AN EXPLORATION OF CANOEING ACTION AS THERAPY FOR SPINALLY INJURED PEOPLE

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Summary This paper outlines the design and building of a kayak machine, for use by persons with spinal injury. We designed an eddy current brake to apply varying known torques on the system, which determine the power required by the user to run the machine. The output of an optocoupler circuit, applied to a computer can be calibrated to become a speedometer. The machine is computer controllable, and replicates well the action of kayaking on water. Use of the machine, in the Physiotherapy Department at the National Rehabilitation Hospital, is, among other advantages, proving beneficial to a person's sense of balance. This aspect will become the basis of further research.

1. INTRODUCTION

We present here an exercise machine designed specifically to suit the needs of people with spinal cord injuries (SCI). The machine imitates the action of kayaking, a sport widely recognised as being beneficial for persons who suffer from SCI [1]. Kayaking is a sport that relies mainly on upper body muscles, and can be successfully accomplished by people with limited upper mobility [2]. Already across the globe, many bodies organise kayaking events for persons with SCI as it gives them a sense of independence and freedom. Wheelchairs are left behind on the bank.

Our kayak machine, shown in Fig.1, allows the user to learn basic skills conveniently, to train and to achieve higher fitness levels. It also enables one to look closer at the physiological benefits of kayaking and its role in the rehabilitation of people with SCI. It is easy to use and wheelchair friendly, requiring little to no supervision during use. The machine is a modification of one bought from Nick Pink in London, one of the few manufacturers of such equipment at the time of purchase. The seat was removed and replaced by a platform on which a chair / wheelchair can be placed. An eddy current brake was designed and fitted to allow the user to vary the effort required from his/her seat. This replaces the original air resistance system in which the cover on the machine's disc had to be adjusted manually at the disc. An electronic speed measurement system was fitted, to feed directly to a computer for recording. Using extra acquisition hardware, which was also designed, means that other information, such as emg (electromyogram) signals [3], could be recorded if required, to give quantitative information on the action of various muscle groups.

2. KAYAK MACHINE

A paddle shaft is connected, from the front of the machine, via ropes and a system of pulleys to the rear-mounted aluminium disc.

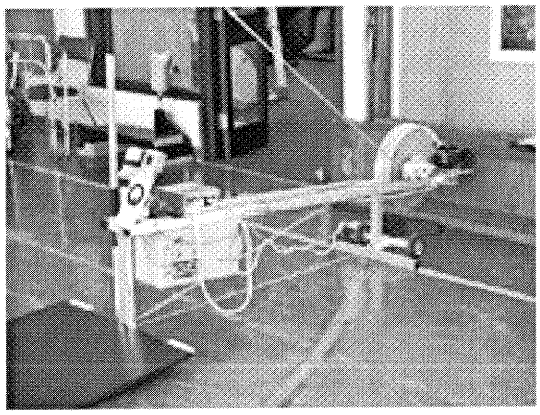

Fig. 1. The Kayak machine as used in the sports hall of the National Rehabilitation Hospital, Dublin.

The torque vs. angular velocity characteristic of this disc is what determines the effort required by the user. All controls and data displays are located in front, where the user is seated.

3. EDDY CURRENT BRAKE

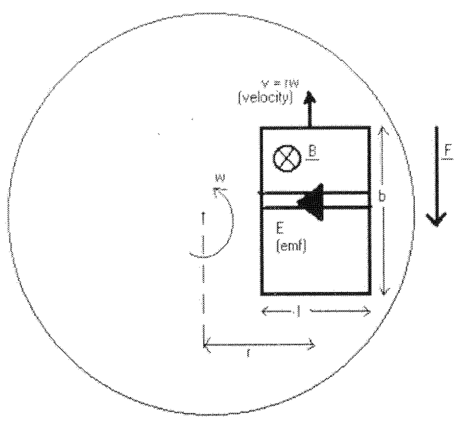

Fig. 2: Plan View of the Eddy Current Brake

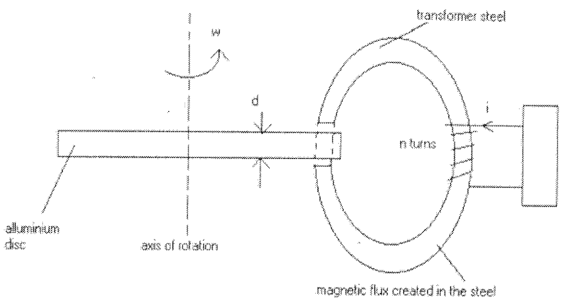

Fig. 3. Side View of the Eddy Current Brake.

Views of the eddy current brake are shown on Fig.2 and Fig3. A coil of wire is mounted on a core of transformer steel through which the disc runs. Current flowing through this coil generates a magnetic flux, which induces current flow in the moving disc. The interaction of this current with the flux produces a braking torque on the disc.

The braking process may be analysed by examining the portion of the wheel in the air gap of the core.

The induced emf (E) has magnitude Blv and points towards the centre of the disc (Right Hand Screw Rule).

$$E = B\,l\,v = B\,l\,r\,\omega \qquad (1)$$

This causes current to flow in the same direction as E. This current is in a moving disc and therefore in a changing magnetic field, thus it experiences a force ($F = B\,I l$), which opposes the motion.

The power absorbed by the eddy current brake where Fr is the resisting torque on the disc, is:

$$P = Fr\,\omega \qquad (2)$$

The resistance presented by the slab of disc in the air gap of the electromagnet is:

$$R_s = \rho l / A = \rho l / bd \qquad (3)$$

As a first approximation, we equate the resistance of the rest of the disc to that of the slab moving in the field, giving

$$I = \frac{B l r\,\omega}{2\rho l / bd} \qquad (4)$$

This implies that torque $T = Fr = B\,I\,l\,r$ is given by the expression

$$T = \frac{B^2 l^2 r^2 l bd\,\omega}{2\rho l} \qquad (5)$$

Now B can be estimated in terms of the magnetising current i.

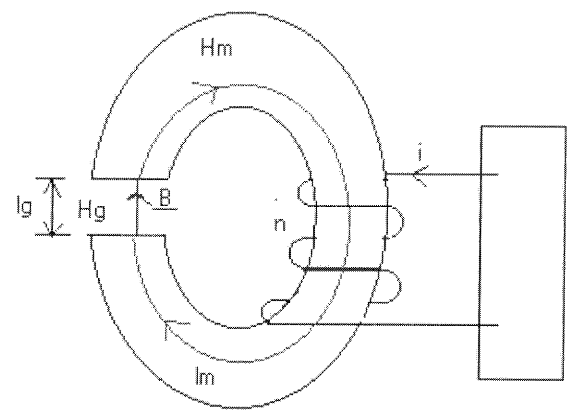

Fig. 4. Sending Current through the Core.

Applying Ampere's Circuital Theorem on Fig. 4 gives:

$$H_m l_m + H_g l_g = ni \qquad (6)$$

H_m = magnetic field intensity in the core, H_g = magnetic field intensity in the air gap, n = the number of turns in the coil, l_g = length of air gap, l_m = mean length of the core.

We assume $H_m l_m << H_g l_g$, giving

$$B = (n\,\mu_0\,i)/(l_g) \qquad (7)$$

Thus the torque now is:

$$T = \frac{\mu_0^2 n^2 i^2}{l_g^2} \cdot \frac{l r^2 bd}{2\rho} \cdot \omega \qquad (8)$$

The important dependences are that T is proportional to i^2 and ω.

As $P = T.\,\omega$, we obtain, for the power absorbed by the disc,

$$P = \frac{\mu_0^2 n^2 i^2}{l_g^2} \cdot \frac{l r^2 bd}{2\rho} \cdot \omega^2 \qquad (9)$$

Thus, power absorbed by the disc can be related to the current in the coil and the speed of the rotating disc. By changing the current through the coil, the resistance of the disc to rotation can be set.

A constant current source was designed to deliver up to 2A of current to the brake. This allows for the paddling stroke to vary from "easy" to "very difficult". As most of the people using the machine have impaired movements, this range is more than sufficient.

4. SPEED MEASUREMENT USING AN OPTOCOUPLER

Rotating on the same axis as the main aluminium disc, there is a smaller disc with 60 small holes spaced evenly just inside its outer edge. A slotted, through-scan opto switch is fitted so that this disc rotates in its slot. This optocoupler is powered by a 5v supply and produces a square wave at the frequency of the rotating disc. This signal is applied to a frequency-to- voltage converter to give out a continuous voltage that is limited to go no higher than 5v [4]. (As a frequency-to-voltage converter is triggered by zero crossings, the signal first had to be dc-shifted to ±2.5v.) The final continuous signal representing velocity is applied directly to a computer.

5. RESULTS

The kayak machine has been in use for over a year at the time of writing this paper. Many patients from the hospital now use it as part of their general rehabilitation routine. It has proved most helpful with patients new to their wheelchairs as it has a positive effect on their sense of balance. The machine is also being used weekly by a group of paraplegic canoeists to enable them to train during the winter months. Feedback from users is that the machine is easy and fun to use.

6. CONCLUSIONS

We have presented here the idea of a kayak machine along with details of two of the circuits designed to control the machine. The machine is working in a real environment with positive results. On the basis of this, further work is continuing to bring the machine fully under computer control, perhaps with a voice control option. Competition with a virtual partner is also planned. An intensive study into kayaking is being carried out to enable us to more closely replicate the force pattern of paddling in water. Other changes to the machine in the foreseeable future include re-dimensioning in line with feedback from users and physiotherapists.

Acknowledgments

The authors would like to thank Pat Mc Nally and Paddy Mathews of our technical staff for their invaluable help with electronic and mechanical aspects of the project. Thanks are also due to Jane Lynch of the Physiotherapy Department at the National Rehabilitation Hospital for advice, for feedback and for putting the machine into daily use.

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