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Model of a Knee Rehabilitation Device. Experimental Data

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***Abstract**: Widely spread knee joint rehabilitation devices use parameters, such as knee flex angle and speed. The presented model in this article can not only work in that modes, but also optimizes the rehabilitation process, through measuring patients' individual pain perception. Listed are the main components, the algorithm, and the way the device works, also is presented experimental data.*

Keywords: *rehabilitation, knee joint, management, experimental data*

1. Introduction

In the field of medicine, often some injuries require patients' knee joint immobilization for some time. That leads to concrescences of the knee joint, so that normal activity is impeded and the patient is no longer able to flex his leg to normal levels. The purpose of rehabilitation is that the patient is able to regain his normal knee joint flex angle – which is more than 135 degrees.

Rehabilitation process is carried out by a rehabilitation therapist, who by hand flexes patient's knee so it may be able to regain normal flex angle. Rate of recovery depends mostly of the pain threshold of the patient, which is highly subjective criteria.

There are different devices used in the field of medicine. Generally are two types of rehabilitation devices – passive and active. Passive devices are mechanical system which is powered by patient's effort. The group of active (fig.1), are those which are powered by special motor.

Fig. 1. Active rehabilitation device for a leg “Atromot”

There are also devices [2-5] (fig. 2) that use data from different sensors such as speed sensor, force sensor and position sensors. This type of devices often use PC connection, so data can be processed exactly like necessary in every single moment.

Fig.2. Robotized device for rehabilitation LEG-100

That kind of devices are still in process, testing in lab conditions and are not widely spread in clinical conditions.

Devices that are often used in the field of medicine have options like fixed target angle, and speed of movement.

The purpose of the development in this article is that a device is made, so it can combine all traditional methods of rehabilitation, but also to implement the subjective patients’ perception of pain. The device have to be easy to use, so you don’t need any medical knowledge to use it. Also it must guarantee patients’ safety.

2. Realization of a model of the device for rehabilitation of a knee joint

The model of the device for rehabilitation of a knee joint is an electro-mechanical system, which is consistent of two modules – electronic control module (fig.3) and a scale module of the mechanical system (fig.4). It is powered by a stepper motor.

Fig. 3. Front panel of the electronic control module

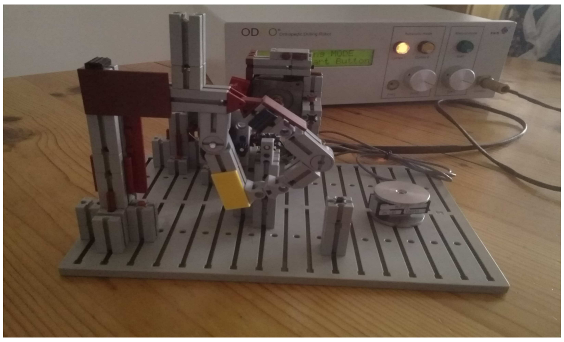

Fig. 4. Scale module of the mechanical system

The scaled model is designed by a specialized constructor for easy realization of a test project. It is suitable for the purpose of this project to use a stepper motor, because that motor offers number of advantages.

Main components of the scale model are – stepper motor CDX1, force sensor MLP-25, LDC AC202BYILY-H, buttons, electronic control module ECM (up to 3 axis of motion) Trinamic Motion Control Module TMCM – 351.

Some of the components of the system, such as – LDC, ECM, buttons and power supply are positioned in a suitable housing (fig.3). It is connected with the scaled model via 10 pin cable and PC10 connectors.

ECM supports 64 microsteps a turn, which combined with 200 steps a turn of the stepper motor, lead to 35 microsteps a 1^0 of movement of the stepper motor. There is also 6:1 gear ratio connected to the rotor of the stepper motor, so it all sums up to 210 microsteps to a 1^0 of motion of the scaled model.

Resolution of the force sensor is 0.2 N per 1 unit of the ECM, so a speed of 1^0/sec (210 microstep/s) transfers to 20 speed units. The speed can be set through a range of 0-2047.

3. Software management

The software management is based on the special Trinamic Motion Control Language (TMCL).

PC - TMCL-IDE specialized software [6] is used for programming, debugging and downloading to ECM.

During Power On, the software is performing a “Self Test”, all systems are being checked for normal functioning. After the check is completed, there are three main cycles of operation: parameters set option, Automatic Mode and Training Mode.

3.1. Mode selection

The choice of the desired mode is selected by the „Mode” button. Other options such as flex angle, start angle and flex speed are available to set by an encoder (fig.5). Corresponding information is displayed on the LCD. The choice of the required mode and parameters in the ECM is done in cycle. Leaving this cycle is done by the „Confirm” Button.

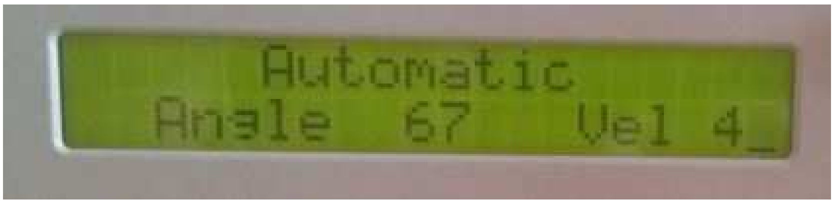

Fig. 5. Choice of a work mode and parameters

3.2. „Automatic Mode”

Automatic mode requires a selection of a desired flex angle of the knee joint and flex speed, so the mechanical system does the rest by itself. Confirmation of all the desired parameters is done by the „Start” button. The mechanical system finds it’s Reference Position and starts moving to the preselected desired angle (e.g. 67 degrees) with the corresponding speed. After reaching it’s desired angle, the system goes back to a preselected Back angle as long as the start button is released.

Start button position is monitored during the whole movement of the mechanical system. If depressed, the movement cycle is paused. A status information about current cycles is shown on the LCD (fig.6). The system is brought back to main menu by depressing of the “Confirm” button.

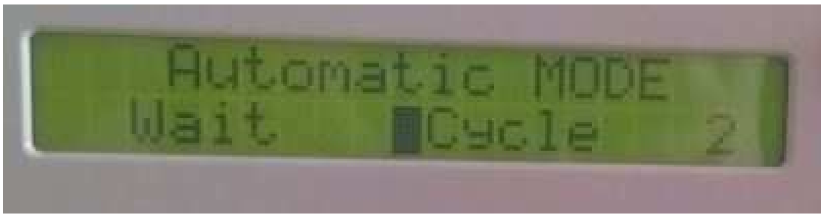

Fig. 6. Status information is shown on the LDC screen when „Automatic Mode” is paused.

3.3.“Training Mode”

A starting angle is required to be set in “Training Mode”, after which the mechanical system will start.

Training mode starts after “Start” button is pressed. Confirmation is brought on the LCD. Next the mechanical system checks back to Reference Position and goes to previously set starting angle. During that movement data from the force sensor is being monitored and stored as a temporary condition. If the patient presses the force sensor by himself, the mechanical system flexes to a further position towards the desired angle. The mechanical system forward steps are preset and depend of the patient's condition and needs. The force sensor's data is monitored again. If the patient presses the force sensor again, the system goes one more step towards the desired angle. Start button condition is monitored permanently, so the motion of the mechanical system can be override and paused. In pause mode an information is brought on the LCD (fig.7). The system is brought back to main menu by depressing of the "Confirm" button.

Fig. 7. Information on the LCD screen when Training mode paused.

4. Self Test

The key to the successful rehabilitation is bound with the normal operation of the different components of the system. That means – the stepper motor, force sensor, buttons and software management. So to make sure every single part of the system is 100% functional there is a Self Test. It is executed after power on and cannot be interrupted manually.

The Self test consists of

- Reliability and functionality of Refference Switch by going to reference position.
- Movement of the mechanical system – going through the working range, a software check of missed microsteps on the way and loading log.

By going through the working range of the system, a reference force value is downloaded in the ECM, so it is considered as a reference point of a normal movement of the mechanical system. It is used if there is any abnormalities or a defect in the mechanical system itself.

During the execution of the self test program instructions are displayed on the LCD (fig.8).

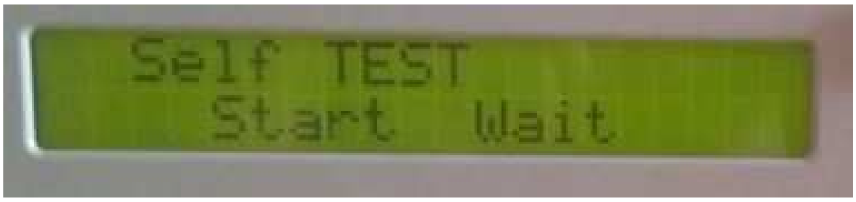

Fig. 8 Information displayed during Self test.

All components are tested to a fixed criteria, if all do not match – self test is failed. If passed, a message is brought on the display (fig.9), and normal operation continue.

Fig. 9. Self test successful (Self Test OK)

If any of the elements fail to match it’s original criteria, a “Self TEST ERR” message is brought on the LCD. An error code is also brought on the screen, so an inspection of that particular element of the system, can easily be performed.

Error code “100” for example, means that during the working range check, missing microsteps are found.

Normal operation could continue only when Self test is passed and the problem is eliminated.

Self test requires some time to test all the systems, so it is performed once on start up. After a successful pass, there is no limit to the number of procedures done by the machine, until it’s powered down.

Self test assures that the machine is fully functional and is in perfect working condition every time. If something is not right, it’s unusable, until the problem is fixed and Self test is passed.

5. Experimental data

5.1. Self Test

During the “Self Test” program, the working range (0^0 – 130^0) is checked at the rate of 7^0/sec, and data from the force sensor is downloaded. (Figure 10); data is cross referenced to a value for normal system operation. A decision is made if the system is operating normally. When the motion is done from the furthest point to the reference point (130^0 – 1^0), the Reff Switch is monitored, so missing steps check is done. 210 microsteps refers to an accuracy of $1^{0.}$

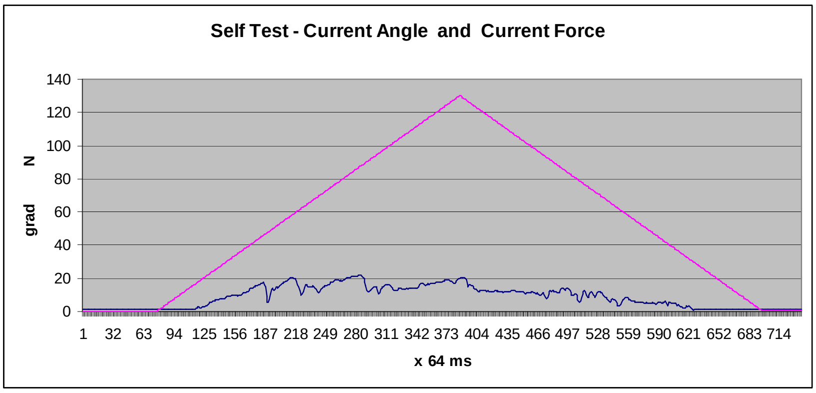

Fig. 10. Force and current angle during"Self Test"

5.2 Automatic Mode

In "Automatic Mode" the device realizes a forward motion until it reaches the previously set flex angle. After the flex angle is reached, the device realizes back motion to a previously set "Back angle". The data from figure 11 corresponds to a flex angle of 60^0 and a "Back angle" of 25^0, Speed is 10^0/sec. During backward motion from 229 to 357 bit, Start button is depressed – system goes in Pause mode. During forward motion from 516 to 555 bit, Start button is depressed again.

System resume happens when Start button is pressed again.

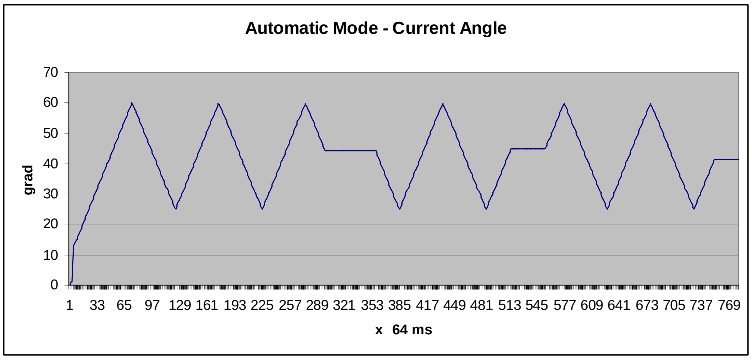

Fig.11. Flex angle variation in "Automatic Mode"

5.3. Training Mode

When working in "Training Mode", the mechanical system positions itself in a previously set "Start Pos" angle. After the "Start Pos" is reached, the force sensor is monitored.

The program reads data from the force sensor and stores it as a stationary condition. Program remains in that state, 1 to 30 bits, until a diversion happens. The diversion is made by the patient through an influence (pressure) onto the force sensor. After an influence is registered, the mechanical system goes to next step (previously set angle of 5^0. On figure 12 – 30 to 110 bit, speed is 1^0/sec.

After moving to a next position, the program reads data from the force sensor again. It stores that values as a current position and waits for pressure again – 150 bit on the graph below. Mechanical system goes to the next postion 150-230 bit on the graph below.

Hysteresis zone is set in the program for the force sensor equal to 3 N. If the registered force is less than 3N, system stays stationary - 230 to 295 bit on the graph below. So a decision is made for going to next position, the redistered force has to be greater than 3N. – 295 bit on the graph below.

The purpose of the hysteresis zone is that an unwanted motion of the system cannot happen. The system can go to a next position (+ 5 degrees of motion) only if the force sensor is pressed by the patient. Data from random force operations over the force sensors is monitored around 420 bit, on the graph below.

Data from the force sensor is not updated when a 5^0 forward motion is realized.

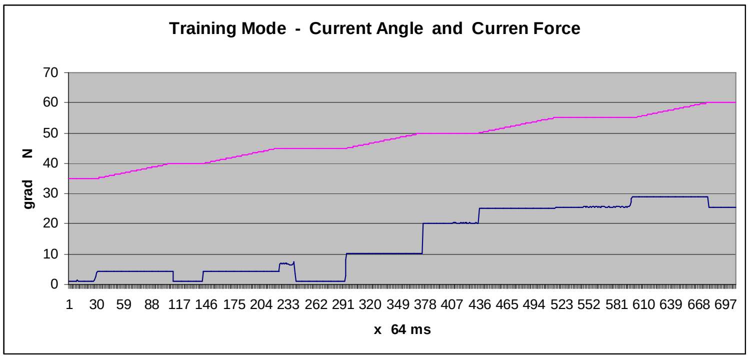

Fig.12. Variation of the force and angle through "Training Mode".

6. Conclusion

A model of a knee rehabilitation device is realized, which operates in two modes:

- Automatic mode
- Traing mode

In automatic mode an angle and speed is set, so the device flexes the knee joint to that angle, with that speed. The number of cycles is defined by the Start/Stop button.

In training mode the patient can define the current flex angle, depending of his rehabilitation state. It is based on individual pain threshold. That assures that knee rehabilitation process could be sped up, by each patient's individual pain perception.

Working with the device is simple enough. There are two buttons and an encoder, so special knowledge is not needed. The specific information, brought on the LCD (number of cycles, speed, angle etc.) makes working with the device and controlling the parameters even easier.

Movement of the mechanical system can only happen when “Start/Stop” button is pressed. Stop happen right away when the button is depressed. In case of electrical hazards, the system cannot go out of control, due to the self test which checks every button’s state.

With that said, the device is under full patient/doctor’s control and cannot do any harm or some kind of traumas. The patients safety is reassured by every means.

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Модель устройства реабилитации коленного сустава. Экспериментальные данные.

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Р е з ю м е

Использованные в практики устройства реабилитации позволяют задать целевого угла, до которого коленный сустав сжимаеться, и задать скорость, с которой механическая система сможет реализовать этот угол. Предуставленны в статье модель устройства реабилитации дает возможность, кроме работы в этого режима, оптимизировать процесс раздвижения, который зависить от индивидуального восприятия боли каждого пациента. Даны основные компоненты устройства, описан и алгорифм его управления и способ работы с моделем. Предоставлены полученные экспериментальные данные.