# TORQUEMETER FOR EVALUATION OF PHYSICAL CONDITIONING WITH WHEELCHAIR ERGOMETER

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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. This prototype went through several modifications and one of them is the development of a torquemeter capable of acquiring necessary signals, easy to mount and dismount and more resistant to the environment that it has to stand. This piece of equipment also aims to be of low cost. Static and dynamic calibrations were made and tests with Wingate protocol were performed to evaluate effectiveness of the project. Although results showed that the torquemeter needs a few adjustments, there was a characteristic behaviour presented 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 modifications and updates to improve its performance and comfort for the user.

One of the main changes in this equipment is located on the system that acquires the effort made by the user. On previous prototype the instrumentation used for this was mounted directly on the axle of propulsion. For one side, it showed good sensitivity, but on other hand maintenance was hampered because there wasn't a way to dismount it without damaging the system.

Following this scenario, the new prototype was built to function 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. This characteristic 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). Age, gender, occupation and level of physical activity are all factors that also have influence on this (Muraki et al., 2000). 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 of time 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. So, this control can have important implications for cardiac rehabilitation and exercises.

Among the many existents protocols for physical evaluation, the wingate protocol (Bar-Or, 1987; Franchini, 2002; Novais, 2009; Salgado, 2009) is one of the most used. It consists of a 30 second test in which the user must overcome a fixed resistance.

## 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 a software developed in LabVIEW. This control software has realtime graphics and other parameters for monitoring. Output variables are power, fatigue index, angular speed, torque and energy, being the latter 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 tube, with a compartment for electrical contact and wire terminals.

Measurement of tube deformation is made by strain gauges. The device was mounted on the resistance system axle. In this case, 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 and 2 shows the calibration data obtained.

Table 1: Calibration data

| Mass (kgf) | Torque (N.m) | Voltage (V) |
|---|---|---|
| 0 | 0 | -0,0003 |
| 6,384 | 18,79 | 0,0806 |
| 16,571 | 48,77 | 0,2618 |
| 26,662 | 78,47 | 0,4352 |
| 27,653 | 81,38 | 0,4449 |
| 32,133 | 94,57 | 0,5246 |
| 36,244 | 106,67 | 0,5960 |
| 46,247 | 136,10 | 0,7605 |
| 51,308 | 151,00 | 0,8392 |
| 54,397 | 160,09 | 0,8908 |
| 58,118 | 171,04 | 0,9583 |

Table 2: Calibration parameters after analysis

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

### 4.2. Dynamic calibration

After the static calibration, the torquemeter was connected to the acquisition system for calculation of power made by the user with realtime data. This, however, was not possible due to limitations of the acquisition system that started to produce wrong values for both torque and angular speed. So, 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 Tab. 3 below is presented the data for the first level of the electromagnetic resistance system and Fig. 3 brings the respective curve.

Table 3: Data for dynamic calibration

| Reference Speed (RPM) | Measured Speed (RPM) | Torque (N.m) |
|---|---|---|
| 15 | 14,89 | 27,71 |
| 25 | 24,79 | 28,36 |
| 35 | 34,68 | 29,45 |
| 45 | 44,56 | 31,30 |
| 60 | 59,36 | 31,32 |
| 80 | 79,09 | 31,36 |
| 95 | 93,89 | 32,59 |

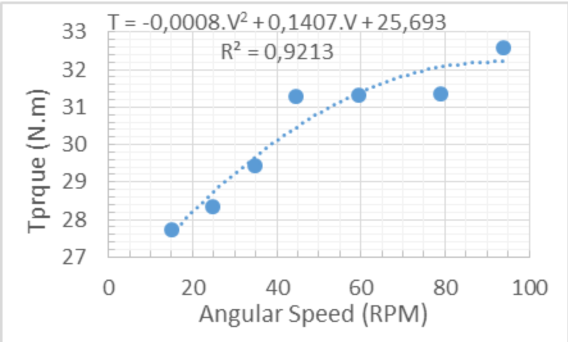


Figure 1: Curve for dynamic calibration of level 1.

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.

## 4. TEST PROTOCOL

Protocol used for the tests was the Wingate protocol. As mentioned before, this protocol consists in overcoming a fixed resistance using maximum possible effort during 30 seconds. 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.

## 5. RESULTS

Data of the volunteers acquired with the Wingate test performed are shown in Tab. 4 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. Table 5 shows a comparison between this study and previous ones.

Table 4: 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 |

Table 5: Fatigue index, heart rate and blood pressure.

| | **Peak Power (W)** | **Mean Power (W)** | **Fatigue Index (%)** |
|---|---|---|---|
| Current Study | 199 ± 40,9 | 167,6 ± 44,4 | 31,98 ± 7,40 |
| Baker et al. (2011) | 627,7 ± 0,9 | 456,5 ± 66,1 | 53,23 ± 6,44 |
| Bradley & Ball (1992) | 608 ± 90,5 | 445,7 ± 68,2 | 45,8 ± 6,20 |
| Vanlandewijck et al. (1999) | - | 852,1 ± 234,9 | - |
| Zupan et al. (2009) | 951 ± 141 | 686 ± 91 | 47 ± 7,6 |

According to the results obtained from the tests executed and the comparison with results from similar studies, one can conclude that the values obtained should be higher. Another factor that leads to this is that torque values of level 1 between angular speed ranges were too close to each other, which differs from manufacturer's data and calibration of previous versions of this prototype.

## 6. CONCLUSIONS

The wheelchair ergometer prototype equipped with the torquemeter designed was able to assess the performance of individuals but still needs some modifications and a new calibration process, since the values obtained during calibration for braking torque and power output for Wingate protocol were lower than expected, indicating a possible lack of sensitivity for the torquemeter. Nevertheless, the overall behaviour 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.

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.

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