Available online at http://www.journalijdr.com

IJDR

ISSN: 2230-9926

International Journal of Development Research
Vol. 09, Issue, 05, pp. 27433-27437, May 2019

RESEARCH ARTICLE OPEN ACCESS

ELECTRONIC BIOMEDICAL DYNAMOMETER DEVELOPED WITH METALON STRUCTURE FOR MEASUREMENT, ANALYSIS AND RECORDING OF GRIPPING FORCE INFORMATION

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ARTICLE INFO

Article History:

Received 03rd February, 2019
Received in revised form
19th March, 2019
Accepted 03rd April, 2019
Published online 29th May, 2019

Key Words:

Dinamometer; Palmar Hold Force; Force Variant; Orthopedics.

ABSTRACT

The developed electronic biomedical dynamometer was able to measure palmar grip strengths and varying forces over time produced by grip forces ranging from 5 N to 1000 N. This dynamometer has a very affordable mechanical structure, compact signal conditioning circuit and microcomputer. The mechanical structure consists of a dynamic support developed in Metalon and a static support also developed in Metalon. In addition, there is a support attached to the dynamic structure that was developed in Acrylic to accommodate the fingers of the hand and other support that was fixed to the static structure that developed in Acrylic to accommodate the palm of the hand. Between the dynamic structure and the static structure was installed a dynamometric ring containing extensometers (Kyowa) that were connected in Wheatstone Bridge and produce electric voltage proportional to the grip force applied between the supports. The electrical voltage produced by the Wheatstone Bridge is subjected to the signal conditioning circuit which amplifies, filters and produces an electrical voltage of the receiver, which is connected to a data acquisition board which converts that analog signal into a digital signal which is sent to the microcomputer to perform the processing by means of an interface developed with the Labview software to plot the behavior. graphs and generate analysis of forces applied over time and obtain fast and slow components of muscle strength, produces information that aid in medical diagnosis and can be stored in a database.

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Citation: Josivaldo G. Silva, Adriane Mello Arakaki, Fernanda G. Paula, Lucas R. Secco and Suzi R. Miziara Barbosa. 2019. "Electronic biomedical dynamometer developed with metalon structure for measurement, analysis and recording of gripping force information", *International Journal of Development Research*, 09, (05), 27433-27437.

INTRODUCTION

The hand comprises the most distal portion of the upper limb being considered one of the complex organs of the body. It consists of nerves, tendons, tissues and bones that in a combined form serve several purposes: as a prehensile organ it is capable of both impressing strength and holding and manipulating delicate objects; as a tactile organ it relates the organism to the environment; being important for verbal communication (SANTOS, 2009).

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The hand performs completely antagonistic activities, ranging from delicate and precise movements, such as writing or playing an instrument, to tasks that require strength and power. It is through this that we can relate to the external environment, interacting with everything and everyone around us (KAEMPF, 2014). However, the hand can be affected by injuries and diseases that generate disorders and limitations in people affected.There are several diseases that reach the hand among them stand out the inflammatory diseases that cause pain, swelling, stiffness and loss of function in the joints of the wrist and fingers. In general, these diseases progress in muscles, ligaments and tendons, making them weak and incapable of functioning normally (COPACABANA RUNNERS,?).Diagnosis of thisis diseases in the initial phase is done by means of an anamnesis with emphasis on the physical examination in the joints and muscular strength, in addition to an X Ray examination, the result of which is more reliable when the disease is at an advanced stage and causes destruction of the joints and causes several disorders of an economic and psychological nature to the patient (SUELLEN, 2009). The grip strength is one of the fundamental elements in the research of the manipulative, strength and movement capacities of the hand (JÚNIOR *et al*., 1996). Measurement of grip strength provides an objective index of functional integrity of the upper limbs. The data obtained help the physician to interpret results, establish adequate treatment goals beyond the clinical application of disability assessment, response to treatment, and the evaluation of a patient's ability to return to work (ASHTON, 2004).According to Soares *et al.* (2011) the manual grip strength measured with the use of a dynamometer may reveal important information such as the correlation with manual motor skills. This method is relevant because it is a fast, safe, non-invasive, low cost procedure and does not require extensive training of the professionals involved.The dynamometry allows determining the grip strength exerted by the hand being of great importance in studies of biomechanics, documentation of the recovery of patients undergoing treatment and surgery in the hands that led to the loss of mobility due to the disease or accident (TERAOKA, 1979).However, the problem with current dynamometry is that the available devices are designed to meet a specific strength limit. This limitation makes these equipment costly and therefore limits its use in clinics and hospitals.In view of the above, this article offers a versatile biomedical dynamometer developed in metalon structure that allows measurement, analysis and registration of information of the strength of hold.

Theoretical Foundations

The fundamental element is the dynamometric ring in which its design is shown in Figure (1). In points (***a***) and (***b***), traction force (***F***) is applied which causes the mechanical structure of the dynamometric ring to deform and especially in the more sensitive regions where the extensometers are bonded.The greater (***F***), the greater the strain (ε) that will occur in the metallic region are extensometers.

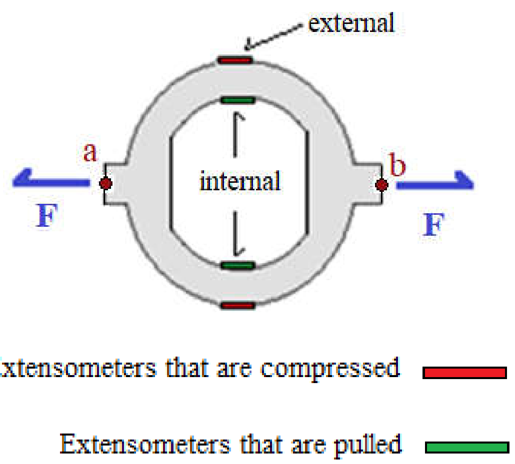

Figure 1. Dynamometric ring. Source: author

Two pairs of extensometers that respond electrically when (***F***) is applied are presented.

The strain (ε_i)due to only (***F***) occurring in the internals extensometers is defined by equation (1).

$$\varepsilon_i = \frac{3FR}{Eae^2}\left(1 - \frac{2}{\pi}\right) \tag{1}$$

Being,

F:Traction force;
R:Middle ray;
E:Modulus of Elasticity;
a:Width;
e:Thickness.

Modifying equation (1) obtain the equation (2) and equation (3) in terms of (***F***).

Making,

$$k = \frac{3R}{Eae^2}\left(1 - \frac{2}{\pi}\right) \tag{2}$$

$$\varepsilon_i = kF \tag{3}$$

Being,

k:Constant that depends on material and dimensions;
ε_i:Strain of internal extensometers.

In addition, considering the effect of the temperature (***t***) on the strain (ε_i) of dynamometric ring obtain equation (4).

$$\varepsilon_i(F,t) = \varepsilon_i(F) + \varepsilon_i(t) \tag{4}$$

Being,

$\varepsilon_i(F)$: Strain generated by ***F***;
$\varepsilon_i(t)$:Strain generated by temperature ***t***.

The strain(ε_e)occurring in the externals extensometers is defined by equation (5).

$$\varepsilon_e = -\frac{3FR}{Eae^2}\left(1 - \frac{2}{\pi}\right) \tag{5}$$

Modifying equation (5) obtain the equation (6) in terms of (***F***).

Making,

$$\varepsilon_e = -kF \tag{6}$$

In addition, considering the effect of the temperature (***t***) on the strain (ε_e) of dynamometric ring obtain equation (7).

$$\varepsilon_e(F,t) = -\varepsilon_e(F) + \varepsilon_e(t) \tag{7}$$

Being,

$\varepsilon_e(F)$:Strain generated by ***F***;
$\varepsilon_e(t)$:Strain generated by temperature ***t***.

The internal resistive extensometers and external resistive extensometers were connected in Wheatstone Bridge shown in Figure (2).

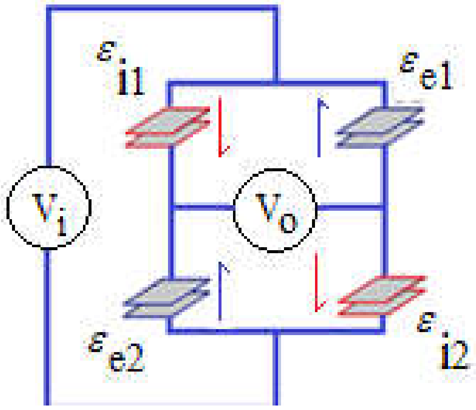

Figure 2. Wheatstone Bridge with extensometer connection. Source: autor

When equating the electrical and mechanical physical quantities, obtain equation (8).

$$V_o = kV_iF \tag{8}$$

Being,

$\boldsymbol{V_i}$: Wheatstone Bridge sinusoidalvoltagesupply;

$\boldsymbol{V_0}$:Wheatstone Bridge sinusoidalvoltage response.

MATERIALS AND METHODS

The implementation of this project resulted in the patent deposit at the National Institute of Industrial Property (INPI) in Brazil under the number BR 1020170270815. The research was developed in the laboratory of Biomedical Engineering and Assistive Technology (ENGEBIO) of the Federal University of Mato Grosso do Sul - UFMS being characterized as explanatory, direct and laboratory.The dynamometer developed to support human grip strength up to 1000 N and the project consisted of three important parts, the first part of which resulted in the mechanical structure, the second part in the development of the signal conditioning circuit and results analysis software while the The third part consisted of the tests and also the calibration of the dynamometer.Figure (3) shows the complete mechanical structure as well as the way of applying the manual gripping force.

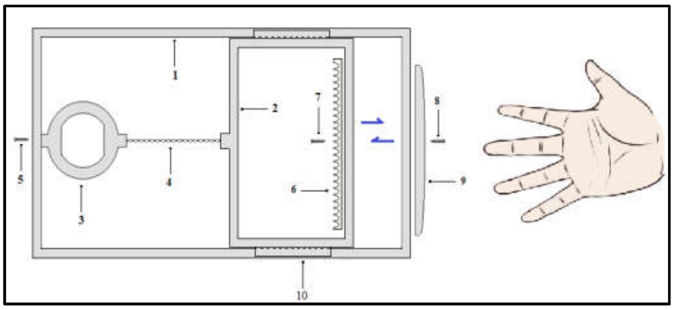

Figure 3. Mechanical structure of the dynamometer: Source: author

Being,

1: Static metal structure;
2: Dynamic metal structure;
3: Dynamometer ring;
4: Connection wire;
5: Fixing screw;
6: Support;
7: Fixing screw;
8: Fixing screw;
9: Support;
10: Rail.

Hold force measurements begin when the person places his or her hand in the mechanical structure of the dynamometer. Thus the person's palm is suitably accommodated to its carrier (9) developed in Acrylic. This support (9) can be replaced by other models that consider the presence of lesions and deformities in the palm of the hand and can be fixed to the static mechanical structure through the screw (8). The support of the fingers (6) of the hand was developed in Acrylic to facilitate its cleaning and also by the ease of machining. This support (6) has been secured to the metal structure (2) by means of the screw (7). Another important factor in relation to the static structure (1) and the dynamic structure (2), both developed in the metalon due to being a metal of affordable cost and easy machining.This dynamic structure (2) has a rail (10) at the top and another rail (10) at the bottom which are engaged in the static structure (1) to allow dynamic movement when the hand applies gripping forces.With the application of the gripping force ($\boldsymbol{F}$), the strain ($\boldsymbol{\varepsilon}$) of the steel wire (4) which is attached to the dynamic structure (2) and also to the dynamometric ring is established. In this situation, this ring dynamometer (3) deforms and stimulates the Wheatstone Bridge, containing resistive bonded extensomteres (model SGD-2/350-DY11 - Kyowa) to produce proportional electric voltage.The supply voltage of the Wheatstone Bridge was 10 V ac with a frequency of 15 kHz while the response voltage ($\boldsymbol{V_0}$) of the same bridge was connected to the signal conditioning circuit shown in Figure (4).

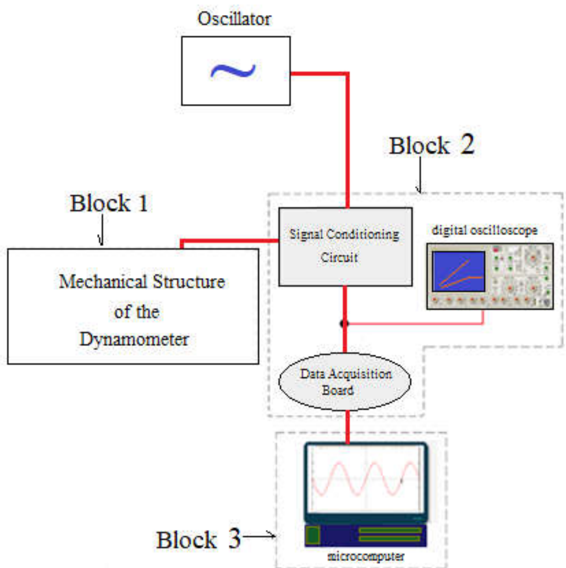

Figure 4. Biomedical dynamometerSource: autor

In the signal conditioning circuit the electric voltage of the Wheatstone Bridge is amplified 13,000 times by means of an amplifier developed with an integrated circuit LF356 (Burr-Brown model), being later filtered its noise using a bandpass filter developed with integrated circuit OPA27 (Burr-Brown model) containing initial cut-off frequency of 12 kHz and final cut-off frequency of 15 kHz and bandwidth of 3 kHz.In the next phase the electric voltage by the filter is submitted to a peak detector developed with OPA27 operational amplifier

Table 1. Measurementswith addition (A_{ii}) of masses and with the removal of masses (A_i)

Mass (kg)	Response (V)									
	A_{11}	A_1	A_{22}	A_2	A_{33}	A_3	A_{44}	A_4	V_m	S.D
00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	2.20	2.20	2.21	2.20	2.20	2.21	2.20	2.21	2.20	0.00
40	4.40	4.42	4.41	4.40	4.40	4.40	4.40	4.40	4.40	0.00
60	6.62	6.62	6.61	6.61	6.61	6.60	6.61	6.60	6.61	0.03
80	8.81	8.80	8.79	8.80	8.80	8.80	8.80	8.80	8.80	0.00
100	11.00	11.01	11.02	11.01	11.00	11.00	11.00	11.00	11.00	0.00

Source: autor.

(Burr-Brown model) in order to generate an electrical signal dc.A power supply whose voltage is adjustable from 0 - 32 V and 5 A MPS-3005A (model Minipa) was used to power all the integrated circuits of the signal conditioning circuit, the oscillator in Ponte de Wien and a digital oscilloscope of two Model 54603 B (HP) channels connected at the output of the signal conditioning circuit to monitor the voltage.The electrical voltage dc produced by the peak detector is subjected to a data acquisition board which converts that analog signal into a digital signal which is sent to the microcomputer to perform the processing by means of an interface developed with the Labview software to plot the behavior. graphs and generate analysis of forces applied over time and obtain fast and slow components of muscle strength, produce information that aid in medical diagnosis and can be stored in a database.

RESULTS

Table 1 shows the dynamometer responses with the calibration: a) hang standardized masses in a basket placed on the dynamic support (2) and b) gradually remove each mass of the basket until it returns to 0 N.

The calculations involving the measurements were obtained by equation (9).

$$V_m = \frac{\sum_1^8 Ai}{N} \qquad (9)$$

Being ***Vm***: average, ***Ai***: Intensity of measurement performed andN: number of measurements. The Figure (5) presented the standard deviation.

$$S.D = \frac{\Sigma\sqrt{(A_i - V_m)^2}}{N-1} \qquad (10)$$

Being ***S.D***: standard deviation.

The resolution was defined as the smallest change in the measured value at which the system is able to detect being 0.10 N.

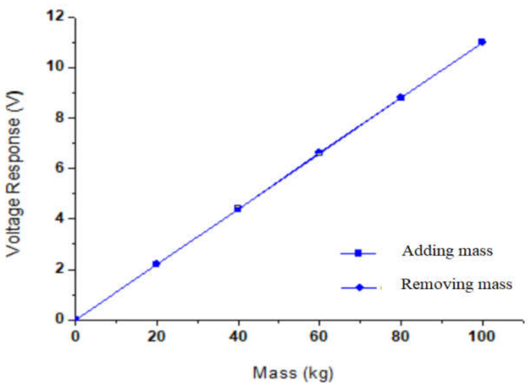

Figure 5. Response with calibration. Souce: author

Figure 5 shows the dynamometer calibration response that was initially performed by placing standard 20 kg masses in the 0 to 100 kg range in a basket that was hung on the dynamic support (2). In the next phase, each 20 kg mass was gradually withdrawn from the hanging basket until it returned to 0. Since the mass of the basket itself was not considered due to zeroing of the signal conditioning circuit. The dynamic response of the dynamometer was evaluated by abruptly withdrawing a 50 kg mass from the basket to measure the time of descent. This time is set so that the response of the dynamometer reaches the value of 63% of the value of the regime. The measured time was 0.52 s and the correlation coefficient was 0.997 while the resolution containing the signal conditioning circuit was 0.10 N.Figure 6 shows the response time of the dynamometer by abruptly withdrawing the 50 kg mass that was in the hanging basket.

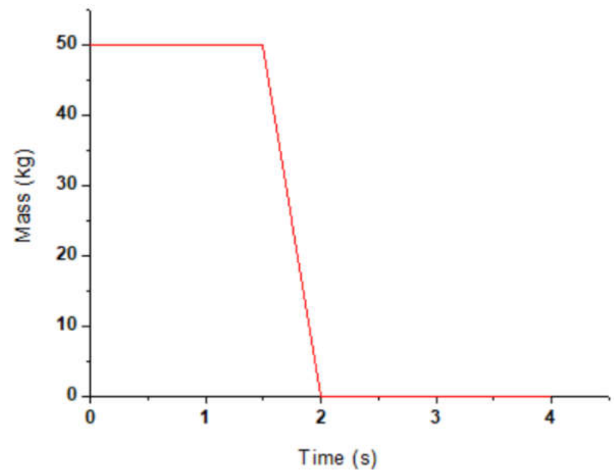

Figure 6. Dynamometer response time. Source: author

Figure 7 shows the dynamic test by applying random dynanic force only with the index finger of the right hand.

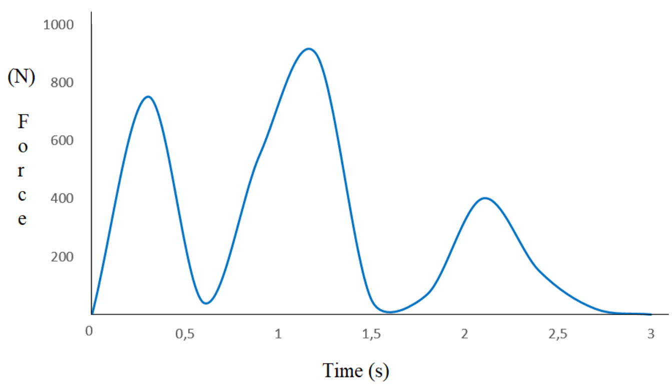

Figura 7. Dynamic test.Source: author

Figure 8 shows the dynamic test by applying random dynamic force only with the middle finger of the right hand.

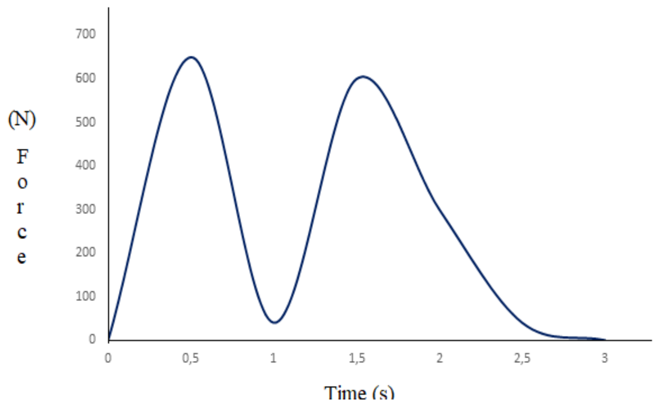

Figure 8. Dynamic test by applying random dynamicforceonly with the middle finger of the right handSource: autor

Figure 9 shows the dynamic test by applying random dynamic force only with the small finger of the right hand.

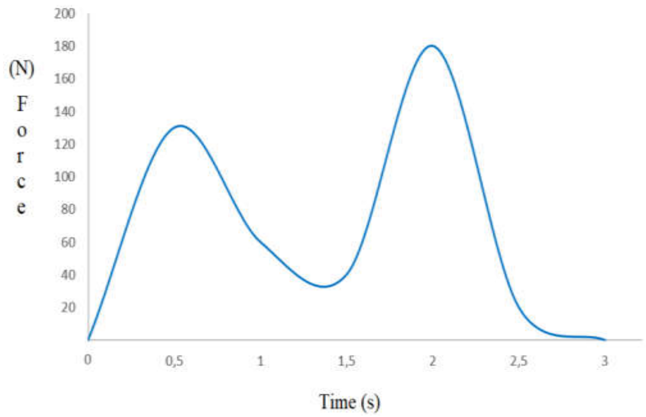

Figure 9.Dynamic test by applying random dynamic force only with the small finger of the right hand

DISCUSSION

In order to ensure that the resistive extensometers have the highest sensitivity, it was important to ensure that the bonding of the resistive extensometers occurs in the longitudinal direction of the dynamometric ring. In addition, to eliminate the undesirable effect of the temperature (***t***) on the response voltage of the Wheatstone Bridge it was necessary that all the extensometers had the same dimensions and were of the same manufacturer. In the design of the dynamometer it was possible to show the potential of the equipment for its use in the health area.

Conclusion

The results obtained show a linearity with a correlation coefficient of 0.997 in the response with a maximum standarddeviation of 0.03 and a maximum response of 11.0 V for 1000 N of gripping force. Finally, a patent deposit of the dynamometer was carried out at the National Institute of Industrial Property (INPI), Brazil, under the patent deposit number BR 1020170270815. In addition, this dynamometer is affordable because its mechanical structure was developed in Metalon while its dynamometric ring was developed in Brass. It can be stated that the presented equipment has great potential for its application in the health area, mainly Orthopedics.

Acknowledgements: The postgraduate Health Center West - UFMS, Brazil.

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