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ERGO1: WHEELCHAIR ERGOMETER FOR PHYSICAL CONDITIONING

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Abstract. *Physical activity is one of the ways to promote health and social integration of people with disabilities. Recently, some actions by the federal government search to guarantee the full exercise of individual rights. Sports are a great way to promote social integration and Brazil has shown a crescent performance in the Paralympics. To evaluate the physical conditioning, ergometers are used. However, these items of equipment are derived from tests that already exist for able-bodied persons and, normally, don't perfectly adapt to the motor gesture naturally executed by people with disabilities, which is the propulsion of the wheelchair through the application of a force on the propulsion rims. According to this, the objective of this work is to develop a new prototype of a wheelchair ergometer that respects the specificity of movements and allows the physical evaluation of people with disabilities. This new prototype is called ERGO1 and it's an evolution of the previous one, ERG-CR09, with a new structure that is lighter and smaller. Resistance generation was made through an electromagnetic brake similar to the previous one, but positioned under the seat. An application developed in LabVIEW language is responsible for controlling the electronic part of the prototype, configuring the load that is going to be used and making the acquisition of the rotation and torque signals from the system so the power, energy and fatigue of the user may be estimated. Definition of load level is made through an weight acquisition automatic system positioned in the seat structure. Besides Wingate protocol, a new test, called incremental protocol was implemented. Through initial tests was observed that the variation of resistance levels allows the evaluation of physical conditioning for both protocols. Also, fatigue levels characterized in the literature were observed. This happened for the fatigue based on power levels and in those based on the equivalent energy. Another important innovation of this prototype comes from the power signals acquired that had its peaks smoothed by inertial flywheels.*

Keywords: *ergometer, wheelchair user, para-athletes, physical conditioning, wingate.*

1. INTRODUCTION

Physical activity is one of the most efficient ways to promote health. Furthermore, is great to combat sedentarism, which is a risk factor for several cronic-degenerative diseases that often affect humanity. The physical conditioning evaluation for disabled people began in the late 60 with the analyses of cardiac frequency, maximum consumption of oxygen, pulmonary ventilation and maximum load reached in an incremental test. Over time, interest for anaerobic power started. Also, ventilatory, metabolic and physiological responses provide a better diagnostic interpretation from the results.

For the execution of those evaluations, it's necessary to use appropriate methods and equipment. It has been noted that there's a great need in this point for disabled persons. The developed apparels, including national ones, are just adaptations from equipment for the able-bodied and, for this reason, do not faithfully reproduce the motor gestures and end up becoming questionable about its full application.

According to this, arises the necessity to develop an equipment that better describes the motion pattern, elevating results reliability and reaching sharper evaluations for the real physical condition of the user. In case of the evaluation of a paralympic athlete for example, the trainer needs of precise informations about these capacities during the training time which can last from two to twelve months.

Even with these difficulties, the brazilian paralympic athletes has shown great results which has made the country to become one of the world powers. In Athens the fourteenth place was achieved, in Beijing the ninth and in the last games

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in London, the seventh place was obtained. Considering all the other nations, it becomes evident the country potential in this needed area.

Inside this context, an earlier prototype of a wheelchair ergometer was built, as seen in Fig. 1, which uses electromagnetic systems and control by computer software. This paper will present the improvements of the early prototype.

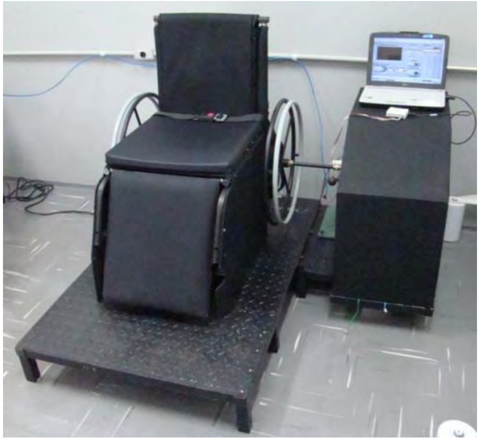

Figure 1. Prototype ERG-CR09 previously developed. Source: Novais (2009).

2. STATE OF ART

To build such equipment, it's necessary to understand the physiology involved in wheelchair users activities, its impacts and what has been developed to solve the current situation.

2.1 Physical Capacity

Physical capacity is described as the capacity of the cardiovascular system, muscles and respiratory system to provide a certain level of physical activity. It is reduced in people with spinal cord injury due to loss of motor control and influence of sympathetic nervous system below the injury level (Haisma *et al*., 2006). Age, gender, occupation and level of physical activity (Muraki *et al*., 2000) are factors that influences physical capacity. A low level of physical capacity is associated to a high risk of cardiovascular complications (Hjeltnes and Jansen, 1990; Yekutiel, 1989) and contributes to a reduction in life quality. This reduction of physical capacity and, subsequently, of life quality, can lead to secondary conditions as obesity, gastrointestinal problems, respiratory complications, joint pain and others (Steele, 2004). According to Margonato (2008), people with spinal cord injury also are more exposed to premature death by cardiovascular accidents.

2.2 Injuries

Shoulder injuries, carpal tunnel syndrome and tendinitis, that arise through repetitiveness of movements, high forces and incorrect postures (Shimada *et al*., 1998) present in daily activities as ramp propulsion and over obstacles, seat transfer and weight handling (Bjerkefors *et al*., 2006; Morrow *et al*., 2010) are common problems affecting this population. According to Morrow *et al*. (2010), pain in upper extremities are frequently reported by 32% to 78% of wheelchair users.

2.3 Motor Gesture

The movement executed to propel the wheelchair is described by Shimada *et al*. (1998) as repetitive simultaneous bilateral movement of upper members. Users receive little or no information at all about how to better propel their wheelchairs to minimize injuries (Boninger *et al*., 2002).

Propulsion cycle is composed by two phases: impulse and recovery, as seen on Fig. 2. Impulse phase is the period in which the hand gets in touch with the propulsion rim and applies a force to maintain or increase speed of the wheelchair, whilst the propulsion phase is the period comprehended between consecutives propulsion phases when the arms are retracted for preparation of the next impulse (Kwarciak *et al*., 2009).

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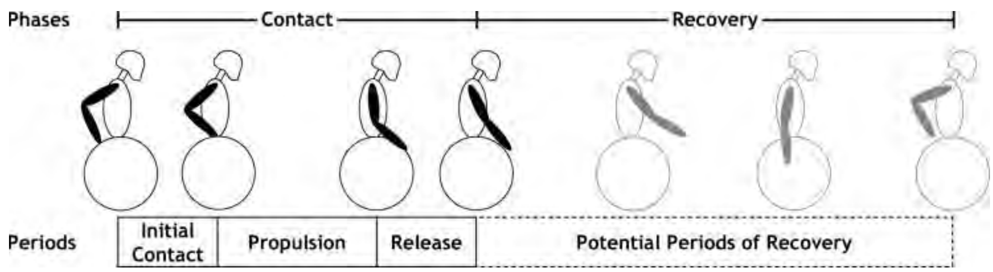

Figure 2. Propulsion cycle with impulse (or contact) phase and recovery phase. Impulse phase is divided in: initial contact, propulsion and release. Source: Kwarciack *et al*. (2009).

One factor that has been highlighted is the movement of the hands before and after the contact with the rim, because it has been related with the mechanical efficiency from the act to propel the wheelchair (Boninger *et al*., 2002; Shimada *et al*., 1998).

The movement pattern was also studied by several authors, resulting in the identification of four predominant types utilized by wheelchair users, as seen on Fig. 3. The patterns are semicircular (SC), single loop (SLOP), double loop (DLOP) (Shimada *et al*., 1998) and arc (ARC) (Kwarciak *et al*., 2009; Boninger *et al*., 2002).

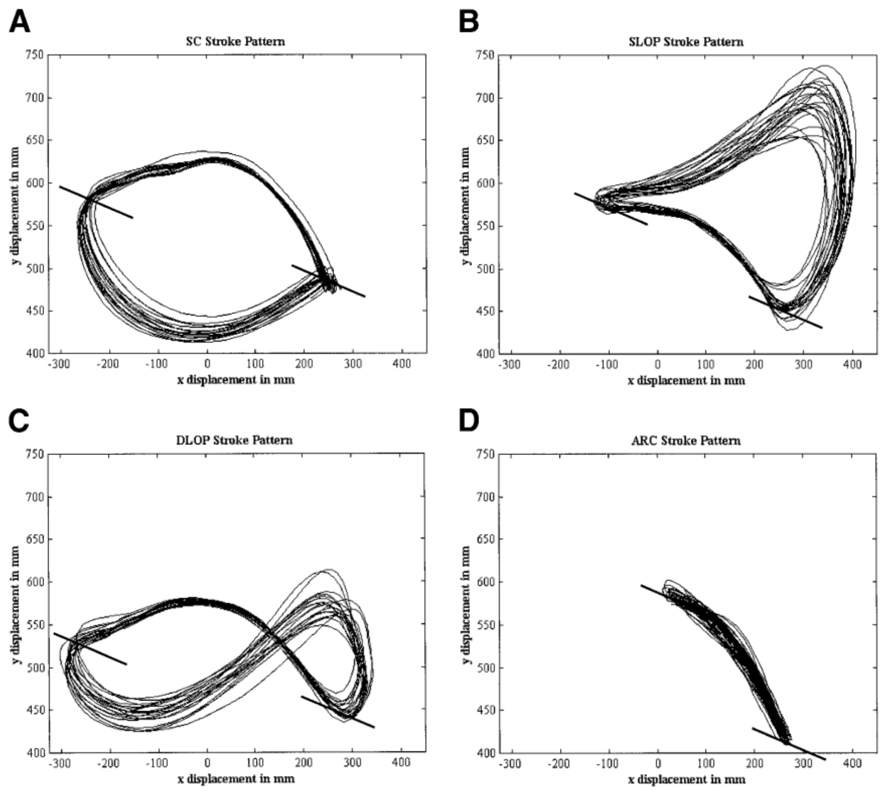

Figure 3. Propulsion patterns (A) semicircular or SC (B) single loop or SLOP (C) double loop or DLOP (D) arc or ARC. The bars separate the phases of impulse and recovery. Source: Boninger *et al*. (2002).

It was found that SLOP pattern is the most used to propel wheelchair, maybe because it's more intuitive, since the person just lifts its hands over the wheels during recovery. However, according to the studies, most indicated pattern to propel the wheelchair is the SC. Although this pattern shows flexion angles and extension significantly bigger compared to the other patterns, maximum and minimum angles are within safe limits and, being so, one concludes that these high amplitudes identified do not predispose users to injuries (Shimada *et al*., 1998). Also according to Shimada *et al*. (1998), this pattern is more biomechanically efficient than others, follows an elliptical trajectory (Boninger *et al*., 2002) and is more advantageous maintain hands below the propulsion rim during recovery phase, letting them accommodate themselves naturally, than of above the rims (Kwarciack *et al*., 2009).

2.4 Ergonomics

It was also identified that the user's position on wheelchair influences propulsion. According Boninger *et al*. (2000), the user's position with respect to the rims propulsion is a significant practical factor. The analysis showed that it is preferable to have a smaller vertical distance between the shoulder and the rim's axle or a lower seat having the same effect. Another conclusion is that the axle more forward that the seat improves the biomechanics of propulsion, reduces the wheel tendency of making curves when descending a sloped surface and reduces vibration of the front wheels.

2.5 Training Protocols

Regarding the training protocols, what it's found in literature are anaerobic exercises, as the Wingate test(Bar-Or, 1987; Franchini, 2002; Novais, 2009; Salgado, 2009), and aerobic exercises, as incremental tests (Knechtle *et al*., 2003; Müller *et al*., 2004). According to authors, more studies and analyses are necessary to obtain better conclusions about developed protocols regarding athletes' training.

Several papers (Cooper *et al*., 1998; Tordi *et al*., 2001; Margonato, 2008) studied the benefit that a regular exercise program can bring to users with little or no training. Some of the benefits identified are improvement of cardiovascular condition, increase of muscular resistance, increase of coronary artery diameter and increase of blood flow. It is noteworthy that even after a short period of training it’s possible to notice an improvement in physical capacity and that the benefits at long-term for wheelchair users, from physiological and psychological standpoints, are the same obtained by able-bodied persons.

Haisma *et al*. (2006) cites the importance of adequate monitoring of exercises and training to evaluate changes in physical capacity, indicating if the training or rehabilitation program in question is being effective.

2.6 Available Equipment and Control Interfaces

As mentioned before, there’s a lack of ergometers to attend the needs of this population. Among the available apparels is the hand cycle ergometer that can be used in initial phases of rehabilitation programs to strengthen the muscles and cardiac rehabilitation (Nilsson *et al*., 1975; Dicarlo, 1998; Andrews *et al*., 1998). Other types of ergometers only adapt the wheelchair in a transmission system with brakes to generate resistance (Langbein *et al*., 1993; Devillard *et al*., 2001; Keyser *et al*., 2001), but, in other hand, succeed in attending the specificity of movements.

Although cheap, these equipment are not available in the market. In other words, it is necessary to project and build one every time the execution of these tests and evaluations are desired (Morrison, 2004).

It’s necessary that ergometry exams' make use of computer-controlled systems and that their systems be electronic or electromagnetic, allowing the normatization of techniques and better control of the load variation and signal monitoring (Guimarães *et al*., 2003).

3. METHODS

The new prototype, ERGO1, includes in its changes a new structure with inertial flywheels, a torquimeter for torque acquisition, load cell under the seat, new computer interface, new mathematical model and new test protocols. These will be presented in the next topics.

3.1 Structure

The new structure was designed aiming to reduce dimensions of previous prototype and to unite the two modules, propulsion and electromagnetic resistance, in one. Weight reduction was also considered and was achieved using aluminum for the majority of parts.

As seen on literature, it is important allow the user to adjust its positioning. With that in mind, a pair of tracks was added on the upper part of the structure allowing the seat to move until the user find the best adjustment. There are 11 positions available that can be set through an adjustment system composed of a pin within a lever system. Seat structure was designed to work as a balance for the addition of the load cell. This particular change was made to provide more comfort to the user avoiding that other equipment were needed, reducing seat transfers. The backrest designed can have its positioning adjusted like the seat. The parts that needed to be fixed or united were welded to minimize vibrations and make the structure rigid.

To evaluate the proposed structure against the imposed loads, a three dimensional finite element model was implemented. The type of simulation chosen was static, with contacts between parts defined as “bonded”. Load was applied on seat surface with maximum value of load cell which is 300 kg or 2943 N.

The structural design assessment was done by analysis of displacement field and Von Mises stresses. Since the seat frame is movable, which influences the distribution of the force applied to the structure, three simulations were made

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being one to the minimum position of the seat, one for the middle and one for the maximum. The higher tension value was found for the maximum position

Considering a safety factor of about three times the highest tension to which the structure was subjected, found for the seat in the maximum position, one obtains a value of 56,6 MPa for the Von Mises stresses, which is much lower than the yield strength for aluminum, which is in the order of 280 MPa. Therefore, one concludes that the designed ergometer structure supports load conditions of the project.

3.2 Inertial Flywheels

During the tests of the first prototype was verified that the torque imposed by the resistance system is pulsating because of the way that the electromagnetic brake operates. Due to the propulsion rim be light, resistance system often made that they significantly reduced their speed or even stop. This effect influences the sensation of movement of the rims that should offer a resistance to movement with a minimum speed at each thrust of the rim, simulating an operating condition closest to the daily situation of a wheelchair dislocation. Given this, to provide this effect were designed a pair of inertial flywheels to minimize torque peaks and standardize the effective force applied to the rims of propulsion, thus providing a smoother movement.

To suit the flywheel to the ergometer, it is necessary to find the amount of energy required to achieve the desired smoothing degree and determine the inertial moment needed to absorb this energy. Through the data obtained in the tests of the previous prototype, ERG-CR09, and using the Eq. (1) until (3) from EL-Naggar and Kholeif (2011) for the design of an inertial flywheel composed by an external ring concentric with a solid disc, seen below,

$$m = \pi\frac{\gamma}{g}r_D^2 t_e + \pi\frac{\gamma}{g}(r_o^2 - r_i^2)b_a \tag{1}$$

$$I_V = \frac{\pi\gamma}{2g}\left[r_D^4 t_e + (r_o^4 - r_i^4)b_a\right] \tag{2}$$

$$\frac{2gI_V}{\pi\gamma} = r_i^4 t_e + (r_o^4 - r_i^4)b_a \tag{3}$$

where m is the mass of the flywheel, r_D is the solid disc radius, r_o and r_i are the external and internal radius of the ring, t_e is the thickness of the solid disc, b_a is the thickness of the ring, g is the gravity, I_V is the desired moment of inertia and γ is the weight density of the material.

Adopting a fluctuation coefficient compatible with the desired effect, moment of inertia was calculated as 18,81 kg.m². Some of the geometric parameters as total diameter, ring diameter and ring thickness were also adopted according to the needs, resulting in a thickness of 14 mm for the main part and weight of 40 kg for each flywheel.

3.3 System for Weight Acquisition

One of the problems found in the first prototype of the ergometer was to obtain the user's weight. Since the test protocol requires the user's weight to calculate the recommended load to be selected, it was necessary to perform weighing of every user before the test in a separate balance. This step, in addition to requiring an extra handset for protocol implementation, became complicated and uncomfortable for the user. Based on this framework, we developed a seat adapted to measure the weight. For this, a load cell was coupled under the seat.

Initially, some commercial items of equipment for powering and signal amplification for load cells were tested. Since none reached the stability and sensibility desired for the project, it was decided to design and build a dedicated circuit to do this part. The designed circuit has an active low-pass filter and a limiter for the output of 9,1V because the maximum input of the acquisition system is 10V. The designed board can be seen on Fig. 4.

Figure 4. Designed board.

3.4 Electromagnetic Resistance System

The resistance system used in this prototype is similar to the one from ERG-CR09. The system comprises a generator for self-powering and an electromagnetic brake responsible for generating the resistante torque. These two components are controlled by computer through a dedicated board, allowing to choose the desired braking level. The output of the braking system is coupled through an axle to a belt transmission system that aims to amplify the resistant torque generated and transmit this to the axle of the propulsion rims. This system can be seen in the schematic of Figure 5.

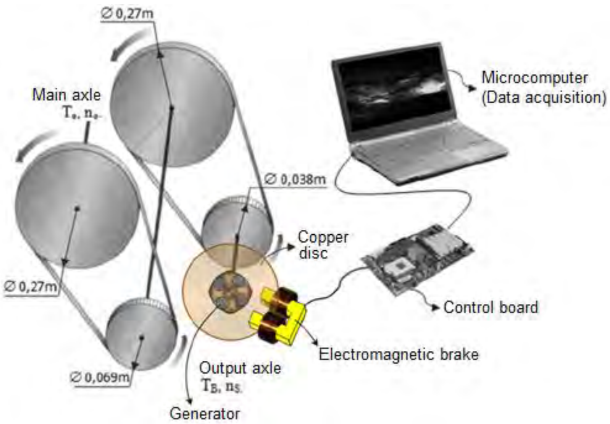

Figure 5. Electromagnetic resistance system used in ERG-CR09 and ERGO1. Source: Salgado (2009).

What occurs in this configuration is that according to the principle of Foucault, induced currents circulating in the opposite direction to the disk are generated on its surface. This energy generated is then dissipated through Joule effect on the metallic conductor producing the braking force responsible for the decrease of the angular velocity of the disk (García, 2008). Final equation for the system is given by Eq. (4) seen below,

$$F_P = 91{,}157[C + A.\cos(4\omega.t)]\omega + 3{,}279.I_V.(\alpha_0 + \omega.t) \tag{4}$$

where F_P is the propulsion force necessary for the user to propel the propulsion rims; A is a constant dependent of the magnetic field from the permanent magnet, spirals number, area of the generator coils and the distance from the copper disc center to the point where the magnetic force acts; C is a constant dependent of the material properties of the disc, magnetic field, dimensions of the area subjected to the magnetic force and total radius; I_V is the moment of inertia from the flywheels; ω is the angular velocity; α_0 is the initial angular acceleration and t is the time.

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3.5 Project of the Torquimeter

To evaluate the power developed by the user on the machine according to the effort that is being employed, a torquemeter was designed to be used in the ergometer. The device in question uses strain gauges forming a complete circuit of the Wheatstone bridge.

The torquemeter was mounted directly on the propulsion axle of the ergometer. In this case when the axel is subjected to a torque, the plans of maximum or principal stress are known (Hibbeler, 2004). These planes are planes inclined at 45 ° to the horizontal plane containing the center line of the shaft.

3.6 Application Developed in LabVIEW Platform

For the execution of the physical conditioning tests involving control the electromagnetic resistance system, get the user's weight and obtain as response power levels, fatigue index and energy parameters, an application was developed in LabVIEW to interface with the user and perform all the necessary acquisition and control of the system. This language was chosen due to the ease of implementation not only of a friendly interface, but also of the acquisition and manipulation of signals.

3.7 Test Protocols

The test protocols used were Wingate (Franchini, 2002; Bar-Or, 1987; Novais, 2009) and a incremental protocol developed for the ergometer. Besides the fatigue index, power and energy (Salgado, 2009), a new analysis of physical capacity was developed based on the energy curve obtained for each user. The project had the approval of the ethics committee.

4. RESULTS

Figure 6 shows one of the volunteers ready to begin its test.

Figure 6. User ready for test protocol.

4.1 Wingate Protocol

Figures 7 and 8 shows the result obtained for the Wingate test protocol.

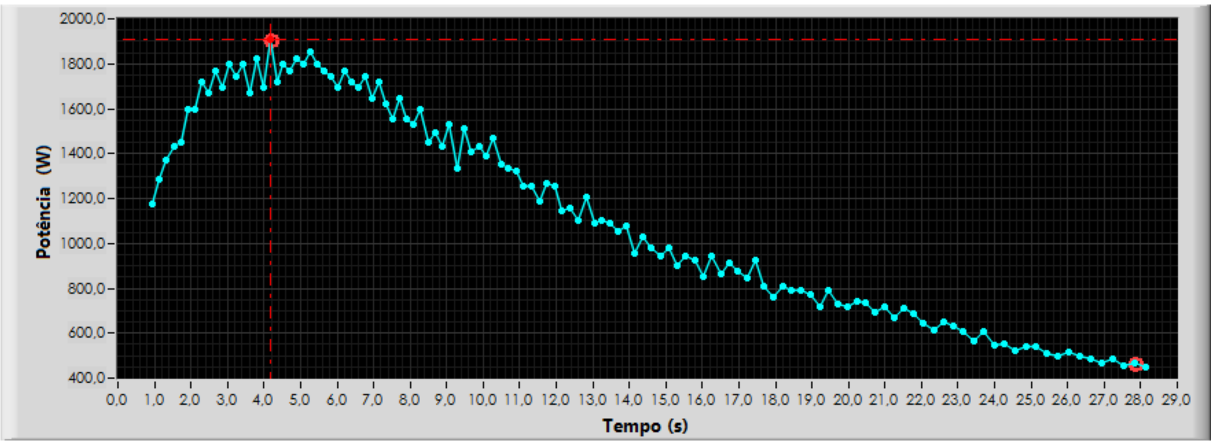

Figure 7 – Absolute power for the volunteer M.P.S.

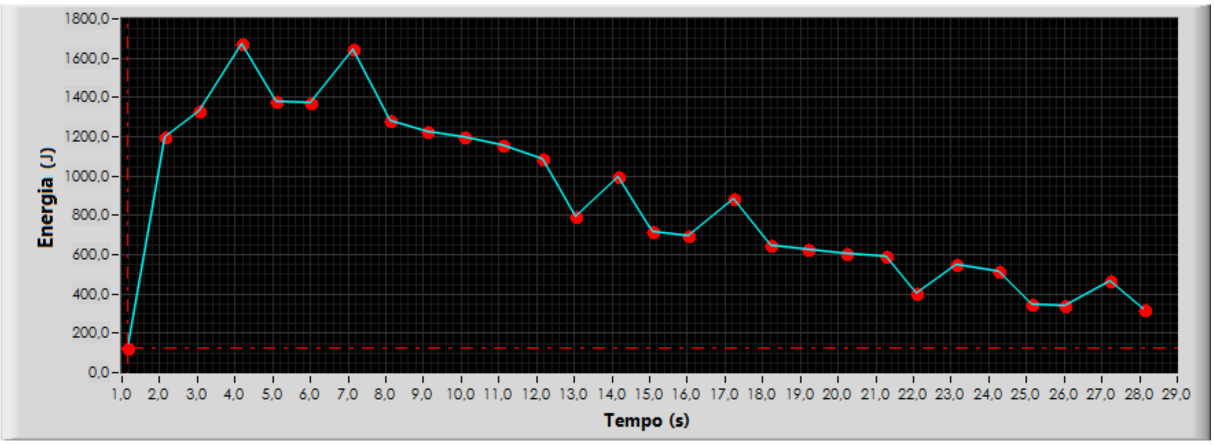

Figure 8 – Absolute energy for the volunteer M.P.S.

As seen on Fig. 7, the power signal is soft concerning the peak amplitudes, allowing better observation of the user's performance. It's also possible to notice more directly the drop of efficiency due to muscular fatigue. This is now possible because of the addition of the inertial flywheels. Energy is calculated trough the absolute power using a sample time determined by the user on the control software. High values seen on graphic are also due the addition of the flywheels that end up amplifying the standard values for a person executing exercises without equipment or in equipment without flywheels. Fatigue was calculated and reached 75,54% which represents the loss of physical capacity.

4.2 Incremental Protocol

These results show a variation in the signal throughout the test. This occurs due to the inherent feature of the protocol where the user starts from the rest and must maintain a rhythm within the range determined. Therefore, the highest points of the curves correspond to the times when the user was near the upper limit of the allowed range and lowest points at the times when the user was near the lower limit of the range delimited. Another factor influencing the sampled peaks is that the capture of the point can occur either at the time the pulse is done, that is, the hands are in contact with the rim of propulsion, as well as in the resting phase of propulsion, when hands are traversing the path outside the hoops to prepare new momentum, which leads to a lower speed due to the deceleration caused by the inertia of the system and the braking. Figures 9 and 10 shows the result obtained for the Wingate test protocol.

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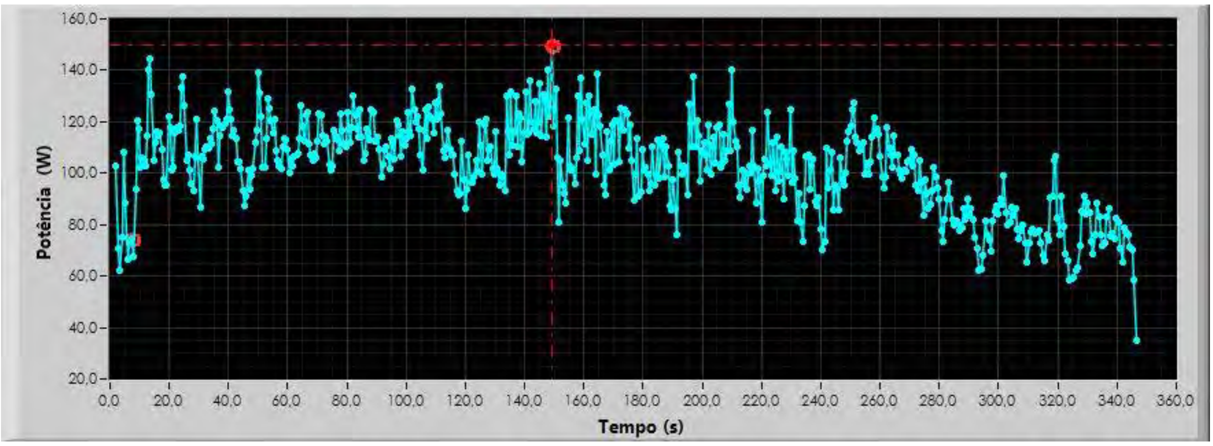

Figure 9. Absolute power for the volunteer G.L.M.

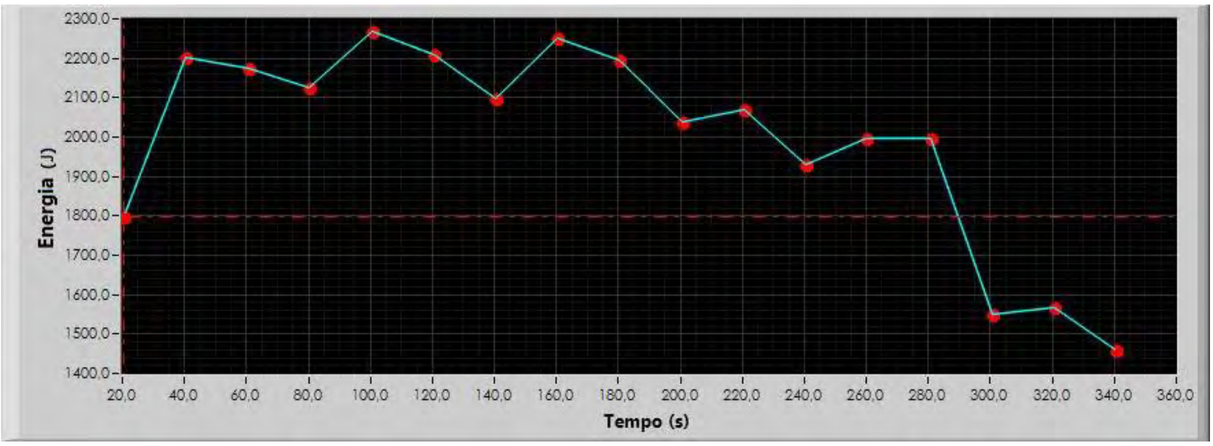

Figure 10. Absolute energy for the volunteer G.L.M.

As can be seen in Fig. 9 and 10, the drop in user's efficiency has also become visible in this protocol. For the user in question, it is possible to see that the income fall began with 260 seconds of the test, ie, 4 minutes and 20 seconds. Considering the load increment every two minutes means that the user failed to keep pace imposed soon after the move to level three of resistance. Again, high values seen on graphic are due the addition of the flywheels that end up amplifying the standard values for a person executing exercises without equipment or in equipment without flywheels.

4.3 Curve of Physical Capacity

During the analysis of the results of the tests, a new way of evaluating the physical conditioning was proposed. This new analysis is based on the calculation results of average energy equivalent and fatigue index, calculating how much of the physical capacity that these individuals showed throughout the test. To execute this analysis, the power curve of each of the users was been treated to remove points which could be outside the overall behavior shown. Figure 11 shows the results of four volunteers.

This adjustment curve represents the decrease curve of physical fitness of each one of the volunteers evaluated. Concerning training and rehabilitation of physical conditioning, this curve becomes interesting even if the final value of fatigue indicated by it is the same as the fatigue index calculated through the power, because it is possible to visualize the evolution of the fatigue of each.

From this new analysis, one verifies that there is a tendency for the loss of energy by the user. This reduction of their physical capacity throughout the test approximates a linear behavior.

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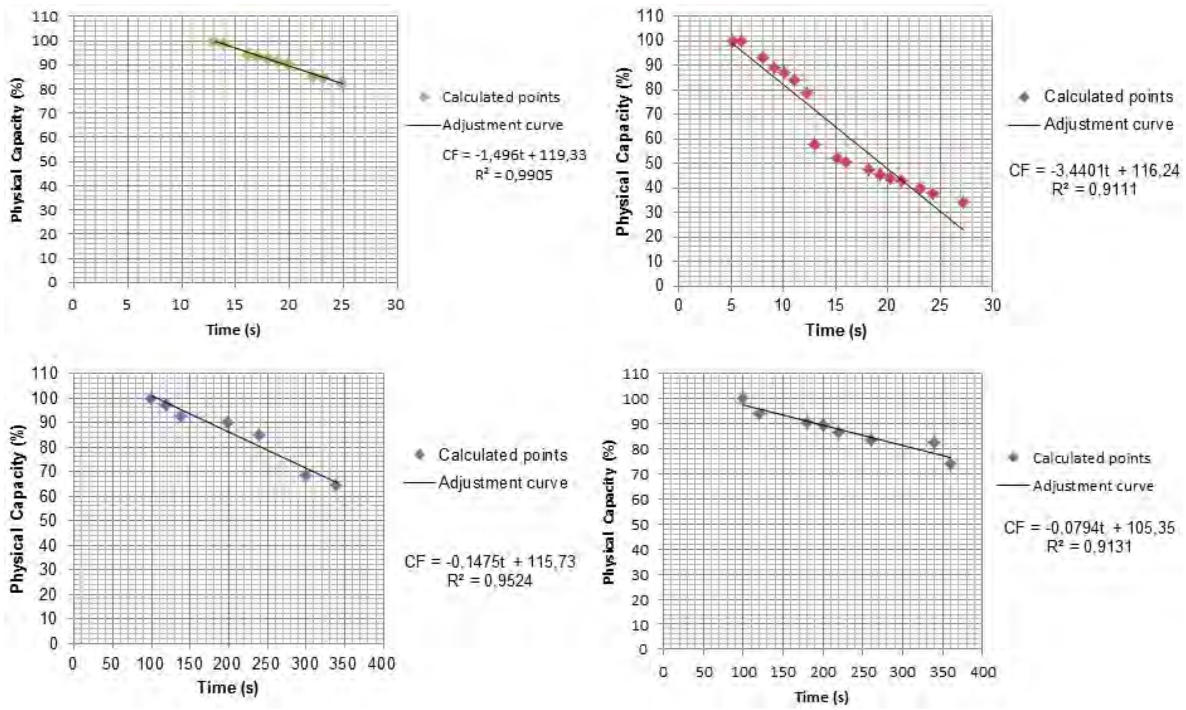

Figure 11. Curve of physical capacity for four volunteers evaluated.

5. CONCLUSIONS

The new wheelchair ergometer prototype has reduced dimensions and weight compared to the previous one, and the propulsion module and the electromagnetic resistance module were mounted on the same structure. This prototype allows the user to position itself more comfortably with respect to the motor gesture, by adding ergonomic adjustments for the seat and backrest. Beginning of the test also became more practical since the user's weight is now captured by the load cell in the seat.

Inertial flywheels added fulfilled their role, softening the acquired signal and preventing the braking force generated by the electromagnetic resistance system interrupt the movement as before.

The tests performed showed a behavior tendency for the new method proposed for determining the physical capacity, despite the low number of tests performed at this preliminary stage of evaluation. This trend should be confirmed by performing tests with a larger number of volunteers.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

Andrews, J. R.; Harrelson, G. L.; Wilk, K. E., 1998, “Reabilitação Física das Lesões Desportivas”, 2 ed., Ed. Guanabara Koogan S. A., 504p.

Bar-Or, O., 1987, “The Wingate anaerobic test: an update on methodology, reliability and validity”, Sports Medicine 4, p. 381-394.

Bjerkefors, A.; Jansson, A.; Thorstensson, A., 2006, “Shoulder muscle strength in paraplegics before and after kayak ergometer training”, European Journal of Applied Physiology 97, p. 613-618.

Boninger, M. L.; Baldwin, M.; Cooper, R. A.; Koontz, A.; Chan, L., 2000, “Manual wheelchair pushrim biomechanics and axle position”, Archives of Physical Medicine and Rehabilitation 81, p. 608-613.

Boninger, M. L.; Souza, A. L.; Cooper, R. A.; Fitzgerald, S. G.; Koontz, A. M.; Fay, B. T., 2002, “Propulsion patterns and pushrim biomechanics in manual wheelchair propulsion”, Archives of Physical Medicine and Rehabilitation 83, p. 718-723.

Devillard, X.; Calmels, P.; Sauvignet, B.; Belli, A., Denis, C.; Simard, C.; Gautheron, V., 2001, “Validation of a new ergometer adapted to all types of manual wheelchair”, European Journal of Applied Physiology, v. 85, p. 479-485.

Dicarlo, S. E.; Supp, M. D.; Taylor, H. C., 1983, “Effect of arm ergometry training on physical work capacity of individuals with spinal cord injuries”, Physical Therapy 63, p. 1104-1207.

ISSN 2176-5480

EL-Naggar, B. B.; Kholeif, I. A. Disk-Rim flywheel of minimum weight. Journal of American Science, v. 7, n. 6, p. 146-149, Junho 2011.

Franchini, E., 2002, “Teste anaeróbio de Wingate: Conceitos e aplicação”, Revista Mackenzie de Educação Física e Esporte 1, p. 11-27.

García, A. F., 2005, “Electromagnetísmo”. Disponível em: <http://www.sc.ehu.es/sbweb/fisica/elecmagnet/induccion/foucault/foucault.htm> Acesso em: 15 dez. 2010.

Guimarães, J. I.; Stein, R.; Vilas-Boas, F.; Gavão, F.; Nóbrega, A. C. L.; Castro, R. R. T.; Herdy, A. H.; Chalella, W. A.; Araújo, C. G. S.; Brito, F. S., 2003, “Normatização de técnicas e equipamentos para realização de exames em ergometria e ergoespirometria”, Arquivos Brasileiros de Cardiologia, v. 80, p. 457-464.

Haisma, J. A.; Van Der Woude, L. H. V.; Stam, H.J.; Bergen, M.P.; Sluis, T. A. R.; Bussmann, J. B. J., 2006, “Physical capacity in wheelchair-dependent persons with a spinal cord injury - a critical review of the literature”, Spinal Cord 44, p. 642-652.

Hibbeler, R.C., 2004, “Resistência dos Materiais”, 701p, LTC, Rio de Janeiro.

Hjeltnes, N.; Jansen, T., 1990, “Physical endurance capacity, functional status and medical complications in spinal cord injury subjects with long-standing lesions”, Paraplegia 28, p. 428-432.

Keyser, R. E.; Rodgers, M. M.; Rasch, E. R., 2001, “Reliability of cardiorespiratory measurements during wheelchair ergometry”, Journal of Rehabilitation Research and Development, v. 38, p. 423-430.

Knechtle, B.; Hardegger, K.; Müller, G.; Odermatt, P.; Eser, P.; Knecht, H., 2003, “Evaluation of sprint exercise testing protocols in wheelchair athletes”, Spinal Cord 41, p. 182-186.

Kwarciack, A. M.; Sisto, S. A.; Yarossi, M.; Price, R.; Komaroff, E.; Boninger, M. L, 2009, “Redefining the manual wheelchair stroke cycle: Identification and impact of nonpropulsive pushrim contact”, Archives of Physical Medicine and Rehabilitation 90, p. 20-26.

Langbein, W.; Robinson, C. J.; Kynast, L.; Fher, L., 1993, “Calibration of a new wheelchair ergometer: the Wheelchair Aerobic Fitness Trainer”, IEEE Transactions on Rehabilitation 1, p. 49-58.

Margonato, V., 2008, “Effects of training on cardiorespiratory fitness and lipidic profile of paraplegics”, Sport Sciences for Health 3, p. 7-9.

Morrison, S. A., 2004, “Guidelines for the Clinician for Development of Fitness Programs for the Physically Challenged”, In. APPLE, D. F. Physical Fitness: A Guide for Individuals with Spinal Cord Injury. Baltimore: DIANE Publishing, cap. 3, p. 33-44.

Morrow, M. M. B.; Hurd, W. J.; Kaufman, K. R.; An, K.-N., 2010, “Shoulder demands in manual wheelchair users across a spectrum of activities”, Journal of Electromyography and Kinesiology 20, p. 61-67.

Müller, G.; Odermatt, P.; Perret, C., 2004, “A new test to improve the training quality of wheelchair racing athletes”, Spinal Cord 42, p. 585-590.

Muraki, S.; Tsunawake, N.; Tahara, Y.; Hiramatsu, S.; Yamasaki, M., 2000, “Multivariate analysis of factors influencing physical work capacity in wheelchair-dependent paraplegics with spinal cord injury”, European Journal of Applied Physiology 81, p. 28-32.

Nilsson, S.; Staff, P. H.; Pruett, E. D. R., 1975, “Physical work capacity and the effect of training on subjects with long standing paraplegia”, Scandinavian Journal of Rehabilitation Medicine 7, p. 51-56.

Novais, D. V., 2009, “Projeto e construção de um ergômetro para cadeirantes”, Dissertação de Mestrado, Universidade Federal de Uberlândia.

Salgado, G. L. A. C., 2009, “Análise de um sistema de geração de resistência eletromagnético utilizado em um ergômetro para cadeirantes”, Dissertação de Mestrado, Universidade Federal de Uberlândia.

Shimada, S. D.; Robertson, R. N.; Boninger, M. L., Cooper, R. A., 1998, “Kinematic characterization of wheelchair propulsion”, Journal of Rehabilitation Research and Development 35, p. 210-218.

Steele, C. A.; Kalnins, I. V.; Rossen, B. E.; Biggar, D. W.; Bortolussi, J. A.; Jutai, J. W., 2004, “Age-related health risk behaviors of adolescents with physical disabilities”, Social and Preventive Medicine 49, p. 132-141.

Tordi, N.; Dugue, B.; Klupzinski, D.; Rasseneur, L.; Rouillon, J. D., Lonsdorfer, J., 2001, “Interval training program on a wheelchair ergometer for paraplegic subjects”, Spinal Cord 39, p. 532-537.

Yekutiel, M.; Brooks, M. E.; Ohry, A.; Yarom, J.; Carel, R., 1989, “The Prevalence of Hypertension, Ischaemic Heart Disease and Diabetes in Traumatic Spinal Cord Injured Patients and Amputees”, Paraplegia 27, p. 58-62.

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