Application of Stepper Motor for Continuous Passive Motion Splint

V. Sladecek, J. Oplustil, K. Frydrysek, J. Kracmar, R. Fousek, L. Pleva, T. Kubin and O. Ucen

Abstract**—** This article reports about the new design of continuous passive motion splint invented at the VŠB - Technical University of Ostrava, Trauma Centre of The University Hospital in Ostrava and MEDIN a.s. This motion splint is designed for rehabilitation of lower limb, especially for knee rehabilitation. This continuous passive motion splint was designed with possibility to attach it with external fixators. These external fixators are used for treatment of open and complicated bone fractures. Next this article reports about possibility of use and control of stepper motor which is used like a propulsion unit of this continuous passive motion splint.

Keywords**—**continuous passive motion splint, control, design, hybrid actuators, knee, rehabilitation, stepper motor.

I. INTRODUCTION

Von Riemke, in his presidential address to the Danish Surgical Society in 1926, stated that, "All joint affections ... should be moved. Movement should begin on the first day (i.e. after the surgery treatment), should be very slow, and as much as possible it should be continuous.", see [13]. Immobilization of patients is obviously unhealthy for joints and body. If intermittent movement is healthier for both normal and injured joints, then perhaps continuous motion (CM) would be even better. Because of the fatigability of skeletal muscle, and because a patient could not be expected to move his or her own joint constantly, he concluded that for motion to be continuous it would also have to be passive. He also believed that continuous passive motion (CPM) would have an added advantage, namely that if the movement was reasonably slow, it should be possible to apply it immediately after injury or operation without causing the patient undue pain, see [13].

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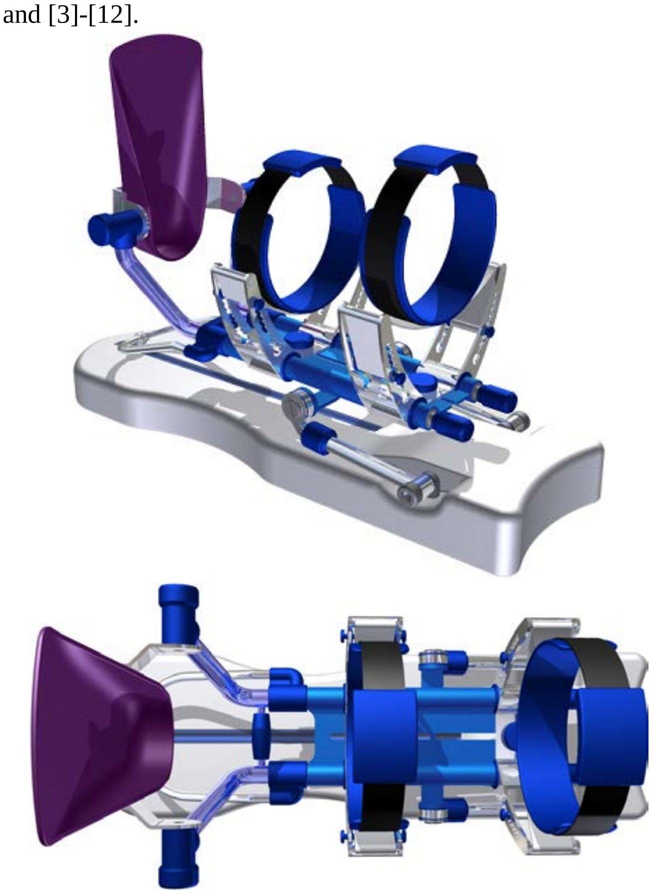
II. New design of motion splint

Any kind of fractures make an important therapeutical problem for their individual and specific character. Hence, our new design of the Continuous Passive Motion Splint (CPM Splint) is intended for lower limb rehabilitation, see Fig. 1. Its applications are mostly in orthopedics and traumatology, see Fig. 2. The difference, compared to existing and competitive designs is especially in the small number of parts, ease of construction and essentially on the possibility to well attach the limb with the external fixator. External fixator (circular or unilateral, see Fig. 2), as a temporary implant placed by surgery on the exterior of limbs, greatly reduces the possibilities of contemporary CPM splints (namely by dimensions). Our design is also a new in that, it directly responds to the needs of proper patients' rehabilitation with external fixators, see Fig. 1, 2 and 3 and references [1], [2], [3] and [3]-[12].



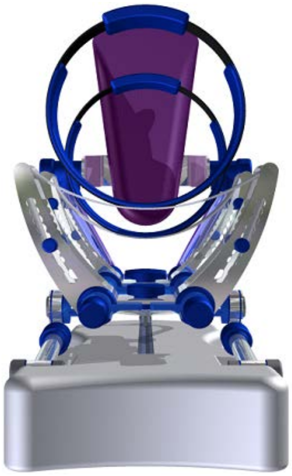


Fig. 1 Our design of the continuous passive motion splint

Fig. 2: Examples of complicated fracture and application of external fixators (after the end of operation, see [6])

Fig. 3 Examples of complicated fracture and application of external fixators (three months after the operation, see [6])

External fixators can be applied in traumatology, surgery and orthopedics for treatments such as open and unstable (complicated) fractures, see Fig. 2, 3 and 4, limb lengthening, deformity correction, consequences of poliomyelitis, foot deformities, hip reconstructions, etc., see [6]-[12].

Fig. 4 Example of complicated fracture

III. Previous Design

In previous time we already worked on continuous passive motion splints. Our previous design was determined for elbow rehabilitation and it has many disadvantages. This CPM splint was directly attached to external fixator, see Fig. 5.

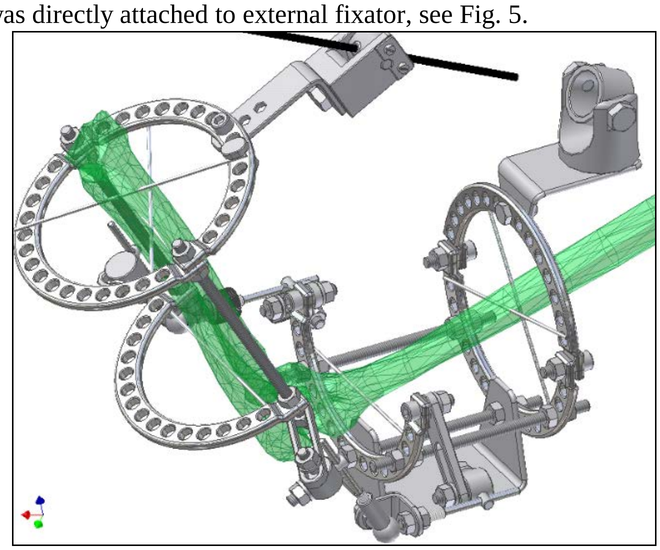


Fig. 5 3D model of previous designed CMP splint

On this prototype, we tested two propulsion units. First one was dc motor. This type of motor caused big current spikes to power source and it was very difficult to keep constant velocity during variable load. That was the strongest reason to use stepper motor like the propulsion unit for continuous passive motion splint.

Fig. 6 Prototype of the designed external fixator with the stepper motor and movement screw with the ball nut

In this first prototype we used driver for stepper motor which was controlled by personal computer. Because of disadvantages that were discovered during development of first prototype we ended development of this type of CPM splint and we moved to prototype two, see Fig. 1.

IV. Motion Splint Drive

As we learned from the first prototype, the best possible propulsion unit is stepper motor. It has small dimension and high torque. It is possible to keep constant velocity even for low speed. We can achieve high accuracy and these motors are made in many variations.

There are two solutions that can be considered for electric actuation with stepper motor.

A. Hybrid actuators

Hybrid actuators transfer rotation movement of stepper motor to movement of the linear screw with the help of a special patented nut. You can see this solution in picture bellow.

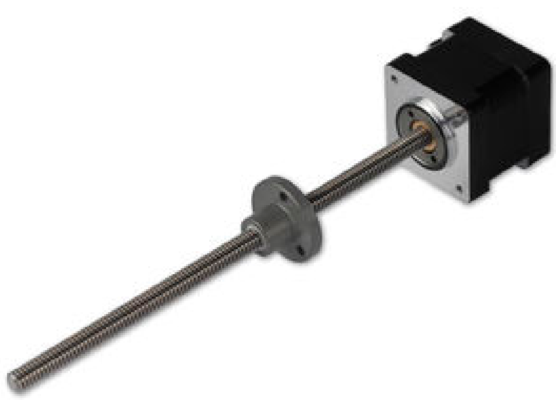


Fig. 7 External hybrid linear actuator

Hybrid actuators represent an affordable solution for all application requiring small and exact control of a linear movement. Actuators create large forces in small spaces. The actuator consists from standard stepper motor and from trapezoidal movement screw with nut. These actuators can be used in medicine, measuring technology, industry and in other areas.

B. Stepper motor combined with a linear lead

The second possibility is represented by combination of standard stepper motor with linear lead. This lead converts rotary movement of stepper motor to linear movement of the positioned lead. The lead is equipped with a ball screw which ensures smooth motion of load. This solution is shown in next picture.

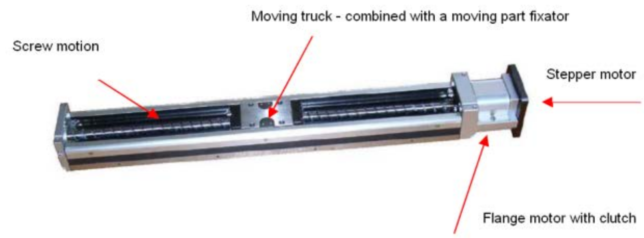


Fig. 8 Ball screw actuator Kuroda

Currently, we are using the second option for our application. Linear lead is SG3310A-600H and it is combined with SX23-2727 stepper motor. This combination makes the best solution for our purpose.

V. Controlling system for stepper motor

Because we need to control the speed and position of the continuous passive motion splint, we need to use some controlling system. For our case, we determined to use microprocessor.

We have two possibilities to control the stepper motor. We can control it directly by microprocessor or we can use standard driver. First option needs processor, pulse generator and amplifier. Processor can ensure also the pulse generation function but the amplifier is always separate part. Because we are working with relatively higher currents (approximately 2A or 3A) we will need cooler for amplifier as well. Due to all these circumstances it is better to use commercial driver.

We chose R356 driver of RMS technologies (see figure 9). This driver has following parameters:

- Supply voltage 12-40 V DC
- Maximum output current 3 A
- Resolution up to 256 microsteps per unit step
- Number of inputs: 4
- Number of outputs: 2
- Communication interface: RS 485
- Communication protocol: AT commands

Fig. 9 R356 control unit

This driver is controller/driver, to be more precise. It combines function of driver (pulse generating and amplifier) and function of controller (commands translation, memory for commands, communication capabilities).

Driver R356 communicates by AT command through RS485 interface. We can use either the personal computer or microprocessor to control this driver. Personal computer was used for our first prototype. We used it to find out how the driver acts. Currently, we are using only the microprocessor to control this driver.

VI. Prototypal Controlling System

In picture bellow, there is a block diagram of our controlling system for stepper motor. This system is composed from three parts: Main Unit, motor driver and controller. Each part of this block diagram is independent module. Every module can work separately and it can be replaced for example by new model.

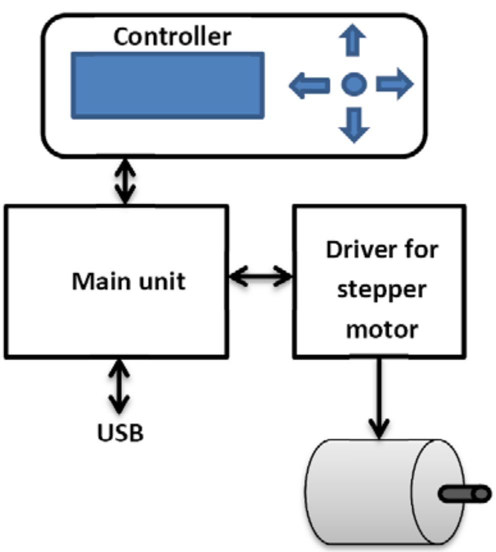


Fig. 10 Block diagram of controlling system

The core of this system is the Main Unit. It ensures interaction between user and stepper motor driver. The Main Unit is collecting data from user and it's making AT commands from them. Data collection can be performed either from computer, which can be connected by Universal Serial Bus (USB), or by our special controller. This Main Unit also ensures safety of continuous passive motion splint which is equipped by optical and mechanical sensors. Optical sensors watch about safety of a user. Technically, they watch about the position of the motion splint and if the splint runs away safety line, the Main Unit stops the motor. The mechanical sensors watch about the safety of the device and they have to prevent of the damage of the device.

VII. Construction of the Controlling System

Controller consists from liquid crystal display, buttons and microprocessor. Main Unit might control display and buttons itself but we will need thick cable with many wires to connect the display and buttons. Due to this fact, we are using second microprocessor which ensures communication with display and buttons and data between processors are transferred by Serial Peripheral Interface (SPI). We chose ATMEGA8 microprocessor for this application. This processor doesn't need precise timing and high processing speed in our application, so we can use the simplest connection of this processor with no crystal oscillator. We can fully control the continuous passive motion splint by this controller.

Microprocessor, used in the Main Unit, is ATMEGA162. We chose this processor because we needed two USARTs (Universal Synchronous and Asynchronous Receiver and Transmitter). It is basically universal serial interface implemented in hardware. One serial interface is used for communication with driver for stepper motor and second one is used for communication by USB. Both of these serial interfaces need convertors.

R356 control unit has RS485 serial interface. This interface uses asynchronous data transmission with maximal baud rate of 38400baud/s. Because RS485 uses differential signaling and ATMEGA162 uses single-ended signaling, we have to use some convertor. We used circuit 75176. It is the simplest differential bus transceiver which ensures all necessary parameters.

For communication through USB we used FT232RL convertor. This convertor supports both USB1.1 and USB2.0 specification. The RL version has almost all of components implemented so we can achieve small dimensions of PCBs (Printed Circuit Board). USB interface can be used for detail monitoring of the continuous passive motion splint and to configure presets in memory of this device. We can use it to creating and to managing of the user preset in the device.

VIII. Controlling Algorithm

The controlling algorithm that we made runs in two parts. First part is named Calibration and second one is named Continuous Run. Both parts of program are accompanied by instructions on display.

The Calibration is performed always after powering on. We need to set the lower position of the splint, next we need to set the upper position of the splint. After we finish these to settings, we can proceed to Continuous Run or we can set velocity and acceleration of the motion splint. These two parameters wave default values after start up so we don't need to set them. In mode Continuous Run, the motion splint is running from lower to upper position all over again.

IX. Electric components design

Electrical parts of CPM splint are currently fully developed at our university and it is fully function. In figure bellow you can see all electric components of the device. Now we only need to design a casing.

Fig. 11 Electrical components of CPM splint

X. Conclusions

Only a brief description of the new and modern continuous passive motion (CPM) splint is presented in this paper. Hence, the new design will satisfy the ambitious demands of modern rehabilitation, traumatology, surgery and orthopedics.

Controlling system, described in this article, is still evolving. Our intention is to adapt the controlling software to demands and to needs of users.

VŠB - Technical University of Ostrava together with University Hospital of Ostrava and Trauma Hospital of Brno are now in the middle of a process creating new design of CPM splint. Hence, they are in cooperation with the Czech producers MEDIN Nové Město na Moravě (Czech Republic).

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