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WHEELCHAIR ERGOMETER

Development of a Prototype with Electronic Braking

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ABSTRACT. A new wheelchair ergometer is described, which compensates for the pulsating character of the work by an automatic control system. This makes it possible to maintain a constant level of power during wheelchair work. Design: An automatic control system has been integrated in an electronically braked bicycle ergometer, and a pedal unit from Rodby Elektronik bicycle ergometer RE 820 has been coupled to a modified test wheelchair. With this device, the physical working capacity during submaximal circumstances can be tested in handicapped persons.

Key words: Wheelchair ergometer, automatic control system, physical working capacity

The estimation of physical working capacity is usually done by a submaximal or maximal ergometer test. The maximal test implies collecting expired air with a mouthpiece and tube and other physiological distresses during the performance. Thus for "everyday use" (e.g. athletics for disabled) a submaximal method is preferred. The most common principle is based upon calculation of mechanical work at heart rate 170 ($\dot{W}_{170}$) or changes in heart rate at given loads from one test to another. For persons who have to use a wheelchair it seems natural to test working capacity in a situation simulating the pattern of movement used in a wheelchair driving. If power output and oxygen consumption are determined in the same test, the mechanical efficiency can be calculated. This might have practical interest to the disabled when choosing different types of wheelchairs at home, at the workplace or during leisure time. Power output at each test must be known to make comparisons between different trials. The central problem is the pulsating character of wheelchair work which makes it difficult to obtain constancy during test performance.

Devices for wheelchair ergometry in the literature all seem to lack automatic control systems.

Wheelchair on rollers

1) Un-controlled application of brakes (2), 2) braking of the rollers (3, 8), 3) braking of the axle (12).

Wheelchair on treadmill

Compensation of frictional resistance ("Power nomogram") (10, 11, 7).

Wheelchair combined with bicycle ergometer

Mechanically braked (1, 13, 4, 5, 6, 14).

Aim

To develop a wheelchair ergometer which compensates for the pulsating character of the work by an automatic control system, making it possible to maintain a constant level of power during wheelchair work.

Earlier experiences

In order to facilitate an even application of force, bicycle and arm ergometers are often equipped with heavy flyweels, generally braked by belts so that the frictional force can be chosen by means of the belt tension. Compared to mechanical ergometers, the electromagnetic braking in its refined application lacks the great mass of the mechanical systems combined with the inertia of the moving parts of the system.

The concept of an electromagnetically braked wheelchair ergometer where kinetic energy exists only in the wheels and driving rings means that inertia must be simulated electrically. In addition to regulating the influence of the pulsating character of the work, another system is needed. This system uses feed-back to vary electromagnetic braking so that the operation of the ergometer is perceived as natural in spite of the fact that the wheelchair ergometer is fixed to the floor (9).

An experimental prototype built according to the

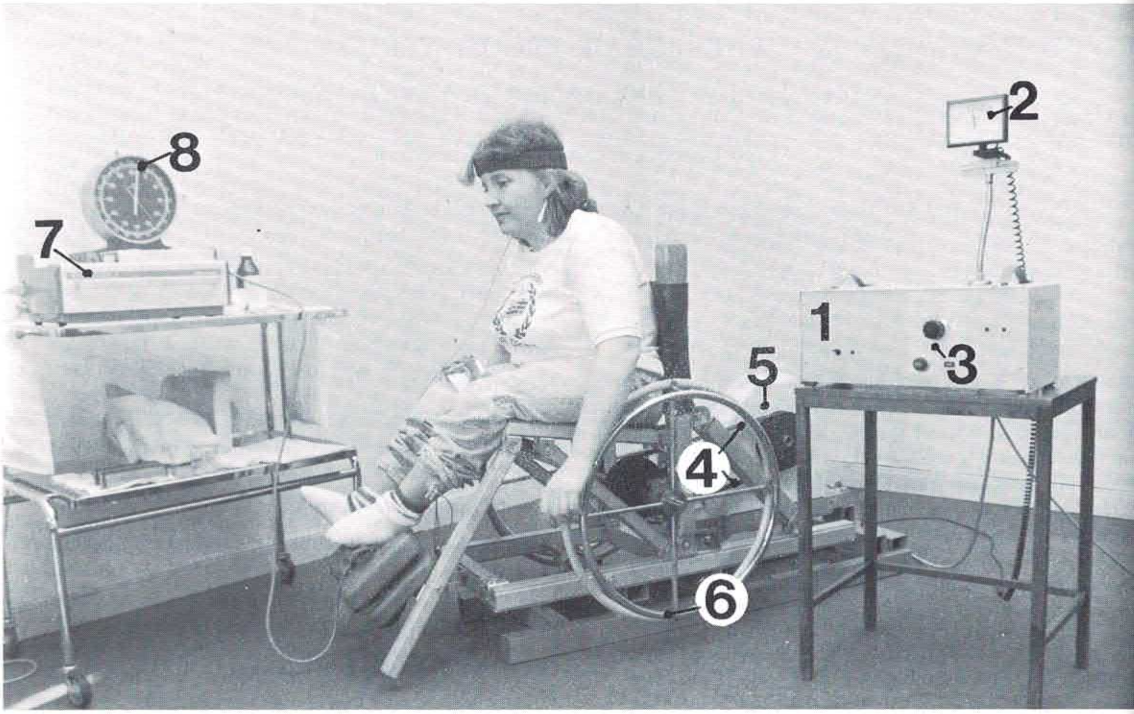

Fig. 1. Wheelchair simulator coupled to pedal unit from bicycle ergometer RE 820 (Rodby Electronic AB). 1) electronic control unit, 2) tachometer, 3) power selector, 4) cog belt from pedal unit to wheelchair, 5) pedal unit, 6) drive rings of wheelchair simulator, 7) electrocardiograph, 8) stop watch.

suggestion above showed that the presumptions made were adequate and that it was possible to simulate inertia within reasonable limits. However, the necessity to dissipate hundreds of watts from the system as heat at maximal effort implied water cooling of the amplifier. This would increase the size of the system and make it difficult to handle. The project was estimated to be so demanding of resources that it was thought more practical to base the wheelchair ergometer on electronically braked bicycle ergometers developed during recent years by Siemens Elema/Rodby Electronic, Dynavit or Monark.

Automatic control systems[1] have been integrated in these designs and it seemed natural to investigate if such a unit in combination with a wheelchair could be a solution to our problems.

METHOD

The pedal unit from Rodby Electronik bicycle ergometer RE 820 was coupled to a test wheelchair which could vary both sitting position and distance between the driving rings (Fig. 1). A control unit with means for selection of power levels and for calibration was connected to the pedal unit.

The RE 820 also lacked inertia simulation through electronic means using instead a heavy flywheel built into the pedal unit. The pedal unit also contains a three phase generator driven by a two-step planet gear with a total gear ratio of 1:9.4. The unit contained a free wheel between the pedal shaft and the planet gear. Mechanical as well as electronic modifications were necessary in order to use the pedal and control units to develop a wheelchair ergometer.

Mechanical modifications

As compared to bicycling, where pedals normally are at rest when one stops pedalling, the driving rings of a wheelchair follow the wheels as long as it is moving. To produce the effect of inertia when using the wheelchair ergometer and to be able to

[1] Automatic control system: A system where the output signal is fed back and compared to the input signal in order to achieve the desired output signal. In this case the aim was a constant power output during wheelchair driving.

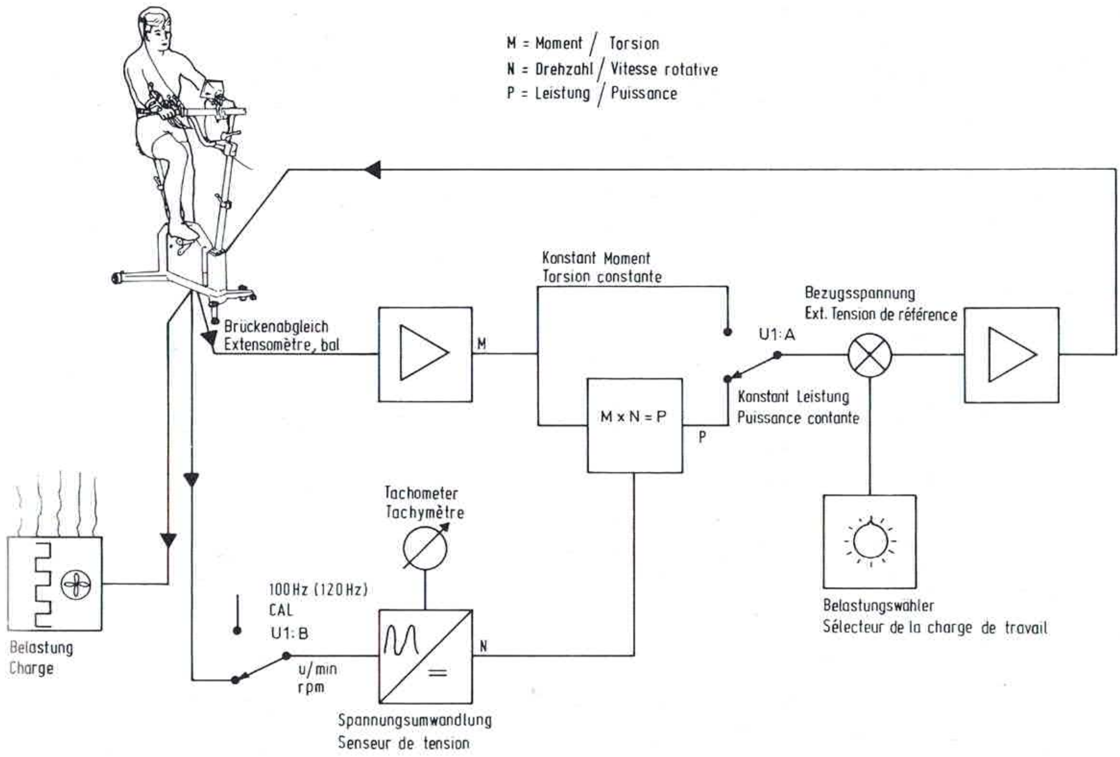

Fig. 2. Schematic diagram of electronic control unit of the bicycle ergometer.

use maximal force on the driving rings, it was necessary to take the freewheel hub out of the mechanical system of the unit. Thus, the kinetic energy in the heavy flywheel was transmitted to the driving rings.

Electronic modifications

The pulsating energy input during wheelchair driving is another important difference between bicycling and wheelchair driving. While the bicyclist maintains a relatively constant effort by means of changing application of force on the pedals, the wheelchair is usually driven in a pulsating way by application of force from both arms at the same time. This results in a great oscillation of power in the system. Fig. 2 shows the principle of the electronic control unit. The work performed is transferred to electrical energy in the pedal unit and is taken up by resistive loads. The electrical power produced by the generator in the pedal unit is dependant on pedal frequency and a magnetic current, regulated to make the power independent of pedal frequency within certain limits. Effort and pedal frequency are continuously multiplied in order to get a mean value of the power. Voltage, proportional to this power is compared with a reference voltage that is controlled by a load selector switch. The difference between these two values is amplified and determines the magnitude of the feed-back current controlling the electromagnetic braking. One may also select the magnetic current so that the torque will be independent of pedal frequency. In Fig. 2 the two triangles symbolize signal amplifiers. The amplifier to the left transfers the electric signals representing the torque during bicycling. The amplifier to the right feeds the signal back to the generator of the bicycle in order to get a constant power. Variations resulting from the use of a bicycle ergometer are moderated in these amplifiers with the aid of capacitors in integrating feed-back links. To further reduce the pulsating nature of wheelchair driving the capacitor values in these feed-back links have been doubled by parallel coupling of capacitors with the same capacitance as those in the circuit. An existing transistor and associated circuitry has been by-passed in the stage

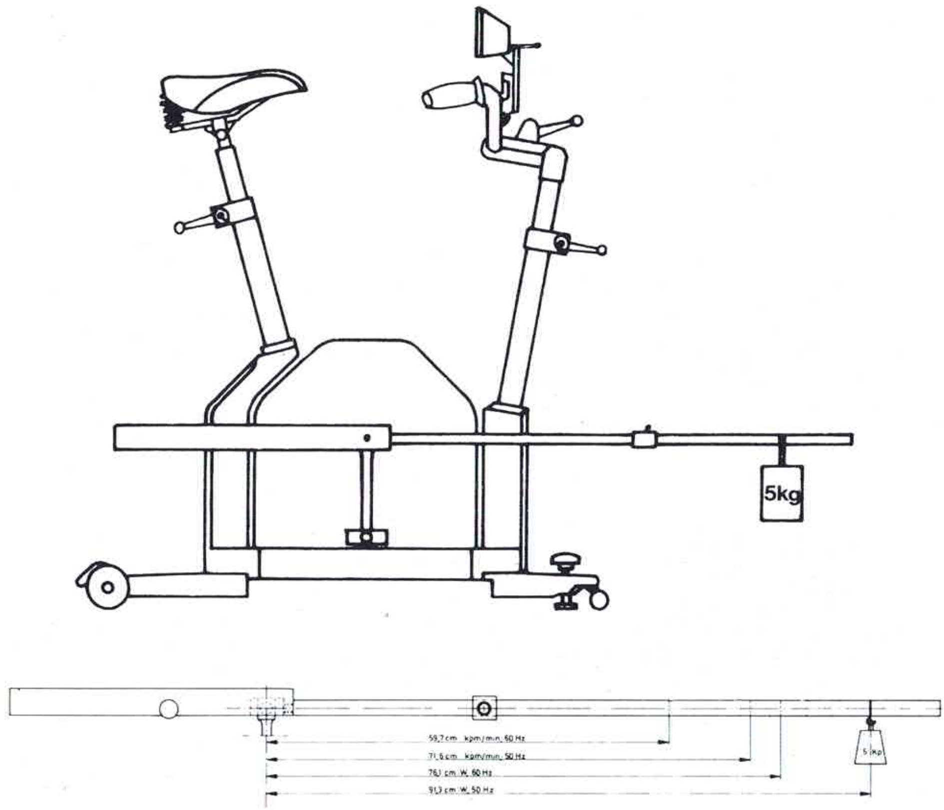

Fig. 3. Calibration of bicycle ergometer.

amplifying the magnetic current to the generator, producing the torque signal. The value of a capacitor in the same circuit was halved also.

Although the pulsations in the wheelchair ergometer are still remarkably greater than in the bicycle ergometer, a further increase of time constants in the integrating links has been avoided in order to keep the error within 2% and keep the range of operation as wide as practical.

Selecting power level

Three methods of power level selection are possible on the control unit. Levels between 20 and 500 watts can be selected by a step switch in 10 watt increments. This range may be reduced to 10 to 250 watts with 5 watt intervals by a separate load switch, so that persons with less physical strength can use the system. Continuously variable power levels from 0 to 500 watts may also be selected using a 10-turn potentiometer and digital display.

Calibration

The power output of the wheelchair ergometer is a product of torque and pedal frequency. The calibration of the wheelchair ergometer thus demands that both these variables be referenced to well defined standards. Torque is calibrated with a rod and attached precision weight, connected to the unit by way of a special outlet (Fig. 3). Revolutions per minute is referenced to the AC electrical net frequency. In a correctly calibrated 50 Hz system the tachometer will indicate 53.3 rpm, when the calibration button is pushed (64 rpm for a 60 Hz system). Calibration can be maintained in a simple manner by adjusting the control signals to produce the desired values when outside torque and pedal frequency are applicated.

Practical use

Recording the power with a chart recorder connected to the unit demonstrated that the mean value of

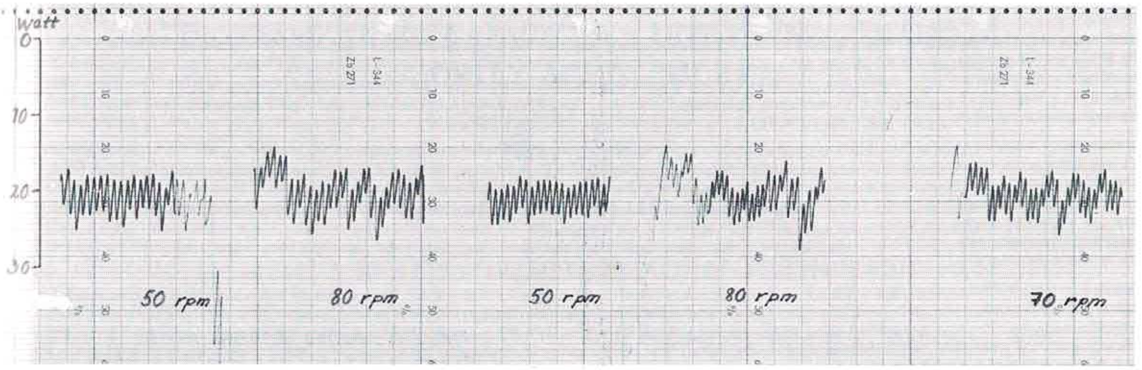

Fig. 4. Measurement of power. The signal is proportional to power generated by driving the wheelchair ergometer. The curve shows the mean value of selected power (20 watts) at 50, 70 and 80 revolutions per minute. Full scale deflection corresponds to 200 mV. 1 watt = 2.8 mV. Speed of paper is 2 mm/sec.

power corresponded to selected value, independent of variations in pedal frequency within the prescribed limits of 35–120 pedal revolutions per minute. Normally, 50–80 pedal revolutions per minute were used (Fig. 4).

Experienced wheelchair drivers expressed themselves positively about the "right feeling of wheelchair driving" in the ergometer.

Handicapped persons now can test their physical working capacity during submaximal circumstances. This is of great value when evaluating the effect of training or treatment, a possibility that the non-handicapped have had for a long time.

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