



24th COBEM - 2017



24th ABCM International Congress of Mechanical Engineering
December 3-8, 2017, Curitiba, PR, Brazil

COBEM-2017-2584

THE DEVELOPMENT OF A DYNAMOMETER APPLIED TO A WHEELCHAIR

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Abstract. *Wheelchair users tend to decrease their activity levels after the injury which can lead to cardiovascular diseases (T. J. O'Connor et al., 2002). This paper proposes the development and construction of a dynamometer (roller system) in order to analyze and quantify the performance of wheelchair individuals. The proposed dynamometer allows wheelchair users to perform the recommended exercises, rehabilitation accompanied by specialized people, or even carry out a professional training in case of para-athletes. It is known that para-athlete's performance depends not only on themselves, but also on specific equipment. It means that para-athletes many times require custom-made equipment to meet their needs, more specifically to those with great sporting potential to reach positions in national and international competition rankings. The roller was motored by an electrical engine that provides the desired velocity of 10, 20 and 30 km/h approximately. After, two tests were carried out with the equipment by measuring power when tested by the parathlete Carlos Oliveira (C.Oliveira, 2017). Preliminary results suggest that the equipment is a good method to quantify the power exercised by the individual as well as to measure the performance of wheelchair sports athletes for the evaluation of mechanical stress along with physical conditioning.*

Keywords: *wheelchair users, dynamometer, physical performance, social inclusion.*

1. INTRODUCTION

Notably, it is observed several mobility and accessibility challenges for wheelchair users. This issue is somehow related to the scarcity of available financial resources, which causes a limitation in the development and mobility of people with special needs or even para-athletes in Brazil. Based on this historical problem, it is increasingly necessary to unite the sports and technology areas in order to provide wheelchair users access to equipment, resources, technologies and professional accompaniment adapted to their needs, providing then what is required to allow their development and increased social inclusion.

The access of wheelchair users to sports or even rehabilitation requires ergometric systems that are able to complete controlled tests with simultaneous measurement of both physiologic and biomechanical variables (J. González-Quijano et al., 2005). The dynamometer allows the measurement of resistance resulted from applied forces, and its operation is based on the relationship between the applied force and the resulting deformation (C. Rech, 2005). From the parathlete's applied power and performance it is possible to establish strategic parameters of training and physical conditioning as the dynamometer can simulate the conditions of load, aerodynamic friction and speed in the racing track. The same also is applied to ordinary wheelchair users, where the use of the dynamometer results in data on the patient's physical condition to allow then a better clinical evaluation.

Usually physiotherapists prescribe to wheelchair users with spinal dysfunction an evaluation of the propulsion capacity in dynamometers applied as assistive technologies. This evaluation aims to obtain ideal measures, since, for this, it is necessary to simulate runway conditions, considering real day-to-day obstacles, as reported by S.D. Gooch et al., 2008.

2. METHODOLOGY

2.1 Materials and Methods

The dynamometer used for performance measurement of wheelchair users is an instrument that allows the measurement of power through propulsion systems based on mechanical and functional principles of a roller dynamometer, which consists essentially of:

a) A Rotating cylinder named dynamometer roller, where the wheelchair is installed. It is constructed of steel, aluminum or even polymers such as PVC, since the mechanical properties of each material are evaluated in accordance to its function, as illustrated in Figure 1

b) Bearing housings – as shown in Fig. 1

c) Flexible Shaft Coupling – See Fig. 1

d) Shaft – See Fig. 1

e) Chassis/platform of components – See Fig. 1

f) Electric motor for calibration of the overall system before loading – See Fig. 2

g) Electric, mechanical or hydraulic brake designed to simulate loading to the system – See Fig. 3

h) Photoelectric rotation measuring sensor, inductive or hall effect – See Fig. 3

i) Force measurement system by electric or mechanical load cell- See Fig. 3

j) Acquisition system, data processing and monitoring by computer using dedicated software – See Fig. 4

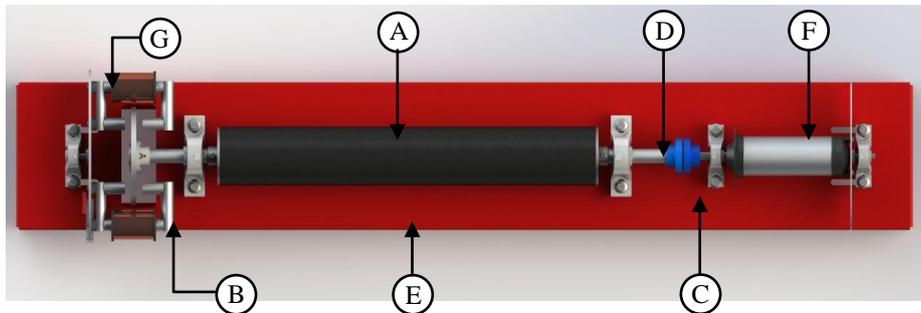


Figure 1. Dynamometer top view.

2.2 Project and Construction

In addition to the cylinder where the wheelchair is installed, there is an electric motor installed to the right end of the shaft as shown in Fig. 2, which aims to apply traction to the system and consequently simulate the power applied by the wheelchair user. At the opposite end, the next stage of the project will include the installation of a brake system (Foucault breaks, see Fig. 3) used for imposing the actual load and considering slopes, track conditions, aerodynamic friction, etc., which are the basic conditions that the user may come across. An example of the use of a Foucault brake on a wheelchair dynamometer is reported by Wesley J. Brin, 2012.

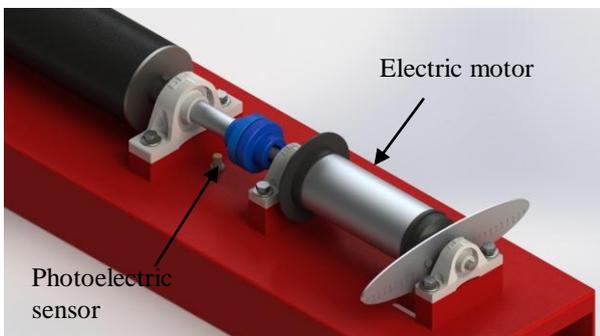


Figure 2. Electric motor and optic rotation sensor

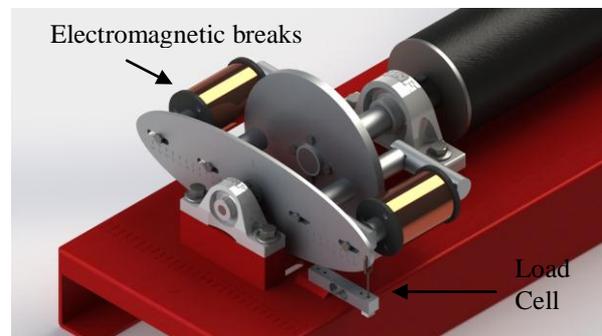


Figure 3. Load cell and breaking system

2.3 Instrumentation

The instrumentation of the system makes it possible to obtain results of the user's performance, by computer, considering the conditions imposed on the track or along the day-to-day of wheelchair users. It is used measurement systems, monitoring and actuators as load cell, optical rotation sensor (it can also be by hall or inductive effect) and a brake system (which includes the next stage of the project).

At this stage of the process, the mechanical measurements can be associated to the measurements of the physical conditioning of the athlete. It is considered an important opportunity for a potential partnership with the health area as the equipment provides important information to support medical evaluation of the user. Therefore, it is the most important stage of the project, once it is possible to evaluate whether the user will be able to practice sports as a professional (focusing on competitions), or for simple physical conditioning and health of wheelchair users. It is also important to note the potential of the proposed equipment for wheelchair users to be evaluated and trained by physical education professionals aiming the behavioral evaluation for the social inclusion effect, since athletics and social inclusion are commonly related.

3. EXPERIMENTAL PROCEDURE

3.1 Data Acquisition System

The equipment allows force and energy measurements through dynamic tests (time-consuming) either to the wheelchair performance assessment or to the user/parathlete performance assessment. The data is acquired through software and A/D converter board, converted to power and torque parameters and dynamically measured in relation the force application angle applied by the user. The electrical voltage values are acquired and processed using the developed programming and the sensors calibration curve, see Fig. 4.

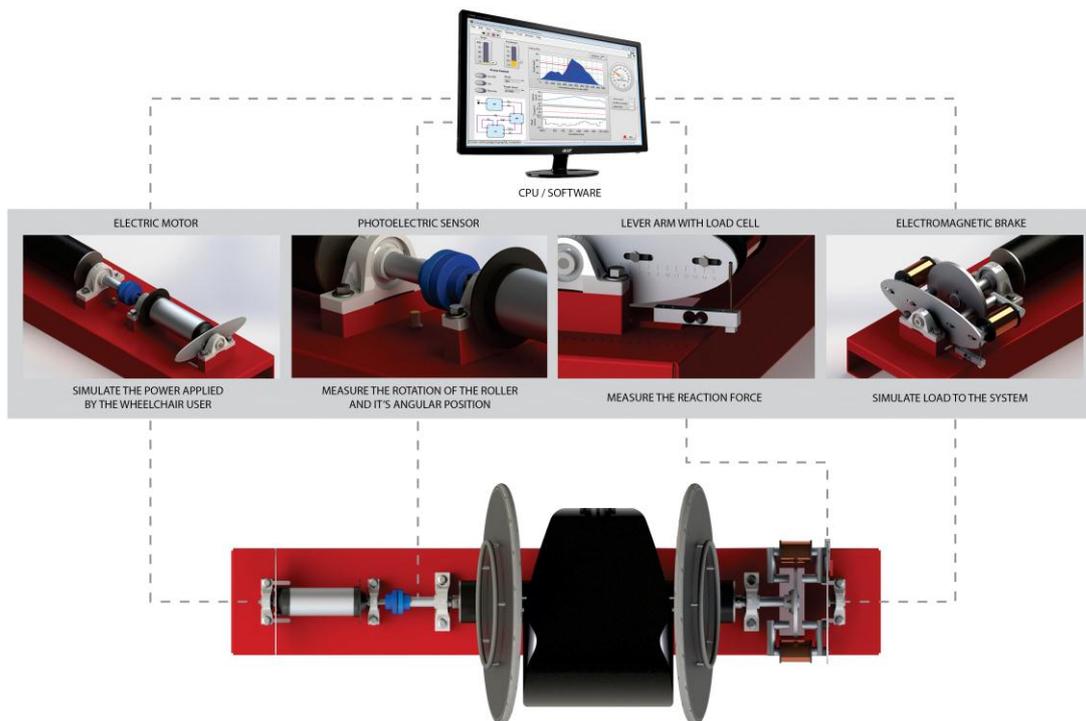


Figure 4. Data acquisition system

3.2 Angular Roller Position

The rotation of the roller is measured by an Autonics optical sensor, see Fig. 5, installed in the dynamometer and positioned to generate electric pulses, which are acquired as frequency and converted to rotation (Zancanaro, 2014). It was used a pattern of lines with total of 20 reading tracks which obtained a resolution of 18° (eighteen degrees) per revolution. The developed software receives the information and acquires the signal from all the sensors at real time. With such procedure, the measurement is performed based on the angular position, and not based on time, which

reduces the uncertainty of the measurement considering that within the propulsion cycle there is a large-scale rotation variation due to the intensity of the torque applied to the system.



Figure 5. Photoelectric Optic Sensor

3.3 Torque

To measure torque it was used a lever arm, which is used in balance and can be coupled to the shaft of the electric motor or the roller. The reaction force is measured by a load cell with a maximum capacity of 1 kg and a relative measurement uncertainty of 0.2% FS (Keyes brand), shown in Fig. 6, and installed at one end of the lever arm (electric motor shaft or roller shaft - load cell). The load cell consists of a Wheatstone bridge, which is required to measure very low values of resistance with a four strain gauges, one for each bridge resistor.



Figure 6. Keyes load cell

3.4 Uncertainty of sensor measurement

The measurement uncertainty, as well as the respective response times of the used sensors, are reported by Rech, 2010 and Soriano, 2012.

4. GOVERNING EQUATIONS

4.1 Dimensioning of the dynamometer (cylinder)

In an inertial dynamometer it is possible to measure the performance of propulsive sources, considering its geometry, material properties and the acceleration time of its spinning mass, in this case, the spinning cylinder named as roller. From these measurements it can be determine the torque and power produced, considering short intervals of time. According to Newton's Second Law, a body under the action of a force undergoes an acceleration that has the same direction of the applied force, and a module that is directly proportional to the force, as reported in Halliday *et al.*, 1996:

$$F = m.a \quad (1)$$

where F represents applied force, m represents s mass, and a represents acceleration. Similarly, it is possible to determine the equation that governs rotation as:

$$\tau = I.\alpha \quad (2)$$

where τ represents torque, I represents the moment of inertia and α represents the angular acceleration. The theoretical moment of inertia that represents mass of a cylinder can be determined by Eq. (3) as follows:

$$I = \frac{m.r^2}{2} \quad (3)$$

where r represents the cylinder radius. Considering a cylinder in a tubular form, the moment of mass inertia consists in the difference between the moment of inertia (considering the external radius) and the moment of inertia (considering the internal radius) of the cylinder. The moment of total inertia will be the sum of all moments of inertia of the rotating masses of the system (cylinders, flanges, shafts, steering wheels, etc.).

The mass m of each cylindrical part of the system can be calculated based on the properties of the material, such as the density, as shown in Eq. (4):

$$m = \pi\rho(r_e^2 - r_i^2)L \quad (4)$$

where ρ represents the density of the used material, L represents the length of the cylinder, and e and i stand for external and internal radius respectively.

The angular acceleration consists on the variation of the angular velocity with respect to a time interval:

$$\alpha = \frac{\Delta\omega}{\Delta t} \quad (5)$$

where ω represents angular velocity and t represents the time interval.

From Eq. (1) to Eq. (5) it is possible to design an inertial dynamometer to measure the performance of propulsive sources (wheelchair users in this case), according to Table 1.

Table 1. Design of a dynamometer for wheelchair considering aluminum and carbon steel, and 100W of power.

Dynamometer (material)	Unit	Abbreviation	Aluminum	Steel
Wheel diameter	[m]	Dr	0,700	0,700
Power imposed by the athlete	[W]	Pm	100	100
Linear final wheel velocity	[km/h]	Vf	20	20
Wheel rotation	[rpm]	Nc	152	152
Roller rotation	[rpm]	Nr	707	884
Roller final angular velocity	[rad/s]	ω_f	74,1	92,6
Outer tube diameter	[m]	De	0,150	0,120
Inner tube diameter	[m]	Di	0,137	0,110
Outer shaft diameter	[m]	Dshaft	0,025	0,030
Length of the tube	[m]	Lt	0,760	0,760
Length of the flange	[m]	Lf	0,010	0,010
Length of the shaft	[m]	Lshaft	1,000	1,000
Number of flanges - Nf	[un]	Nf	1	2
Density	[kg/m ³]	ρ	2690	7890
Moment of inertia – tube	[kg.m ²]	Jt	0,0303	0,0359
Moment of inertia – flange	[kg.m ²]	Jf	0,0009	0,0011
Moment of inertia – shaft	[kg.m ²]	Je	0,0001	0,0001
Mass of the tube	[kg]	mt	5,858	10,832
Mass of the flange	[kg]	mf	0,398	0,750
Mass of the shaft	[kg]	me	1,320	5,577
Time	[s]	t	1,72	3,28
Total moment of inertia	[kg.m ²]	J	0,0313	0,0383
Roller acceleration	[rad/s]	α	43,1	28,2

5. RESULTS AND DISCUSSION

5.1 Calibration tests – without the wheelchair

Initially, for the calibration of the system, a test was carried out without the wheelchair user, where the energy was measured on the roller using masses of 20 kg, 40 kg, 60 kg, 80 kg and 100 kg in order to simulate the load (mass of the user) on the wheelchair, and the electric motor for applying traction to the system. Figure (7) shows the variation of power in relation to the velocity, considering five different measurement tests, with variation of the load applied to the system. For each point, five measurements were carried out where the arithmetic mean was considered. It is observed that there is linearity in the relationship between power and the increase of the velocity. This behavior can be explained as only rolling friction forces are being measured, where aerodynamic friction is negligible.

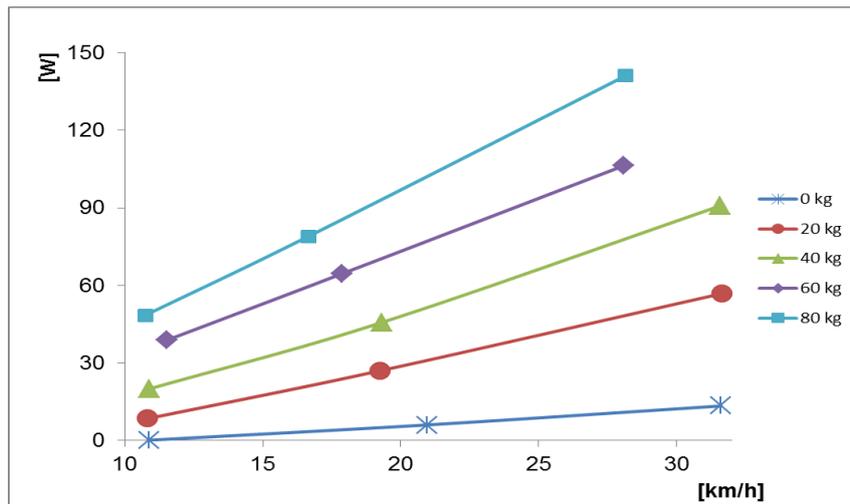


Figure 7. Variation of power versus velocity for different applied loads.

5.2 Tests with the wheelchair user

Afterwards, tests were carried out with a wheelchair user for applying load to the system, where characteristics curves related to the performance of the wheelchair marathoner Carlos de Oliveira (2017) were obtained aiming to measure and analyze the physical performance of the wheelchair marathoner under different conditions (requiring different physical power from the marathoner) to set the benchmark for future training. Figure (8) shows the variation of power versus time, in two different tests. It is observed that each impulse applied by the user results in an increase in power, as expected, where a sum of the power due to the friction forces in the roller and inertia.

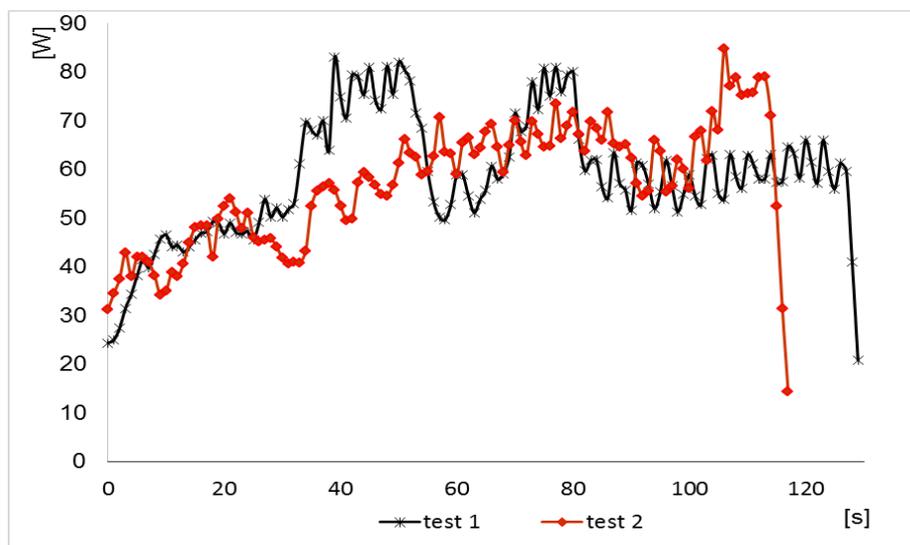


Figure 8. Power versus time in two different tests



Figure 9. Wheelchair marathoner Carlos Oliveira (Carlão), during measurement, Source: Authors

6. CONCLUSIONS

According to the results of the tests carried out, the dynamometer was able to provide data of rotation, torque, power, velocity, acceleration, etc., resulting from different loads applied to the system. It can be observed, according to the graph shown in Figure 7, the existence of linearity in the obtained results, which evidences the good quality of the measurements, considering that only the power resulting from the frictional rolling forces was measured. The power measurement (Figure 8) results from the sum of the power associated to the rolling friction plus the inertial power resulting from the acceleration at each interval of time. The results indicate that higher propulsion speeds result in higher power required from the wheelchair user. The equipment allows physical exercises to be completed and quantified as power. However, the use of the dynamometer in training to improve cardiovascular fitness requires development as well as assistance from health care professionals. The resulting parameters were stored and will soon be used to define training strategies based on the performance of a high performance marathoner, which can be used for the training of new athletes, even without the presence of a trainer. The validation of the experimental methodology applied to this project will be possible based on results that will be acquired on a track, which will include power due to the aerodynamic friction, as well as the working condition that is related to rolling friction. The reproduction of real track conditions (applied to specific wheelchair athlete training) will be possible by the installation of a break system to the equipment to impose load to the system.

7. ACKNOWLEDGEMENTS

Special thanks to the Brazilian marathoner Carlos Roberto de Oliveira, Carlão, holder of the world record in the category Indoor Race by the Guinness Book of Records, as the first parathlete in the world to reach the mark of 186 kilometers within 24 hours of testing - Globo Esporte (2013), for his special attention and dedication to this project.

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