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CONSTRUCTION AND CALIBRATION OF A LOW-COST FORCE PLATE FOR HUMAN BALANCE EVALUATION

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Force Plates are dynamometers instruments extremely useful in biomechanical evaluations used for gait and balance assessment, also used for jump height measure, for example. There is a shortage in Brazilian market of products with affordable prices and quality resolution for professionals, which makes necessary to develop force plates with lower cost. The scope of this study was to build a low cost force plate, proposed a calibration procedure for stabilometric assessment based in strain gauges. We conclude that the characteristics of the instrument compared to other systems developed and reported in the scientific literature, are within the values found for sensitivity in the state of art of this field of knowledge.

KEY WORDS: Force plate, human balance, instrument calibration, dynamometry, stabilometry

INTRODUCTION: Force Plates are dynamometric instruments that are extremely useful in biomechanical evaluations for gait and balance assessment and jump height measurement. For example, Ávila et al. (2002) explained that these instruments quantify the dynamic variation of the ground reaction force during the contact phase between bodies – phase in which the transfer of these external forces occurs, inferring changes in movement conditions. Regarding stabilometric assessment, analysis of postural balance is particularly useful in areas such as sports, for assessment and verification in improvement of physical conditioning, diagnostics and rehabilitation of diseases. There is a shortage of products in the Brazilian market with affordable prices for professionals who want to work with instruments fitted with suitable resolution, being necessary to develop lower-cost force plates. The aim of this study was, besides build a force plate, propose a calibration procedure for stabilometric assessment, based on electric resistance strain gauges.

METHODS: The load cells were designed ring-shaped, due to project simplicity and reduced machinery cost, based on equation suggested by Beck (1983), which takes into account the yield point of the material used. Four Variable Electrical Resistance Strain Gauges (VERSGs) were fixed in each cell, located on the inner tube, forming right angles between them, of 0º, 90º, 180º e 270º. A full Wheatstone bridge configuration was used in each load cell. Deck boards were developed using steel 1020. This material was used because of high hardness and resistance properties, with a reduced cost. The deck boards are sized of 500mm wide by 500mm length and height of 6 mm, showing similar dimensions to other commercial models available on the market for human balance assessment. The principles for calculating the force components and their moments were based on classical formula for force plate calibration, in which the force and torque elements are determined by the sensitivity of each of the six channels for every load component applied (Zatsiorsky, 2002). Calibration force plate consisted, initially, in measuring the masses of load implements to be used in the protocol, through a process of loading and unloading, following a protocol of 10s for each loading and unloading stages. The goal of calibration was to determine the relationship between the forces applied to the force platform and the output voltages from the strain measurement system, besides the verification of linearity, hysteresis and standard error of the instrument for each axis. To achieve this objective, we used the method proposed by Hull and Davis (1981), also used by Gurgel et al. (2005), which was based on the application of known loads that allowed the calculation of a calibration matrix. For weighing the load implements, the same calibration as proposed by Gurgel et al. (2005) was applied, a digital scale (Filizola ®) with accuracy of 4 digits and attested by Inmetro was used. The data were collected using an A/D converter (Dataq, di-174ena model, with 14 bits resolution and 16 channels). The data were acquired and analyzed at a sampling frequency of 2000 Hz per channel and were filtered using a low-pass filter (Butterworth Fourth order) with a cutoff frequency of 50Hz.

RESULTS: The three force elements (Mx, My and Fz) were calculated according to Equation 1, as proposed by Gurgel (2005).

$$V_{Mx} = A + B - C - D$$
$$V_{My} = A - B - C + D$$
$$V_{fz} = A + B + C + D$$

Equation 1 - Calculation of force components and moments.

The linear regression procedure for the values of loading and unloading of each force and moment elements for each axis was calculated in Microsoft Office Excel 2003 software. This procedure allowed the calculation of the slope elements (Gregor et al., 1985) which is necessary to calculated the calibration matrix and the sensitivity matrix (Ávila et al., 2002). Furthermore, we calculated the sensitivity and hysteresis of the Z axis and the moments Mx and My. Matrix of calibration has been calculated based on Equation 2.

$$\begin{Bmatrix} V_{fz} \\ V_{Mx} \\ V_{My} \end{Bmatrix} = \begin{bmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{31} & C_{32} & C_{33} \end{bmatrix} \times \begin{Bmatrix} f_z \\ M_x \\ M_y \end{Bmatrix}$$

Equation 2 - Matrix of calibration.

The results of calibration of force in the Z axis, and moments on the X axis and Y can beseen in Figures 1-3.

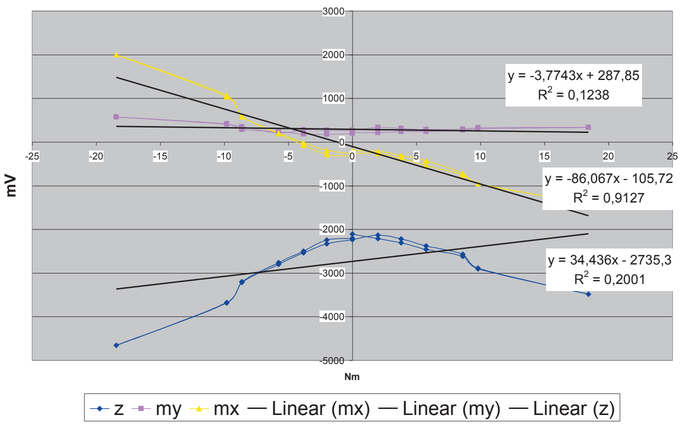

Figure 1: Responses to the calibration of the axes of Mx

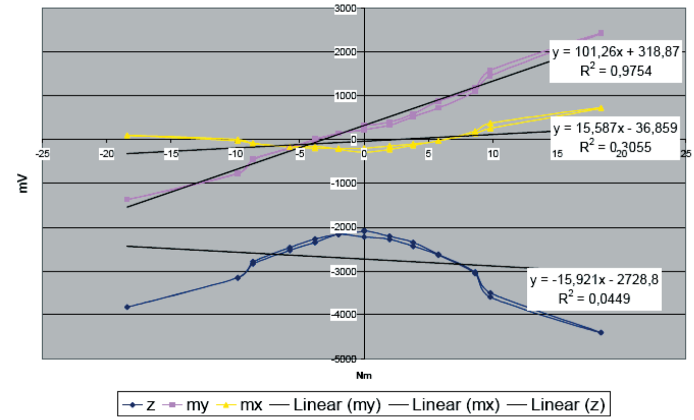

Figure 2: Responses to the calibration of the axes of My.

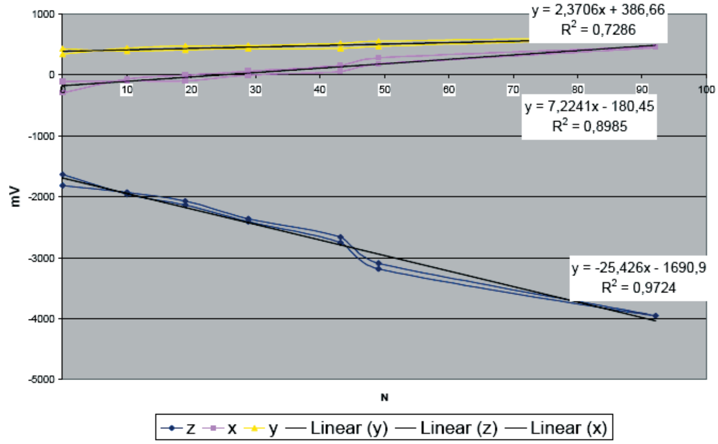

Figure 3: Responses to the calibration of the axes of Z.

Basead on the slopes of the linear regression curves, it was possible to calculate the calibration matrix (Table 1). Calculating the inverse matrix, we obtained the sensitivity matrix (Table 2).

Table 1
Calibration matrix

Axis	z	Mx	My
Vfz	-25.426	7.2241	2.3706
VMx	34.436	-86.067	-3.7743
VMy	-15.921	15.587	101.26

Table 2
Sensitivity matrix

Axis	z	Mx	My
Vfz	-4.4767	-3.592	9.1415
VMx	-1.7722	-0.3119	-0.4116
VMy	-4.3106	1.4547	1.003

DISCUSSION: The system was efficient for the measurement of the variables proposed, presenting satisfactory resolution and sensitivity. Beck (1983) highlights strengths and weaknesses of force plates based on load cells. The small dimensions and low weight coupled with the high rigidity of the material provides a high-resonance frequency. Another interesting aspect of a load cell refers to the process of calibration. The calibration procedure is considered as one of the most crucial aspects of measurements equipments during it development (Gurgel, 2005). After Calibrating (and with proper protection from weather factors like rain and others), it is not necessary to repeat the calibration process, because the load cell is characterized as an instrument that stabilizes over time. The hysteresis was calculated: Mx = 4.84%, My = 6.11%, Mz = 5.78%, which is an expected result for a force plate (Hull & Davis, 1981; Gurgel, 2005). Another study by Beck (1983) cited as a desired hysteresis a value near to 5%. The linearity obtained My = 0.9754, Z = 0.9724, Mx = 0.9127 was adequate when compared with that obtained by other authors (Gurgel et al., 2006). The force plate after the calibration process achieved all proposed objectives, presenting a resolution of 0,004255 Nm in Mx, 0,003617 Nm in My, and 0,014403 N in Z axis, what are considerable a satisfatory resolutian for this kind of instrument (Hull & Davis, 1981; Gurgel et al., 2005).

CONCLUSION: This instrument, based on the mechanical characteristics appears to be effective in assessing changes on the pattern of the COP, serving as a low-cost proposal for the scientific community. The simplicity in the manufacture of load cells, mounting and calibration of the structure indicate a possibility of dissemination of this stabilometric technique. Given that the relatively high cost of Balance evaluation systems is still considered as the main factor limiting application of this technique, the proposed force plate appears to be a possible low-cost solution to this problem.

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