Building a continuous passive mobilization machine (CPM) for the inferior limb recuperation

M G Statache[1], E Vultur[1] and C N Drugă[1]

[1]Product Design, Mechatronics and Environment Department, "Transilvania" University of Brasov, Brasov, Romania

madalina.statache@student.unitbv.ro

Abstract. This paper is presenting the projection and realization of a passive mobilization device (CPM), used for rehabilitate lower knee articulation conditions, such as post-traumatic conditions, degenerative, ligamento-plastic chirurgical interventions, meniscectomy and in special patients who have had been under knee prosthesis chirurgical interventions, this one being the one which causes the biggest issues in the rehabilitation process. Also, in this paper are figured the main steps which are followed throughout the building process of a Low-Cost functional prototype and its way of function.

1. Introduction

Most of the rehabilitation treatments start with the result of the passive mobilization of the affected segments, this one having as purpose to reduce the appearing swelling, reducing pain through special methods, called neuro proprioceptive facilitated methods, keeping the kinesthetic memory and the last but not least growing the movement amplitude at the affected articulation level.

The next steps in the rehabilitation treatment are the muscle force grow at the affected muscle level, coordination recovery, motor system control, balance, muscular resistance growth, skill reset, sensitiveness reset, increase capacity of effort etc. Of course, the rehabilitation objectives and the therapeutical condition are stated depending on many factors like the condition that the patient is suffering, the status of the injury, the severity degree, general patient status, the contraindications to some rehabilitation procedures etc. In this paper we are going to focus on the objectives which are made possible thanks to the articulated passive mobilization, and on its benefits, and especially about the continuous passive mobilization occurred trough medical machines [1],[2],[3].

The Continuous Passive Movement (CPM) devices, are medical devices which are being used to perform a continuous passive movement of the treated articulation, the movement being generated by an external force, with the objective of sustaining and growing the movement amplitude at the affected articulation level, where the mobility is limited. The method is being used on a large scale thanks to the positive clinical experience and its benefits observed by the medics, therapists and patients [4].

2. Material and Method

To build a CPM device was made possible by using mechanical components, electrical and electronical which are available on the market, the final purpose being the completion of a functional prototype, well calibrated for recovering from knee affections, easy to use by the therapist or patient, reliable, qualitative from a construction point of view and with a small production cost. Having in count that the

anthropometry dimensions are different from individual to another (Specially the one from the lower limbs and the bone segment components), the metal support was built with the option of length adjust of the two main segments (thigh and leg) so it could be used for a large number of patients.

2.1. Functioning principle of CPM device

The CPM devise is powered to the 230V network and started through the ON button (figure 1).

The input elements (Amplitude, Speed, Acceleration) will be introduced through the integrated keyboard of the controller, also with the help of the limit switches, this one performing among others the role of regulating of the amplitude of movement realized by the CPM device. The controller will take the input elements, displaying them on the integrated screen and sending them at the same time to the motor driver. The motor driver will command the stepper motor (SM), controlling its direction and the rotation speed. The stepper motor will train the linear platform, which at its time will move the articulated support, making a complete movement happen. The limit switches, besides amplitude regulation, in the moment when they will be executed on the linear platform, will send a feedback to the controller, to command the motor work in the opposite way (figure 1).

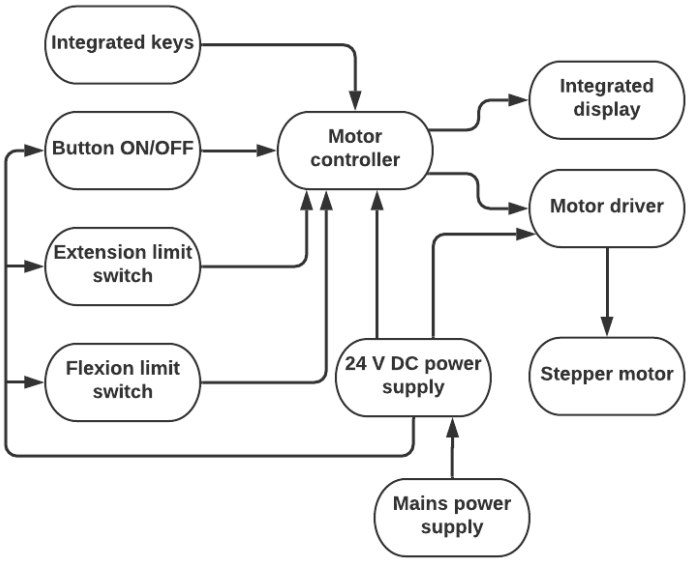

Figure 1. CPM device block diagram.

2.2. Choosing the materials and the components

The base materials and components were chosen to fulfill the tasks planned for constructing and the well performing of the prototype. These were chosen and acquired after an analysis of the different producer and trader offers, the most important criteria was the value for money of the different components.

2.2.1. Motor controller. For the proposed application, the controller has the command unit and control purpose of the continuous passive mobilization device, this one will be the ”brain” of the system. This will take the data imputed through the keyboard, will read the data coming from the two limit switches and transmit the order of movement to the motor through the motor driver [4].

The chosen Controller for the accomplishment of this project is one for the stepper motor, from Fuyu (figure 2), with a screw linear platform, this one having the capacity to control systems formed with only one movement axis, as the CPM are as well. The controller has as a component an ARM Cortex-M0 processor, having as a possibility the control of speed and distance covered on the engine platform. The previous mentioned comes as a part with a remote control (figure 2) which can set the motor speed and can stop it at any time. The remote control would be used as a safety system by the patient, having

the option to stop the system whenever would appear an above the normal level pain or any other issue related to the therapy or device.

This controller has within its components a display (figure 2) where the system function parameters and the values set by the user will be shown.

Besides the display we will find also 5 buttons through which the user will introduce the data necessary to perform the therapy with the CPM device.

Figure 2. Fuyu Controller [5].

2.2.2 Motor Driver. The motor driver chosen for this purpose comes from the same range of Fuyu products as the Controller and the Engine, having the name Nema 23-Driver for SM, FMDD50D40NOM (figure 3). It is a two phases driver based on DSP control. It comes with twelve contacts with whom the electric circuit necessary for the device functionality works.

Figure 3. Motor Driver Nema 23 [6].

2.2.3 Stepper motor with linear platform. Around CPM, the motor performs the main role, creating the power which makes possible the movement of the mobile elements, achieving on a knee level a Flexion-Extension movement. The movement happens on a maximum amplitude lapse set by the two limit switches [4].

The motor chosen to accomplish the project is also Fuyu built, therefore being a SM, with a linear platform working along with a ball screw system (figure 4). To satisfy the CPM type of devices demanded requirements, regarding the movement amplitude where it will be executing its way, the length of the screw where the platform with the articulated support has to be long enough (In this case is about 900mm).

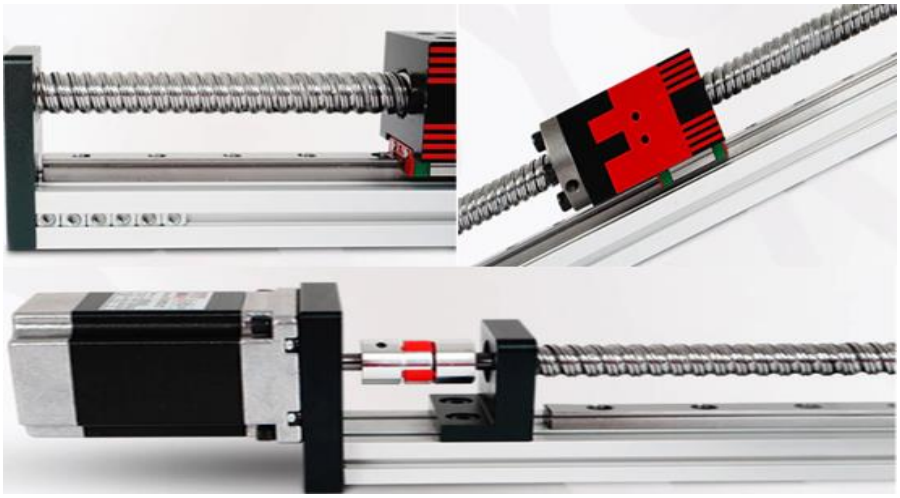

Figure 4. Stepper motor with linear platform [7].

2.2.4 Limit Switch. The device can execute a flexion-extension movement until the maximum set length. This limit switches (figure 5) are frequently used within the linear gliding systems and also as a stop-indicators which stop the engine when engaged. Functionally speaking it is really simple, the switches send a digital feedback, 0 when is not pressed and 1 when it is pressed.

For a correct functioning of the device, the switches must be mounted on the device at the maximum flexion-extension spots. Also for the completed prototype, the switches also accomplish an extremely important role for the correct functioning of the device, which is the movement amplitude regulation. The two switches will be mounted on a sliding support giving the option to move the switch on a scaled band until the desired movement amplitude having in count the patient needs. The movement amplitude regulation is one of the most essential characteristics of the CPM device.

Figure 5. Limit Switch [8].

2.2.5 CC Power Supply. The power supply was chosen so it would satisfy the system requirements, therefore it is a power supply which transforms the network 230V AC into small voltage energy with 24V, having three exits so it can supply all components.

2.2.6 Articulated metal support. To transmit the movement to the patients lower limb, he has to be placed on an articulated metal support. The support articulations at the knee level executes the flexion-extension of the knee articulation, and the articulations at the hip level executes the flexion-extension movement of the hip.

To be functional, the support has to fulfill the following requirements:

- Stability – For a safe and an adequate therapy process.
- Resistance – It must resist to the therapy demands.
- Mobility – The articulations must cover the movement amplitude of the knee's articulation.

- Adjustable size – So it can be used to different patients with a different anthropometric size, the length of the support segments must be adjustable.

Used materials:

- Round pipe made of laminated steel with a 16mm diameter and 1m length;
- Round steel bar with a 16mm diameter and 1m length;
- Round steel bar with a 14mm diameter and a 1m length;
- Steel sheet, polished made of zinc iron 300x1000x0,75mm.

2.3. The device building and assembly

The first step to build the CPM device was to create the device's design, specially the one of the articulated support (figure 6), the element which holds the lower limb and prints the movement to it. The device follows the general design of the actual models of the market.

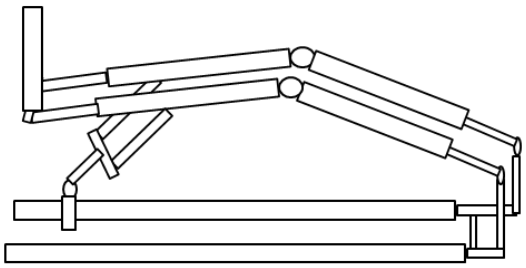

Figure 6. Device's Design.

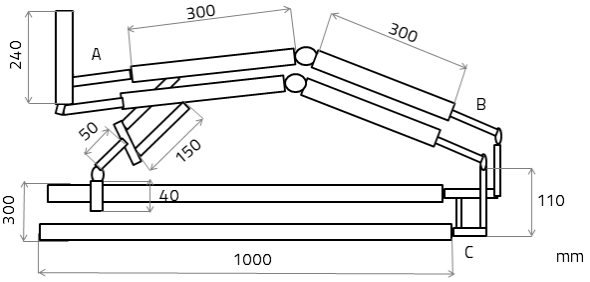

Figure 7. Sketch quotation.

To measure the size of the device's support was used an algorithm to calculate the anthropometric sizes from woman and men. Therefore the sizes of the segments from the support for different size individual were determined.

The calculus formulas for this sizes are the following:

- Leg: (0,246H) for men, (0,244H) for woman;
- Hip: (0,245H) for men, (0,248H) for woman, where H represents the height of the individuals.

After the calculus, the Sketch quotation was determined and the figure 7 support was created.

2.3.1. Articulated support assembly. To assembly the articulated support there used the previous mentioned materials which were manipulated through cutting to reach the required size. The articulations were made out of 16 mm diameter steel bar, being manipulated through turning and milling (figure 8) In the next phase al the articulated segments were assembled, the articulations were introduced and welded at their ends (figure 9).

Figure 8. Articulation creation.

Figure 9. Articulated segment assembly**.**

The next step was to mount the motor and the linear platform on the steel sheet with the 300x1000mm dimension, this represents the lower part of the device where all other elements will be mounted (figure 10). After fixing the engine in place, the support elements previously manipulated were welded following the chosen design (figure 11).

Figure 10. Mounting the motor and linear platform.

Figure 11. Welding the support.

The next step was building the leg fixing support and welding it on the articulated support (figure 12).

Figure 12. Leg fixing support.

2.3.2 Assembling the electrical components. To mount the control and command components, there was performed an extension of the device's chassis, this extension was mounted on a Plexiglas with 240 x 300 x 15mm dimensions (figure 13).

Figure 13. Assembling the electrical components on a Plexiglas sheet.

Limit switches were mounted on the lateral part of the linear platform, in order to perform the role of setting the minimum and maximum limits of the movement amplitude of the articulated support and implicitly of the knee (figure 14).

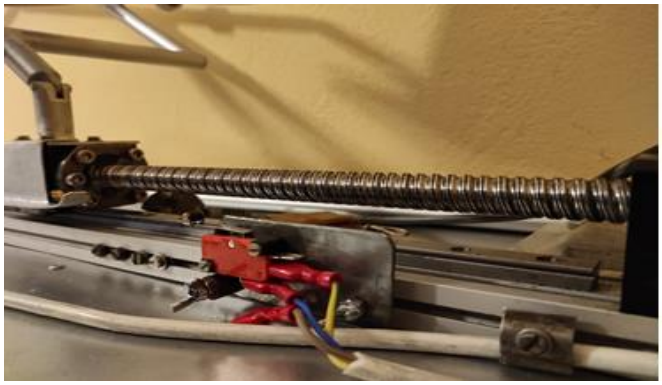

Figure 14. Mounting the limit switches.

4. Conclusions

At the moment, the passive continuous movement devices are being used on a large scale in rehabilitation sections, kinesiotherapy clinics, at the patients home and also at the orthopedic sections, surgery, neurosurgery, neurology. Using this passive continuous movement devices is essential to accelerate the rehabilitation process of the patient and reintegrating it in the social life on one hand, and on the other hand eases the work of the medical personal from the rehabilitation sections.

Therefore this low-cost built device is capable to fulfill the necessary functions to recuperate from a variety of articulation conditions at the knee level, to execute the flexion-extension movement that the knee articulation performs on a bigger movement amplitude and fulfill extra functions such as regulating the speed and amplitude. Therefore, it is easy to use by the therapist and patient and it can me easily manipulated fulfilling the size and weight requirements.

The CPM system can by also used for a didactic purpose in the Medical Engineering lab (Environment and Product Design Faculty) and by: Construction and Maintenance of medical devices and prothesis engineering or by the Kinesiotherapy specialized students from the Faculty of Medicine from the Transilvania University from Brașov.

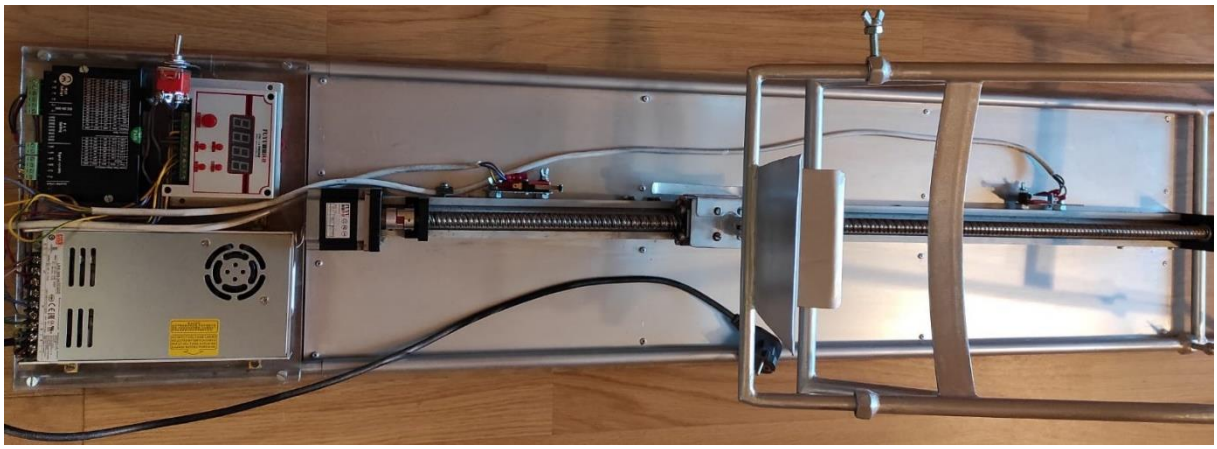

Figure 15. The final result of the CPM device.

Acknowledgements

Practical realization of this project was made possible thanks to funding received in the ***My License Project-2021*** competition held in the Transilvania University of Brasov.

References

[1] V. Papilian and V. Albu, *Human Anatomy* (*Anatomia omului), Vol I*. ALL, 1998.

[2] C. Costache and D. Costache, *Anatomy course notes* (*Anatomie note de curs)*. Universitatea Transilvania Brasov, 2015

[3] I. A. Tatulea, C. Druga, and I. Serban, "Multicriteria analysis of medical devices for passive recovery of the upper limb" (Analiza multicriterială a dispozitivelor medicale de recuperare pasivă a membrului superior) no. April, 2020, [Online]. Available: https://www.researchgate.net/publication/344171697_Analiza_multicriteriala_a_dispozitivelor_medicale_de_recuperare_pasiva_a_membrului_superior.

[4] P. Erin and S. Robert, "Control system design for a continuous passive motion machine," *ISSN 2502-3632 ISSN 2356-0304 J. Online Int. Nas. Vol. 7 No.1, Januari – Juni 2019 Univ. 17 Agustus 1945 Jakarta*, vol. 53, no. 9, pp. 1689–1699, 2019, [Online]. Available: www.journal.uta45jakarta.ac.id.

[5] "FUYU Ball Screw Linear Guide Actuator Stepper Motor Controller for Industrial Single Axis Pulse Controller[Basic Version]|Motor Controller| - AliExpress." https://www.aliexpress.com/item/4001084967585.html (accessed January 06, 2021).

[6] "Nema23 stepper motor driver for FLS40 FUYU linear motion guide|stepper motor driver|motor drivermotor stepper driver - AliExpress." https://www.aliexpress.com/item/32589549569.html (accessed April 15, 2021).

[7] "Mini Linear Guide Slide Rail CNC Small Stage Actuator Screw Lead Motion Table System Nema 14 Robot Part Motorzied Stepper Motor|Linear Guides| - AliExpress." https://www.aliexpress.com/item/33005212720.html (accessed March 20, 2021).

[8] "The micro switch, Push Button SPDT Momentary Snap Action Limit switch, travel switch|Switches| - AliExpress." https://www.aliexpress.com/item/1005001537363013.html (accessed March 20, 2021).