Trainings- and Measurement- System for FES- Cycling

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Abstract

Due to Functional Electrical Stimulation (FES) of lower limb muscles persons with complete or incomplete paraplegia can perform a cycling movement. To quantify the progress of therapy and rehabilitation it is helpful to examine the induced forces during pedalling and the development of these forces over the period of rehabilitation. Therefore a trainings- and measurement- system for FES- cycling was designed, which combines various functions for rehabilitation, including motor controlled FES- pedalling on a test stand with force measurement devices on the cranks, a control program, documentation and data management of defined trainings units, and the possibility of regular outdoor FES- cycling. First tests with paraplegic subjects have shown good usability and acceptance of the system and an enlarged study is being started to evaluate the usability in the daily therapy and the functionality for recording the therapy progress. We assume that the system will be a valuable amendment of the therapeutic equipment of rehabilitation centers.

Keywords: Spinal cord injury, FES, cycling

1 Introduction

The activation of lower limb muscles through FES is an important supporting therapy for persons with complete or incomplete paraplegia. The contraction of the paralysed leg muscles increases perfusion of the lower limbs and improves the cardiovascular condition and the pulmonary system [1, 2]. Additionally, muscle mass [7] and bone density increase when FES is performed continuously [3, 4]. To keep the FES therapy attractive and efficient it can be combined with cycling either on cycling ergometers or specially adapted cycles for outdoor use [5, 6, 7]. Studies from Hunt et al. [8, 9] also focus on efficiency aspects of paraplegic cycling and underline the advantages of an assisting motor in FES-cycling systems, both for efficiency investigations and as driving support.
The here described FES-cycling system includes three channel force measurement cranks with telemetric data transmission and a software, which supports the realisation of individual therapy profiles, data acquisition and evaluation.

2 Methods

2.1 Mechanical design and functionality

As the basic frame for the described FES- cycling system a standard tricycle (AnthroTech) was adapted (see Figure 1). For easier transfer from a wheelchair to the tricycle the right steering handle can be dismounted by opening a quick clamp. Additionally a transfer board can be hugged on to the frame.

Fig. 1: Trainings- and measurement system for FES-cycling

For efficiency and force measurements a motor, mounted underneath the crank beam, can control the cycling cadence or hold the crank on a defined position for static measurements. This allows reproducible force measurements and a quantification of the power output for each leg. Therefore stimulation parameters for the different muscle groups can be adjusted to optimize power output.

When using the system as an outdoor tricycle the motor can support the user to get over slopes. Motor power is controlled by a turning handle on the left steering bar end by the patient. If no motor support is necessary the motor can be decoupled by switching off the electromagnetic coupling.

The gears of the gear hub in the back wheel are changed by turning the outer part of the right steering bar. (Deconvolution range: 1 to 5.5 m).

To detect the angular position of the crank during pedalling an angle encoder is integrated in the crank axis. The angle information is processed in the 10-channel current controlled stimulator (Fig. 2), which stimulates the involved leg muscles (m. quadriceps femoris, mm. hamstrings, m. gluteus maximus) via attached surface electrodes. The crank angle areas where the muscle should be stimulated for maximum power output are determined for each muscle/muscle group by automated measurement routines and stored in the stimulator. For running these routines the Laptop/ Stimulator communication works via an RS 232 Interface.

Taking the dynamic characteristics (activation and deactivation times) of the muscles into account the stimulator automatically shifts the stimulation pattern forward as a function of the actual cadence.

Fig. 2: Current controlled 10-channel stimulator: induces biphasic rectangular pulses with a stimulation current from 0-150 mA (at 1 kΩ), frequency from 0-100 Hz, and pulse width from 0-700 µs

For a smooth start of the stimulation the preset stimulation currents can be scaled from 0 to 100 % by turning an adjusting knob on the right steering bar.

2.2 Force measurement cranks

The force measurement cranks (see Figure 3) are based on strain gauge technology. The strain gauges are arranged in three full Wheastone bridges on the aluminium corpus of the cranks.

Fig. 3: Right force measurement crank with removed pedal and orthosis. (Displayed cable for battery charging)

The arrangement of the strain gauges allows measurement of the radial force (in the direction of the crank axis), the tangential force (rectangular to the crank axis), and the torque around the crank axis. These three signals of each crank are amplified, digitised and sent to a laptop. Therefore a specialized time synchronized telemetry network (Austrian Research Centers, Wr. Neustadt, Austria) is used to ensure time-correlated measurements between left and right leg.

2.3 Orthoses

Fig. 4: Orthoses for leg stabilization on the pedals

Figure 4 shows the orthoses which are mounted on the pedals. Their function is to stabilize the legs in the parasagittal plane during pedalling. Due to the telescopic shaft the orthoses are adaptable to the lower leg length of the individual user. The open design of the footplate makes the orthoses useable for a wide range of shoe sizes.

2.4 Control software and data processing

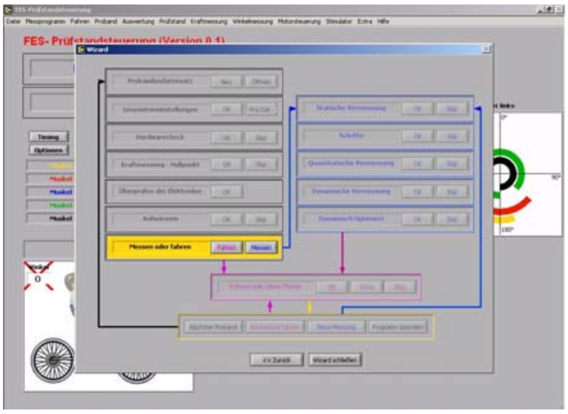

Fig. 5: Control panel on the computer with opened "wizard"

The control software is written in LabView 7 and offers two modes of operation. The expert mode can be entered via password and enables the user to change numerous settings concerning the serial communication, the appearance of the user interface and the predefined test routines. For routine use by therapists the number of adjustable parameters are limited and a "wizard" is implemented. This "wizard" mode guides the user step by step through the training units (see Figure 5). The data processing is automated and the measurement data of all the training units of one person are stored together with the personal log file.

3 Results and Discussion

First measurements with patients have shown promising results. A higher number of patients will test the system as a rehabilitation tool in clinical rehabilitation of spinal cord injured subjects in a clinical study over the next two years.

4 Conclusion

The introduced system offers multifunctional equipment for FES-cycling therapy. Used in rehabilitation centres it should provide an additional attractive therapy tool. Due to the force measurement and the automated data processing the therapy progress can be well monitored.

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