LOW COST TORQUEMETER FOR WHEELCHAIR ERGOMETER

"PROJECT OF NH/RESP"

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Abstract. *A new prototype of a wheelchair ergometer was developed aiming to be faithful to the motor gesture made by wheelchair users. Along with this prototype there is the development of a low cost torquemeter capable of acquiring signals, easy to mount and dismount and more resistant to the environment around. Static and dynamic calibrations were made and tests with Wingate protocol were performed to evaluate effectiveness of the project. Variables measured were heart rate, blood pressure, power, energy and fatigue index. Although results showed that the torquemeter needs a few adjustments, power curves obtained with the protocol presented a characteristic behavior as previously seen in an early assembly of the prototype where instrumentation was permanent.*

Keywords*: Wheelchair ergometer, Physical Evaluation, Torquemeter*

1. INTRODUCTION

One of the possible ways to evaluate physical conditioning is using ergometers. However, when the subjects to be evaluated are persons with disabilities, most equipments are derived from tests that already exist for able-bodied persons and, normally, do not perfectly adapt to the motor gesture naturally executed by those who uses wheelchair, which is the propulsion through the application of a force on the propulsion rims.

According to this, the Mechanical Projects Laboratory at the Federal University of Uberlândia developed in 2007 a prototype for a wheelchair ergometer. More recently, in 2012, at the new Habilitation/Rehabilitation Center in Paralympic Sports (NH/RESP) this prototype went through several updates to improve its performance and comfort for the user. This new version was built to operate with a torquemeter that could be assembled and disassembled from its location whenever necessary, making maintenance easier and allowing updates to be done with minor impacts on the system.

This paper aims to show the project of this torquemeter, its calibration processes and the results obtained with it in tests using Wingate protocol to obtain a previous evaluation for the equipment developed.

2. STATE OF THE ART

The term physical capacity can be described as the capacity of the cardiovascular system, muscles and respiratory system to provide a certain level of physical activity and is reduced in persons with spinal cord injury due to a loss in motor control and influence of sympathetic nervous system below injury level (Haisma et al., 2006). A low level of physical capacity contributes to cardiovascular complications and reduction of life quality (Hjeltnes e Jansen, 1990; Yekutiel, 1989).

According to Cooper et al. (1998), a regular exercise program executed during long periods can bring important cardiovascular benefits. The authors also state that monitoring heart rate by computer in a minimum supervised environment reduces the risk of injuries or overcharging the patient. Therefore, this control can have important implications for cardiac rehabilitation and exercises.

3. ERGO1

The prototype uses an electromagnetic resistance system to provide the load to be overcome by the user. The equipment is controlled by computer through software developed in LabVIEW. This control software has real-time information and other parameters for monitoring. Output variables are power, fatigue index, angular speed, torque and energy, being the latest presented by Novais (2009) and Salgado (2009).

Among these variables, the angular speed and torque are the basis for calculation of the others. While a simple encoder attached to the system acquires the angular speed, the torque uses a torquemeter built for this project.

4. TORQUEMETER

The electromagnetic brake has resistance levels triggered by respective voltage levels. In order to evaluate the power exerted by the user in the equipment in accordance with the effort being employed, a torquemeter was developed. The equipment in question was designed to be modular so it can be removed at any time when necessary. Its form consists in a cylinder, with a compartment for electrical contact and wire terminals.

Measurement of deformation is made by strain gauges. When the axle is subjected to a torque, the planes of principal (or maximum) stress are known (Hibbeler, 2004). Combining the equations for principal and shear stress on a cylindrical bar with the effect of an elemental angular distortion on the axle, Hooke law and the concept of torque, one obtain the equations for the maximum supported forces on the axle and torquemeter. Applying project dimensions and material data, one finds that the limiting factor for this system is the force supported by the axle which is 1126,6 N.

4.1. Static Calibration

Static calibration of this system was performed by locking the transmission system and applying a known load through standardized masses in a support attached to the closest flywheel. The analytical torque calculated could then be related with the electrical signal generated.

For this part a system for signal acquisition and analysis from the Lynx company model AC2122 was used. The module was configured with signal gain of 1000 and 5 V of excitation voltage. Table 1 shows the calibration data obtained.

Table 1: Calibration parameters after analysis

Se (V/N.m)	Offset (V)	Residue (V)
0,0057	-0,0120	0,0202

4.2. Dynamic Calibration

Due to limitations of the acquisition system that produced wrong values for both torque and angular speed in real-time acquisition, it became necessary to adjust a curve for dynamic torque in terms of angular speed.

Experimental setup for this calibration was made using a frequency inverter to control an induction motor that is attached to the main axle of the ergometer. The procedure consisted in acquiring a torque curve for each level of resistance at speeds of 15, 25, 35, 45, 60, 80 and 95 RPM. In the Fig. 1 below is presented the equation and curve obtained for the first level of the electromagnetic resistance system.

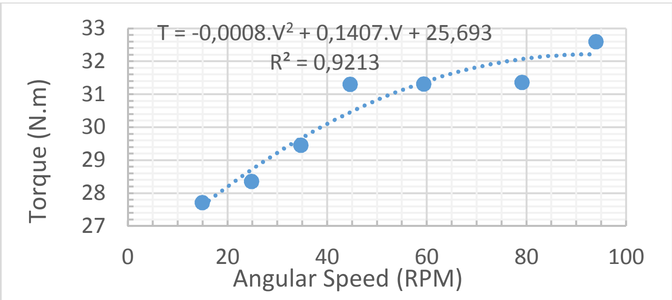


Figure 1: Curve for dynamic calibration of level 1.

As seen on Fig. 1, resistance torque becomes higher along with the increase of angular speed. This is a characteristic from the kind of electromagnetic system used.

5. TEST PROTOCOL

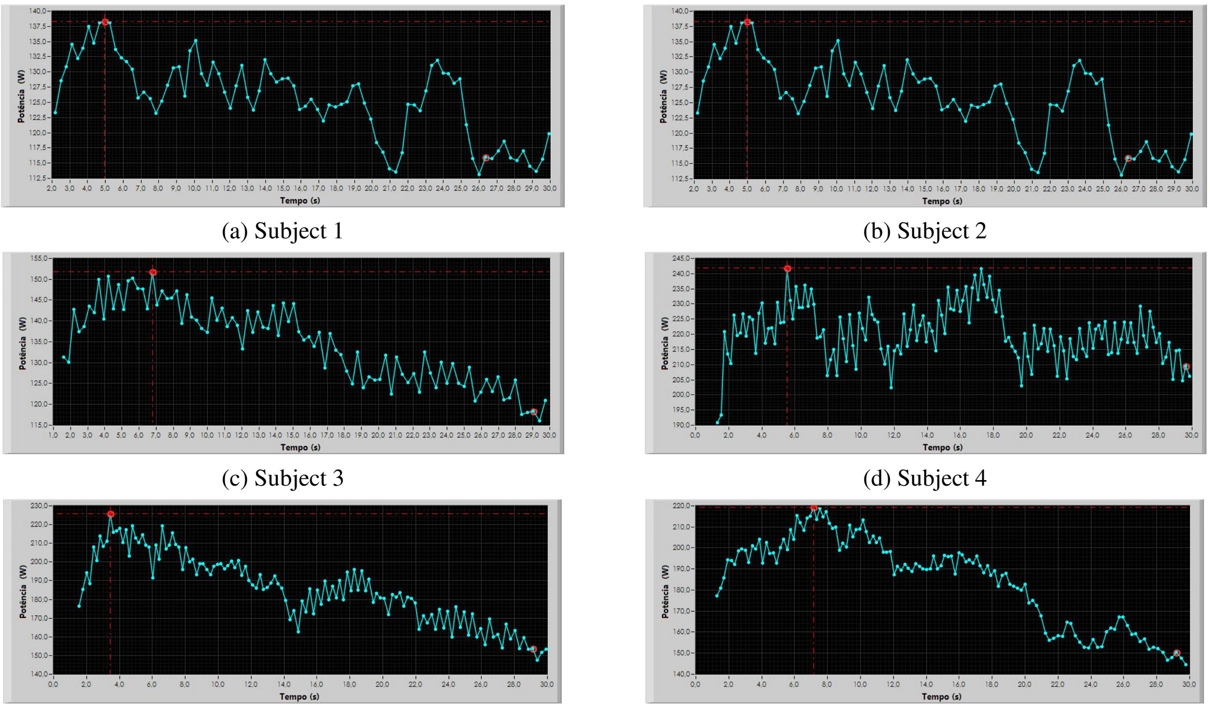
Protocol used for the tests was the Wingate protocol. This protocol consists in overcoming a fixed resistance using maximum possible effort during 30 seconds (Bar-Or, 1987; Franchini, 2002; Novais, 2009; Salgado, 2009). Subjects had a 5 minute warm-up stage with no load on the equipment before the beginning. For now, only able-bodied persons tested the equipment and only the first level of the resistance system was used. None of them is an athlete. Subjects' are three male and three female with medium age of 30,17 ± 7,8 and weight of 70,67 ± 16,5 kg.

6. RESULTS

Data of the volunteers acquired with the Wingate test performed are shown in Tab. 2 where maximum power indicates the peak reached by the subject during the protocol and minimum power is the value presented by the subject at the end of the protocol. Figure 2 shows the absolute power curve for each subject. Table 3 shows a comparison between this study and previous ones.

Table 2: Results in terms of power and energy for the Wingate protocol.

Volunteer	Absolute Power (W)		Relative Power (W/kg)		Average Equivalent Energy (J)		Relative Average Equivalent Energy (J/kg)	
	Max	Min	Max	Min	Max	Min	Max	Min
1	138,30	113,09	3,07	2,58	249,36	164,41	5,54	3,65
2	146,58	114,91	2,33	1,91	255,89	203,75	4,06	3,23
3	151,86	116,14	2,41	1,88	253,76	204,48	4,02	3,24
4	241,79	203,06	2,75	2,38	426,89	368,35	4,85	4,18
5	225,84	147,69	2,82	1,92	388,92	244,01	4,86	3,05
6	219,30	144,70	2,58	1,77	386,88	250,75	4,55	2,95



(a) Subject 1

(b) Subject 2

(c) Subject 3

(d) Subject 4

(e) Subject 5

(f) Subject 6

Figure 2: Absolute power curve for each subject.

Regarding Tab. 2 and Fig. 2, subject 4 shows a more different behavior due to a problem in the system that regulates seat position, making the user slide while performing the protocol, thus impairing its performance.

Through the curves from Fig. 2, one can see a tendency where the user first reaches its peak of performance and then starts to lose power until the end of the test. This tendency is the same as the one presented in the previous assembly when instrumentation was made directly on the propulsion axle, as seen on Fig. 3.

Table 3: Comparison between studies.

	Peak Power (W)	Mean Power (W)
Current Study	199 ± 40,9	167,6 ± 44,4
Molik et al. (2013)	384,9 ± 83,9	232,4 ± 43,5
Vanlandewijck et al. (1999)	-	852,1 ± 234,9
Dallmeijer et al. (1994)	310,3 ± 75,6	49,1 ± 12,6
Hutzler (1993)	393,24 ± 68,76	324,01 ± 55,93

According to the results obtained from the tests executed and the comparison with results from similar studies, one can see there the values obtained are close but do not follow a tendency. This might be due to the torquemeter calibration, which presented torque values for level 1 too close from each other between angular speed ranges. This differs from manufacturer's data and calibration of previous versions of this prototype. In addition, the values presented in this study do not represent the real final state of exhaustion showed by the subjects after the tests. Another point to be taken in account is the movement specificity, as some studies in the comparison where executed in arm crank ergometers and others in wheelchair ergometers that, actually, are a wheelchair over a treadmill or

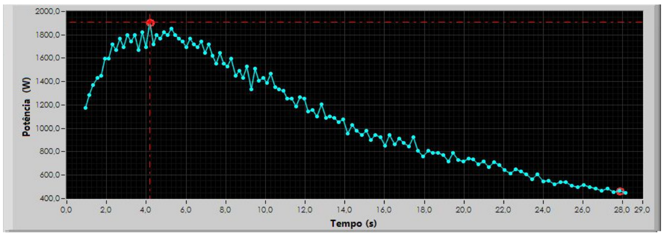


Figure 3: Power curve from a volunteer using previous version of the prototype in a Wingate test.

Regarding heart rate – which is presented in Fig. 4 – all subjects showed practically the same behavior. Subjects 3, 4 and 5 have a more active life style doing exercises regularly, which explains the minor values for heart rate than the others. Also, it was noticed that heart rate tends to increase faster until approximately the 12 second mark and increasing in a lower rate after that.

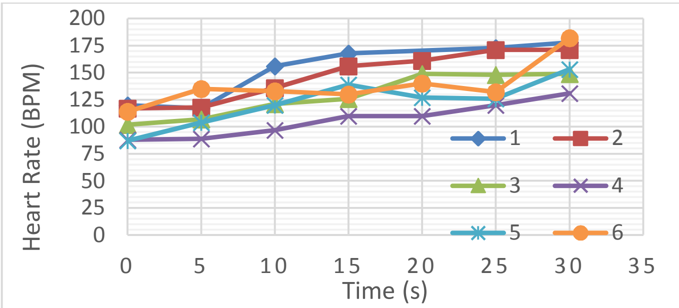


Figure 4: Heart rate of the subjects.

The torquemeter was then disassembled to be analyzed in an attempt to discover the reasons that led to the differences pointed before. The authors found that, after several hours of use, the system responsible for transferring the signal from the transducers to the output terminals had left a residue on the tracks that wasn't expected. After a complete cleaning of each part and reassemble, a new calibration process was made following the same procedures. Regarding static calibration, the data obtained were the same, but for the dynamic calibration of torque related to angular speed new results were obtained, as seen on Fig. 5 and Tab. 4.

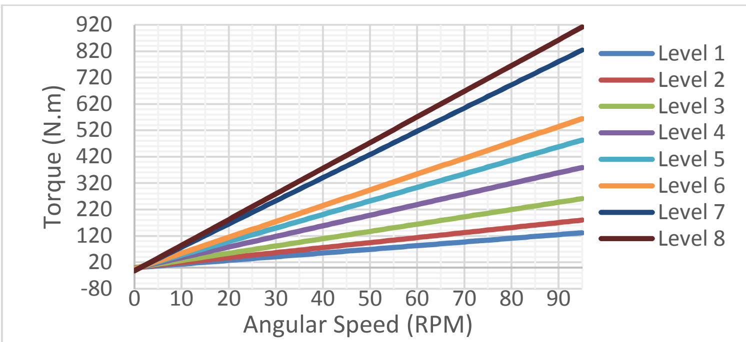


Figure5 – Curve for dynamic calibration for all levels.

Table 4: Data obtained from new calibration

	Curve Equation	**Mean Torque from Brake Manufacturer (N.m)**	**Obtained Mean Torque (N.m)**
Level 1	$T = 0{,}4124.RPM^{0{,}6792}$	5	5,72
Level 2	$T = 1{,}523.RPM^{0{,}449}$	10	8,478
Level3	$T = 1{,}5197.RPM^{0{,}5422}$	15	12,22
Level 4	$T = 1{,}0226.RPM^{0{,}7271}$	20	17,2
Level 5	$T = 0{,}7794.RPM^{0{,}8503}$	25	21,57
Level 6	$T = 0{,}6148.RPM^{0{,}9436}$	30	24,82
Level 7	$T = 0{,}3056.RPM^{1{,}2073}$	35	36,66
Level 8	$T = 0{,}2518.RPM^{1{,}2805}$	40	40,94

As seen on these results, this second calibration is closer to manufacturer's data and provides a good behavior for level characterization.

7. CONCLUSIONS

The wheelchair ergometer prototype equipped with the torquemeter designed was able to assess the performance of individuals but still needs some modifications, since the material used on this version produces residues that can interfere in signal acquisition. Nevertheless, the overall behavior obtained were the same as presented in the previous assembly of this version of the prototype and within expectation, allowing the evaluator to identify the peaks and decrease of performance more easily. More tests are now needed to evaluate the second dynamic calibration and confirm this tendency.

Although it wasn't predicted at the beginning of the project, once this torquemeter is fully adjusted with proper corrections, it may be used for measurement in other systems by changing its coupling parts.

8. REFERENCES

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10. RESPONSABILITY FOR THE INFORMATION

The authors are the only responsible for the content of this work.