Wheelchair Exercise Device

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Abstract
Cycle training for persons with paralysis of the lower limbs in combination with functional electrical stimulation (FES) improves their physical status. A stationary training apparatus for mounting on a standard wheelchair was designed and built to support, evaluate and monitor the training progress. It features a position controlled brushless servo motor connected to the crank arms via a planetary and a bevel gear set. The direct mechanical connection allows good controllability and flexibility in concern of training programs also allowing motor support in only distinct angular regions of the crank revolution for patients after stroke. The system can be used with length adjustable- and force measurement crank arms. Ongoing clinical tests with a training tricycle using a similar training software, motor control and stimulator are promising so that we assume that the wheelchair exercise device will be an additional useful therapy and diagnostic rehabilitation device.

1 Introduction

Functional electrical stimulation was shown to be an attractive supporting training method for complete and incomplete paraplegics. The mobilisation of paralysed leg muscles can strengthen the cardiopulmonary system [1, 2], increase the bone density, muscle mass [3] and perfusion in the lower limbs [4], thus delaying or avoiding secondary diseases. A servo motor assisted tricycle was built to provide mobility for paraplegics [5] using FES. Therefore a 10-channel stimulator was developed and the tricycle was adopted for the special needs including servo motor, motor control, power supply for motor and stimulator and force-measurement cranks. During clinical testing the need for a second, stationary system for training purpose only arose. The here described wheelchair based trainings device comes up to these needs utilising the same stimulator, trainings software and motor control. Moreover it is planned to introduce this training device also in the rehabilitation of patients after stroke or other sorts of complete or incomplete paralysis of the lower limb musculature.

2 Methods

2.1 Mechanical design

The system consists of the attachment frame, the drive-train and the controller box. The attachment frame can be mounted on a variety of standard folding wheelchairs. It is quickly fixed on the lower tubes of the wheelchair with four clamps and is adjustable to various lengths and a seat-width from 38 to 48cm. The adapting to the body size of the trained person is done via a horizontal telescoping mechanism. Figure 1 shows a digital mock-up of the system designed in the 3D CAD software “Catia V5”.

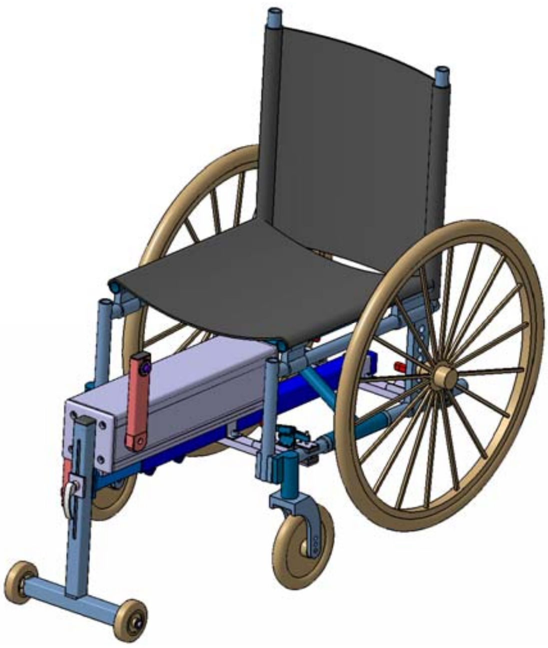

Fig. 1: Digital mock-up of the mounted system.

The drive-train (Fig. 2) consists of a 48V, 300W brushless servo motor, a 1:60 planetary gear set and a 1:1 bevel gear. The crank arms are directly mounted on its two sided output. A wheeled stand in the front increases the stability when in service to meet the EN 957 requirements for stationary exercise machines. The motor control and power supply find place in an external controller box (Fig. 3) connected to the 230V AC power network. It contains a switching power supply, a braking chopper and the digital positioning controller "maxon EPOS 70/10".

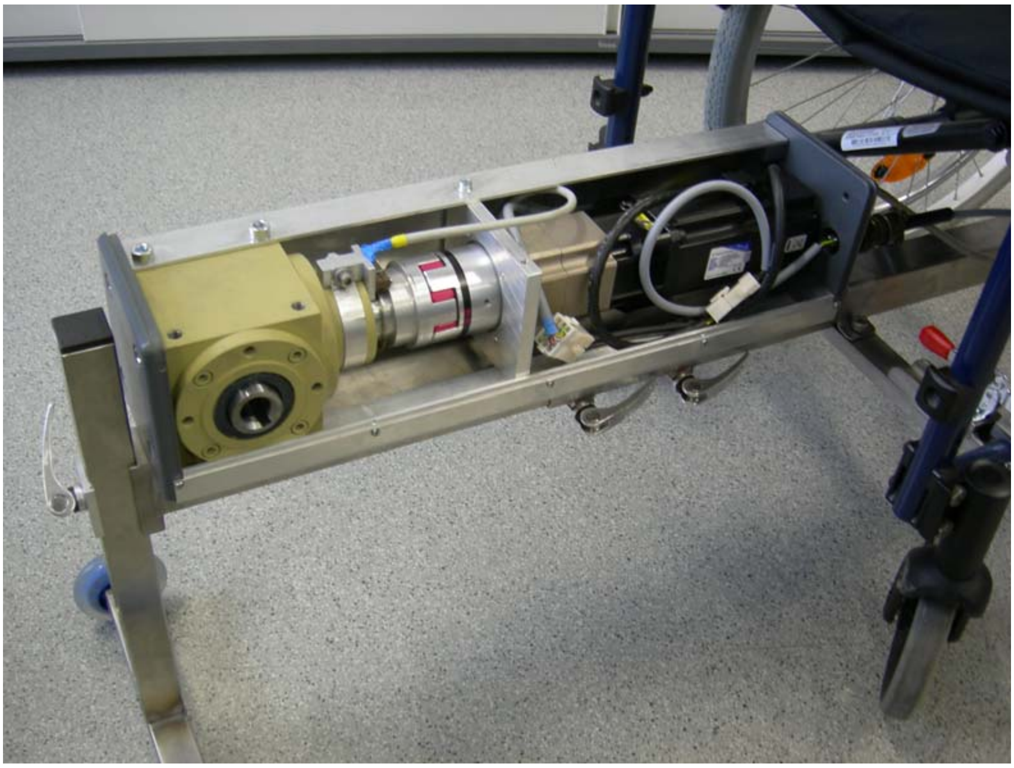

Fig. 2: The drive train with enclosure removed. From left to right: bevel gear, incremental encoder, coupling, planetary gear, motor.

Fig. 3: The controller box (dimensions 250x200x120mm) including an on/off switch, a device fuse and connectors to the drive-train (power and data separated), the stimulator, the emergency stop button, the handheld stimulation intensity controller and the 230V~ electricity network.

2.1 Functionality

Once adjusted to the measures of the wheelchair, the whole apparatus can be easily removed and remounted from underneath the standing wheelchair. The wheels on the stand allow easy manoeuvring and tilting up to its correct position under the seat.

In the hollow shaft of the bevel gear different crank arm designs can be mounted. The System features length adjustable crank arms, force measurement crank arms and ones for adjustable pedal-pivot-shaft on the orthoses which have the pedal bearings inside the crank arms allowing to set the joint near the ankle or even higher along the lower leg, virtually shortening it. When run with force measurement cranks various additional diagnostic applications are enabled and the therapeutic progress can be evaluated with force data.

By setting the distance of the crank arm pivot relative to the hip joint, the crank arm length and the pedal pivot position the resulting knee and hip angles can be influenced and optimised for the user. The kinematic equations were implemented in “matlab” to investigate the changes on the joint angles in different setups. Exemplary graphs of knee angle and hip joint angle over the crank angle can be seen in Figure 4. Statistical data of the DIN 33402 was used to determine the necessary adjusting ranges for different body heights.

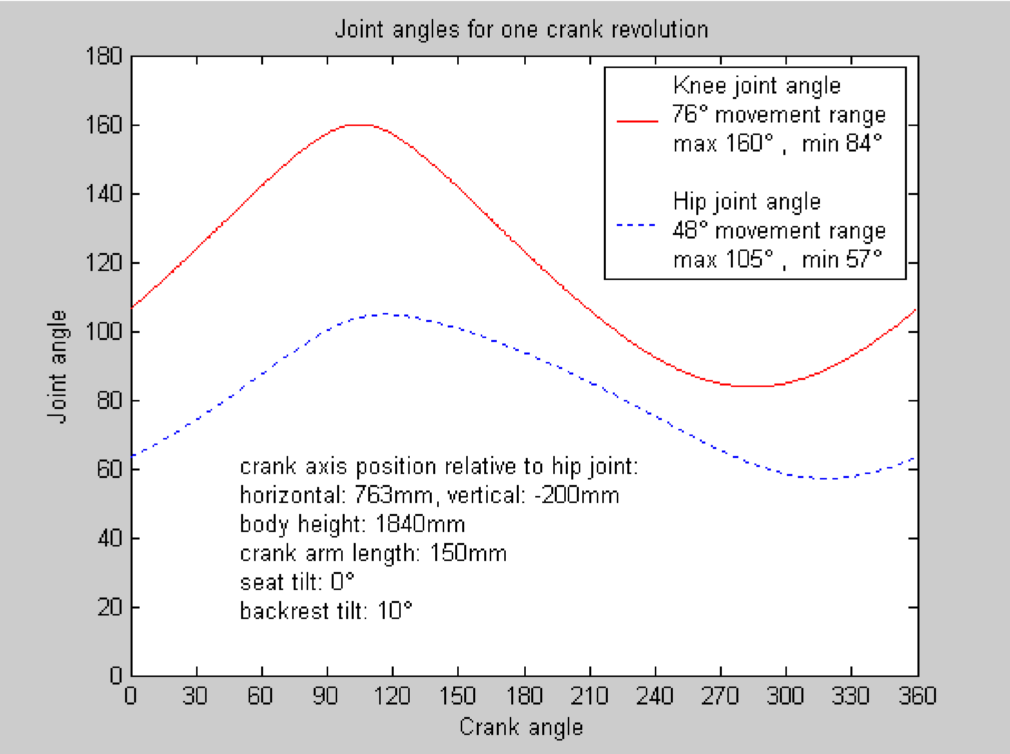

Fig. 4: Plot of knee and hip joint angles for a typical configuration.

The stimulation is controlled by the same 10 channel stimulator that is used for the mobile FES tricycle [5]. The angle signal of the crank arms is recorded by an incremental encoder on the input of the bevel gear and forwarded through the controller box to the stimulator.

The specially developed training and evaluation software can be transferred from the mobile tricycle to the new hardware without restrictions. Also further developments shall be shared by both systems. For running and evaluating the training a laptop PC is needed. The subject can regulate the stimulating current using a hand held potentiometer. Motor movement and stimulation can be terminated at any moment by pushing an emergency stop button mounted individually on the wheelchairs arm rest or similar.

3 Results and Discussion

Ongoing clinical tests with the mobile FES tricycle with paraplegics at the rehabilitation center “AUVA Rehabilitationszentrum Weißer Hof” (Austria) are promising. It is suggested that the new training machine will be equally useful for the exercising of paraplegics. Moreover it is expected that it can be used for rehabilitation of patients after stroke or other forms of incomplete paralysis of the lower limbs too. For that the motor will only give support when it is needed. Quick changes of motor moment from driving to breaking in only parts of a crank revolution are possible due to the sophisticated motor control and direct drive train featuring very little backlash.

4 Conclusion

The system is an improvement especially in flexibility and regulating accuracy compared to commercially available wheelchair cycle training devices. Thus it will offer new possibilities for more complex training programs requiring better controllability. Actual tests of the exercise machine will show its practical usability in rehabilitation centers and point out the necessity of further improvements

Acknowledgements

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Literature

[1] Janssen T.W.J., Glaser R.M., and Shuster D.B.: “Clinical efficacy of electrical stimulation exercise training: effects on health, fitness, and function.” Top Spinal Cord. Inj. Rehabil., (1998), 3, 33-49.

[2] Figoni S.F., Rodgers M.M., Glaser R.M., Hooker S.P., Faghri P.D., Ezenwa B.N., Mathews T., Suryaprasad A.G. and Gupta S.C.: “Physiologic responses of paraplegics and quadriplegics to passive and active leg cycle ergometry.” J.Am.Paraplegia Soc., (1990) 7, 33-39.

[3] Heesterbeek P.J.C., Berkelmans H.W.A., Thijssen D.H.J., Kuppevelt van H.J.M., Hopman M.T.E. and Duysens J.: ”Increased physical fitness after 4-week training on a new hybrid FES-cycle in persons with spinal cord injuries”; Technology and Disability, 17 (2005),103-110

[4] Frotzler A., Coupaud S., Kakebeeke T.H., Hunt K.J., Allan D.B., Donaldson N., and Eser P.: “Effects of high volume FES-cycling training on bone parameters of subjects with chronic spinal cord injury,” in Proc. 45th ISCoS Annual Scientific Meeting, (Boston, USA), June 2006.

[5] Reichenfelser W., Gföhler M., Angeli T.: "*Design of a test and training tricycle for subjects with paraplegia*"; Technology and Disability, 17 (2005), 2; S. 93 - 101.

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