior limb (hip, knee, ankle)

The paper presents a constructive solution for continuous passive motion equipment, the novelty residing in its actuation by means of pneumatic muscles.

2. Passive exercising

At present, several methods are utilized in order to alleviate the dysfunctions of the bearing joints (hip, knee, ankle), like dynamic kinetic techniques, based on motion in all its forms. Within the category of kinetic techniques, passive exercising is achieved by applying an external force to the disabled limb at the time of total muscle inactivity – determined by illness, or at a time of maximum muscle inactivity – determined voluntarily.

The effects of passive motion are directed at [1]:

- the locomotive apparatus:
  - maintain normal joint amplitudes and the trophicity of joint structures in cases of paralysis of the respective segment;
  - increase joint amplitude by slenderizing of ligament capsule structure and by tendon and muscular extending of the cutaneous and subcutaneous tissue;
  - maintain or even increase muscle excitability (Wekskull's Law: muscle excitability increases with its degree of extension);
  - increases the stretch reflex by passive extension motions of the muscle, that determine muscle contraction;
  - maintain kinaesthetic memory for the respective joint, by means of the proprioceptive information originating from articular and peri-articular receivers
  - prevent or eliminate immobilization related oedema
- the nervous system and psychic tonus:
  - diminishing the psychological negative effects (perception of a severe affection)
- the circulatory apparatus:

- passive motions have the mechanical effect of pumping on small muscle vessels and on the venous and lymphatic return circulation;

- other apparatus and systems:
  - maintain tissue trophicity – from skin to bone – of the immobilized segments;
  - increase gas exchange at lung and tissue level;
  - increase intestinal transit and facilitate the emptying of the urinary bladder.

The following previous information is needed for a correct execution of passive rehabilitation motion degree of patient affection, diagnosis of patient affection based on muscle and articular tests, as well as the morpho-pathological state of the structures to be mobilized.

The main control parameters of passive exercising are the applied force, completed displacement, velocity, acceleration, duration of motion, frequency, all having to be adapted to the clinical state of the patient and the set aim. This entails passive exercising equipment to allow adjustment between certain limits of all parameters enumerated above.

The first concrete modality of passive exercising is traction that can be continuous or discontinuous.

- *Continuous tractions* or continuous extensions are carried out by means of installations with counter-weights, springs, pulleys, inclined planes etc. These are used mostly in orthopaedic units for realignment of the fractured bone or displacements of the articular heads, and in recovery units for corrections of joints blocked and deviated in flexia, extension etc. Control elements are force and duration. Force is estimated based on the magnitude of the segment, the muscle and tissue mass to be stretched, the pain threshold. Duration is variable too, in the range of days.
- *Discontinuous tractions* can be carried out both manually by the kinetic therapist or by means of equipment, in the manner described above. Discontinuous tractions are recommended particularly in the case of joints of reduced mobility that cannot attain anatomic position, and in the case of painful joints with muscle contraction. Joint inflammatory processes can also benefit from such traction with moderate forces, also used for immobilisation.

The manoeuvres carried out as part of passive exercising can vary, the typical ones being small, progressive motion of different amplitudes. The force applied by kinetic therapists at maximum amplitude is usually dosed depending on pain onset, but also based on their experience in the case of patients with exceedingly high or low pain thresholds.

The velocity of motion needs to take into account also the aim of the exercise; thus, slow motion decreases muscle tonus, while rapid motion increases it.

Motion rhythm can be simple, oscillating, 2 or 4-takt, the extension being maintained at the ends of stroke. The duration of one motion is of about 1-2 seconds, the resting time at the end of stroke of about 5 - 15 seconds. A session of passive exercising of a joint lasts for a maximum of 10 minutes, its duration depending on the endurance of the patient. Sessions have to be repeated 2 - 3 times a day.

3. Equipment for passive exercising

Equipment for passive exercising developed to date can be divided into two categories: pluri-articular (multi-joint) devices allowing by means of accessories the testing and rehabilitation of most major joints, and mono-articular (single-joint) devices aimed at a single specific joint. Worldwide such systems have been developed specially designed for knee or ankle recovery, as the one illustrated in figure 2.

The first figure presents a rudimentary constructive variant of passive exercising equipment, actuated manually, where, by means of a lever the patient controls himself motion velocity and amplitude of the affected leg. The next figure presents a modern variant of such equipment, where the patient's leg is strapped into the device, and the unit then moves the leg back and forth in a slow, controlled, continuous pattern to flex and extend the muscle tissue [2].

Figure 2. Variants of passive exercising equipment

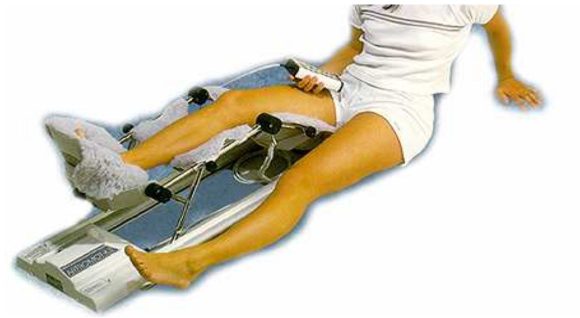

Figure 3. Position of the patient inferior limb in the considered equipment

For the correct deployment of such equipment that patient needs to positioned such as to benefit from maximum comfort. Preferably the segment to be subjected to passive exercising should be uncovered (clothing removed) (figure 3).

All equipment required for passive exercising currently available on the market place are driven by electric motors with a rigid linkage structure. The prices of such equipment are high, in the range of thousands of Euros, often exceeding the financial possibilities of the potential users.

The carried out research yielded the idea of conceiving pneumatic muscle actuated isokinetic equipment for the continuous passive motion of bearing joints, at a final cost below the current offers available on the market place.

4. Proposed constructive solution

The equipment for passive exercising of the inferior limb bearing joints developed in the Laboratory of Fluid Drives and Automation at the Transilvania University of Braşov, Romania, utilizes pneumatic muscles as means of actuation [3]. One of the most attractive aspects of pneumatic actuation is the low weight of the utilized components, and implicitly their favourable response to commands. Favourable response to commands, known as compliance is due to air compressibility, and hence can be influenced by controlling/adjusting the command pressure. Compliance is an important property concerning the man - machine relationship, as well as the completion of operations of high sensitivity, like the handling of fragile objects. Compliance ensures a soft contact as well as the safety of the human individual interacting with the working equipment.

Thus, the development of light, pneumatic muscle actuated rehabilitation equipment represent a solution worth exploring, given its potential of yielding high performance kinetic-therapeutic systems.

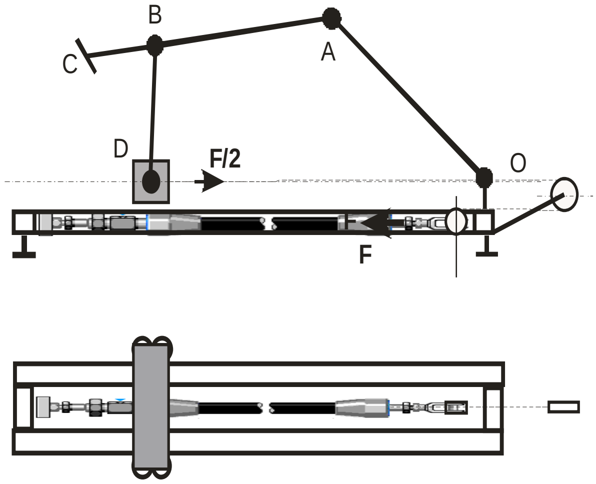

Figure 4. Kinematic diagram of the equipment

The kinematic diagram of such equipment is presented in figure 4.

The required stroke of the sliding block is of 300 mm. 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). A mobile pulley was placed between the muscle and the sliding block in order to amplify the sliding block stroke to the required value (Fig. 5).

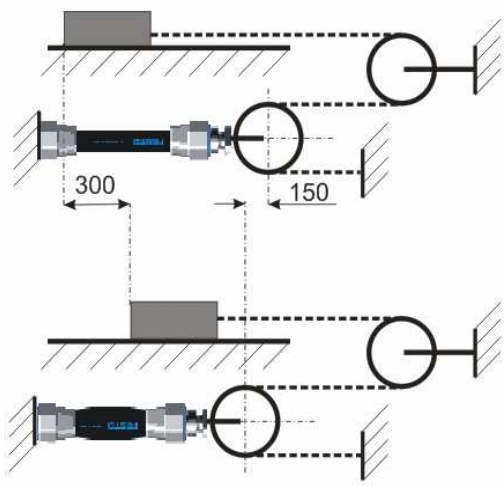

Figure 5. Amplification system of the sliding block stroke

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

Figure 6 presents the construction of the rehabilitation equipment.

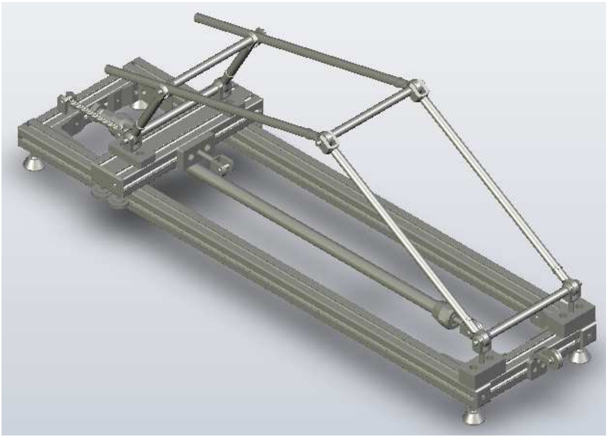

Figure 6. Construction of the rehabilitation equipment

The pneumatic control of the equipment allows the programming of the stroke length, the velocity of the motion, the number of cycles to be carried out, as well as of the maintaining time of the leg at the ends of the stroke. The pneumatic actuation diagram is presented in figure 7.

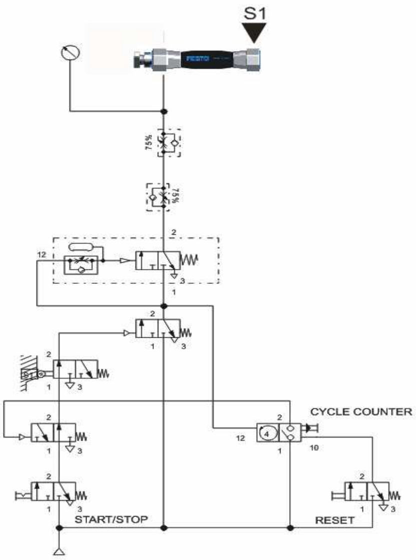

Figure 7. Pneumatic actuation diagram

It can be observed that the velocity of the pneumatic muscle free end is adjustable in both directions of the motion, thus allowing rehabilitation of joints in various stages of healing. Further, at the right hand end of muscle stroke (completely relaxed leg), adjustable delay of the motion is achievable, thus preventing overstraining of the patient.

The equipment allows the programming of single or multiple cycles of exercises, depending on the degree of recovery of the affected joints.

The magnitude of the force straining the dysfunctional leg can be easily adjusted by charging the muscle with a pressure varying between 3 and 8 bar.

Deployment of the equipment is extremely simple. In order to start the rehabilitation exercise the patient programmes the number of desired double strokes from the cycle counter and presses the START/STOP button.

5. Conclusions

The proposed rehabilitation equipment benefits from a cost efficient, simple and robust construction, being easy to use by persons affected by dysfunctions of the bearing joints. Another major advantage of the proposed system is the utilized as source of energy, namely air that completely absorbs all shocks occurring at the ends of the stroke. The current, electro-mechanically actuated rehabilitation systems introduce shocks upon reversion of the sense of motion, thus causing discomfort to the user.

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