Multi Moment Chair System to measure isometric moments in the paraplegic lower limb - improvements to the original design

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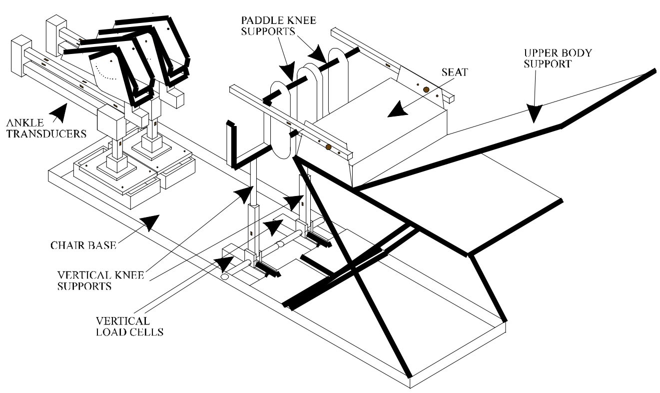
1 Introduction

The 'multi-moment chair system' (MMCS)[1] measures the isometric moments in the paraplegic lower limb during stimulation from a Lumbosacral Anterior Root Stimulator Implant (LARSI). The human lower limb has seven degrees of freedom and the MMCS can measure all moments simultaneously: hip-extension, -abduction and -rotation; knee extension; and ankle-abduction, -inversion and dorsiflexion. The results from the system are used to develop combinations of stimulation patterns to restore lower limb function. Primarily aimed at FES assisted standing, it has also been used in alternating gait and cycling patterns. From clinical experience, several difficulties with the system became apparent. These and the improvements to reduce them are discussed.

2 Description of the MMCS

The MMCS primarily consists of a mechanical chair, transducers with bonded strain gauges, a bank of strain gauge amplifiers and a PC-486.

Fig. 1 ‘Multi-moment chair’



The subject sits with their upper body supported by a back board. The hip, knee and ankle joints are fixed so that the calculated joint moments are isometric. This allows many stimulation patterns to be sent in rapid succession to minimise fatigue. The forces and moments generated during stimulation are measured using strain gauges at the supports. Each feet box is mounted on a six-axis load cell, which measures the three forces and three moments translated through to the ankle. The remaining movement, lateral at the knees, is measured at the paddle knee supports (‘seated’ tests) or vertical knee supports (‘extended’ tests). The system accommodates for different joint angles by the adjustable seat height, the reclining back support, movement of the ankle transducers in the longitudinal direction and the adjustable feet boxes. Software controls communication between the PC and the LARSI controller, the logging of data and the calculation and display of the joint moments for each lower limb.

3 Improvements to the original design

3.1 Vertical restraining forces at the knee

Despite the foot being 'fixed', strong plantar flexion may raise the heel. Originally the knees were 'clamped' using hard concave rubber pads. Due to the friction between the knees and the pads, the vertical force resulting produced an equal change in the vertical force through the ankle transducer. This was calculated as an erroneous hip extension moment. The problem has been reduced by using the paddles of polished steel.

3.2 Changes in the knee angle in a seated posture

In ‘seated’ tests, high knee extension moments can push the pelvis back into the padding behind. The pelvis is now no longer fixed which may change the knee angles, introducing errors into the calculated knee and hip moments. The accuracy has been improved by measuring the changes in the knee angles during stimulation and using these in the joint moment calculations.

3.3 Problems from high knee extension moments in the extended posture

In a near ‘extended’ posture, very high knee extension moments can be produced. To prevent high pressures at the heels and damage to the ankle transducers, movement in the longitudinal direction is released by mounting each ankle transducer on a slide. The new vertical knee supports measure the lateral forces and fix the knee using moulded foam casts. The loss of one measurement from the ankle transducer is compensated by measuring the vertical force under each support.

3.4 Aliasing from the stimulation frequency

The transducer signals were originally sampled at 5Hz. However, during tests there was a sinusoidal component superimposed on the calculated moments. Its frequency was of the order of a few Hz with an amplitude as high as 30Nm - clearly unacceptable for our tests. The errors were shown to be from aliasing of the 20Hz stimulation frequency; significantly from the first and second harmonic. It is eliminated by sampling at 100Hz and averaging over sixteen samples for each channel; effectively a data transfer rate of 6.25Hz.

3.5 Calculation of the joint moments

The calculated joint moments are displayed after each stimulation run. Originally these were saved, but to allow processing of the results at a later stage using MatLab the system now saves the transducer signals. MatLab is used to calculate the joint moments and the error associated with each. In 'real-time' MMCS still calculates and displays the joint moments, because it has proved useful in identifying any problems with the test.

4 Conclusions

Only two paraplegics have had a LARSI implanted (December 1994 and December 1996). The second is still rehabilitating from the operation and from suspected neuropraxia, therefore to date our practical experience in using the MMCS has been with just one. Twenty-one 'chair sessions' have been conducted over this two year period - the number limited by the time needed between sessions to process the results and to assess them in functional tests. It has proved to be useful in the rehabilitation programme to restore lower limb function in paraplegics with LARSI. Examples of its use have been in mapping responses to root stimuli, evaluating the results from nerve blocks performed to reduce unwanted movements and in developing FES programs.

References

1 Worley ACM. Multi-Moment Chair. *4th IPEMB FES Conference:* Strathclyde, UK; April 1995.