2D MINIPLATFORM FOR MEASURING FORCE AT A COMPUTER KEY BUTTON

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By the usage of computers, both at work and home, health problems due to typing started appear, mostly by the individual's posture, upper limbs repetitive movements, forces, etc. Several studies for understanding the causes for these health problems have been carried out since the early 90's. The main objective of this work is the development of a force platform to measure the finger's applied force at the keyboard during computer typing. This platform will be used in Biomechanics and Motor Control applications. It was designed and built in order to measure vertical force Fz (z direction), horizontal force Fx (x direction) and transversal force Fy (y direction) and the moment applied in the horizontal (and longitudinal) axis Mx (x direction). Resistance strain gauges were used as sensors bonded in cantilever beams. These sensors are connected to a Wheatstone full bridge, in order to measure, independently Fx, Fy and Mx. To developing the conception adopted, the force platform was evaluated and tested by a numerical model (finite elements technique). The data acquisition system is composed by (a) a computer, to acquire and further processing the collected information by (b) an A/D converter, (c) a signal conditioner and (d) the software SAD 2.0. The static calibration of the force platform presented linearity within the range of 3%. Dynamic tests showed that the platform has a fundamental frequency higher than 2300 Hz, and consequently permits its use for analysis of the applied forces during typing.

Keywords: Biomechanics, motor control, dynamometry, force platform, keyboard, typing.

INTRODUCTION

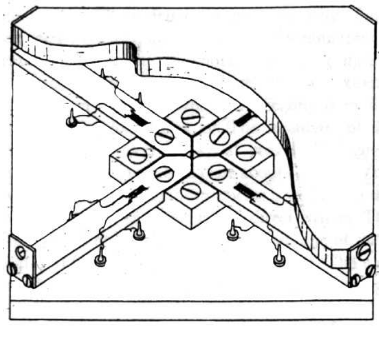
The first measurements of the force applied by fingers at a computer key button was carried out by Armstrong (1994) and Rempel (1994a). These authors developed two measuring systems: (a) one with two load cells connected to the lower part of the keyboard, and (b) another one with a piezoelectric sensor under the keycap. These two systems were used in several experiments to study the force applied to the computer keys. Some remarkable experiments were developed by Rempel (1994b, 1997, 1999), Serina (1997) and Smutz (1994). In all these studies, the systems were restricted to the measurement of force in a single axis (vertical). Today, force platforms (which measure forces and force moments at three axes) are being produced to analyze either human and animal body movements.

The objective of this work is to develop a force platform that measures the force applied by the fingers on the surface of a computer key button during typing. This platform measures the force in two axes: y (transversal to the keyboard) and z (vertical), and the moment in one axis, x (longitudinal to the keyboard). With this data it is possible, in a bidimensional analysis, to determine the magnitude of the resulting force vector applied on the key button, its angle in relation to the keyboard's transversal axis (y axis) and the position of the force vector at the key in relation to the x axis.

THEORETICAL FUNDAMENTS

In 1964, Petersen built a force platform to work with small animals. It was composed by 4 cross-shaped cantilever beams, with edges fixed at the superior base (contact surface), and its center fixed at the inferior base (Fig. 1). This equipment reads the same value of force regardless the surface region where the force is applied.

Fig. 1
Petersen (1964)



In 1987, Lywood developed a force platform that measures force at three orthogonal axes. The structure is similar to that constructed and reported by Petersen's (cross-shaped), in which it was measured the vertical force. However, two other sets of four beams were added in order to measure the two force components in horizontal position.

Based on Lywood's project, Roesler used a similar structure and developed, in 1997 a platform that measures forces and force moments in three axes. This platform is waterproof, in order to be used in researches related to activities carried out in swimming pools (hydrogymnastics).

PROJECTING THE FORCE PLATFORM

The small dimensions involved in the making of this force platform and the limitations related to the size of the sensors (resistance strain gages) determined the unfeasibility of tridimentional analysis. The chosen option was a system which is capable of a bidimentional analysis at the transversal position (sagittal plane). Therefore, the measurement of one of the force components and one of the moments was disregarded. This analysis needs the force measurement at z, Fz direction, and at y, Fy direction and the x, Mx moment. By determining the force at z, Fz, and the force moment at x, Mx direction, it is possible to determine the force vector position in relation of y axis, Dy, since $Dy = \frac{M_x}{F_z}$ and that Fy does not cause force moment at x axis.

To measure these three components, it is necessary to have three independent Wheatstone bridge circuits, which means twelve sensors, a number considered too high to fit in the available space.

The force platform boards were built in two parts: (a) the upper part, with elastic elements (boards), where the sensors that measure force at z, Fz direction and moment at x, Mx direction would be placed, and (b) the lower part, composed by the elastic elements (boards) where the sensors that measure force at y, Fy direction would be placed.

The upper part is formed by a structure with a "H" shape. This format enabled a very interesting solution for measuring Fz and Mx. At a force platform used to study human gait, the sensors that measure force can be fixed at the same side of the sensors that measure the force moment; the beams are wide enough for that purpose. However, the width of the beams in this project is determined by the sensor's width, which allows only one sensor to be fixed at each side of the platform.

The lower part is formed by four cantilever beams; the force is applied at the upper edges.

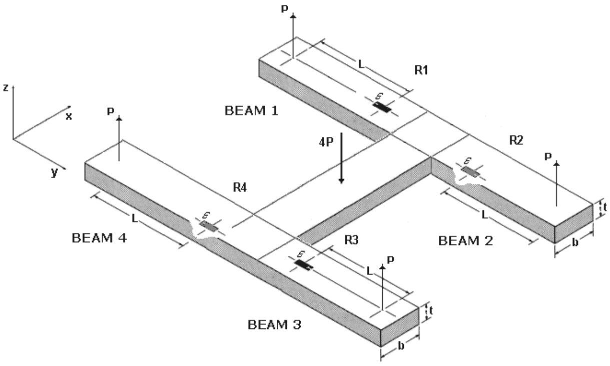
HOW THE FORCE PLATFORM WORKS

This force platform works similarly to a table where every leg is substituted by a spring. When a load is applied to the center of the table, each spring suffers equal deflection; however, if the load is exentrical to the center of the table, a bigger strain will be induced at the nearest spring. Regardless the position in which the force is applied, the average strain in the four "springs" (cantilever beams) will be the same.

The same principle should be applied to the "H" format structure in order to allow the measured force to be the same, regardless the point of application of this force at the surface of the key button. As the force platform circuit is mounted in a full bridge type, the bridge's unbalance will be similar to the case where the force is applied at the center of the key. Therefore, if the applied force by the finger is displaced from the center of the key button, the reading of this component will not suffer any distortion, since the force platform was developed to compensate variations in positioning of the applied load. The same will happen with force moments.

Fig. 2 shows a drawing that illustrates the force platform structure conceived to measure the force applied at z, Fz axis, and the force moment at x, Mx axis. This structure has two sensors attached at the upper part, on cantilever beams 1 and 3, plus other two at the lower part of beams 2 and 4.

Fig. 2
Force platform upper part



DIMENSIONING THE FORCE PLATFORM

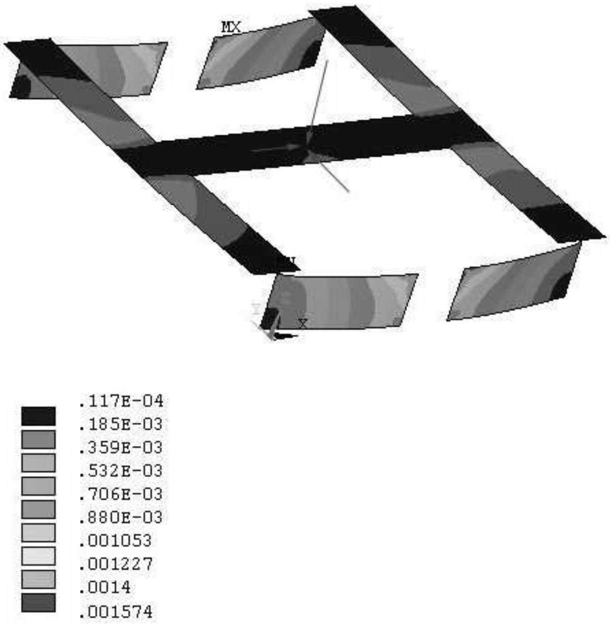
The small surface dimensions of a computer key button, 12 mm × 14 mm and, comparatively, the large dimensions of the sensor used, 2 mm × 5 mm, do not allow many options about the dimensions of the structure. The complete set should have dimensions close to the conventional key button and the width of the cantilever beam can not be less than the sensor's, that is, 2 mm, and length over 5 mm.

Thus, the upper part of the extensometric transducer is composed by 4 "H" – shaped cantilever beams, 2.0 mm wide, 6.0 mm long, 0.4 mm thick each, total length of 14 mm between the anchors at the lower part, and 15.0 mm wide. This geometry allows the sensors' to be set like two complete Wheatstone bridges circuits, one to read the force at z, Fz axis, and the other to read force moment at x, Mx axis.

The lower part is also formed by four cantilever beams, which are 5.5 mm long, 2.0 mm wide and 0.2 mm thick, with four sensors connected in a full bridge type circuit, in order to read force at y, Fy direction.

To illustrate a typical responde of a H cantilever beam structure subjected to a force, Fig. 3 presents the strains calculated using the Finite Elements theory when forces are applied at three directions simultaneously, one at x direction, Fx = 2N, another at y direction, Fy = 2N and the third at x direction, Fz = –3N.

Fig. 3
Force applied, Fx = 2N, Fy = 2N and Fz = –3 N; strain analysis using von Misse's method



BUILDING THE FORCE PLATFORM

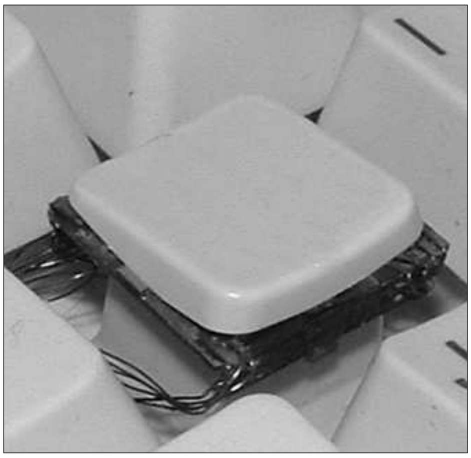
To produce the elastic elements, the force platform, it was built on 304 stainless steel (210 × 109 N/m^2). Young modulus, 2.8 × 108 N/m^2 of tensile strength, poison coefficient 0.28, density of 7.9 Kg/m^3 (Sandivik, 1994). The choice was due to the high resistance to oxidation, mechanical high resistance and to be adequate for work with electroerosion process.

The extensometric sensors used at the force platform are Kyowa's, KFG-1-120-C1-23N15C2 model, with a grid of 1 mm. It used the MB35 glue – (Micromeasurements) to fix the sensors at the beams' surfaces.

The base of a key button was prepared in order to fix sensors at its inferior structure. The two sets with two serial cantilever beams were attached at the center of the base. The "H-shaped" upper structure was attached at the cantilever beams edges of the lower structure. The contact surface of the force platform was built using a computer key button, which was attached at the center of the "H-shaped" structure.

The connection between the upper and the lower structures should be round so that it could only transmit force to the lower beams. However, it is not mechanically possible to produce such part with the required dimensions. Since the beams deformation is irrelevant, the option was to unite these parts with a small amount of glue, so that the stiffness of the union would be significantly less than the stiffness of the metal parts. Cyanacrilate glue was used because it glues fast and it is apropriate to unite metals (Fig. 4).

Fig. 4
Platform lower view



CALIBRATING THE FORCE PLATFORM

Statistic calibration

In order to calibrate statically the force platform, a structure has been set to apply Fz, Fy and Mx loads independently in each of the directions. Therefore, when a load is applied in one direction, there can not be any other component in another direction (as suggested by Gola, 1980; Hall, 1996), avoiding "mechanical coupling".

The signal generated by the force platform was amplified by a signal conditioner and sent to an A/D converter. Usually, the input signal of the Wheatstone bridge circuit of the load cells is 4V or 10V. However, due to the beams' tiny structure, the best option was to 2V, since the objective was to avoid overheating of the structure.

The calibration was made by applying force using dead weights. According to Gola (1980), if the dynamic analysis shows that the force platform is light and stiff enough, and if the vibration modes are sufficiently high compared to the vibration modes of the applied forces during measurement, the static calibration is valid.

Several data aquisition sets where conducted at one direction with the load applied in order to verify mechanical coupling, repetitivity and linearity. The results presented are the mean of three values each of a series of different measurements.

SAD32 software was used for signal analysis; it was used the mathematical function called Mobile Weighted Mean, with a cut-off frequency of 0.45 Hz. The sampling rate chosen was 10 points per second.

When a force of 0.53 N was applied towards z axis, in several points of the load cell surface, the maximum error range was less than 4%. At the central position of the surface of the force platform the error range was less than 2%. Force readings towards y, Fy direction were almost zero. The system's sensitivity at z axis, force Fz, was 0.0063 N, with R2 = 0.9998.

The force moment variation at x, Mx direction, caused by the applied force towards z, Fz, was zero.

To an 1N force applied towards z direction, the maximum force registered at Fy was inferior than 0.001 N, a considerably low value if compared to the values registered during typing, which almost reached 0.4 N. Taking this value as a reference, it can be stated that Fz force generates mechanical coupling at Fy of 0.25% from the maximum value registered when typing at normal speed.

The calibration curve of the applied force towards y, Fy direction, displayed a correlation coefficient R2 = 0.994. The calibration curve at the moment at x, Mx direction, displayed a correlation coefficient R2 = 0.9991.

When a moment is applied towards x, Mx direction, not exceeding 0.0070 Nm, which is approximately the maximum value mean registered during typing, the highest value registered by force at z, Fz direction, is 0.032 N. Considering that the force at z, Fz direction, reached maximum values close to 1.6 N during typing, it is appropriate to say that the mechanical coupling that Mx causes at Fy is less than 2%.

Concerning to the force at y, Fy direction, the highest value found was 0.0022N. Considering that Fy registers maximum values close to 0.4 N, it can be assumed that the mechanical coupling caused by Mx at Fy force component measurements during typing is less than 5.5%.

Dynamic calibration

For the dynamic calibration, it was used a Thüringer Industriewerk Bauestein vibratory table set. 5000/300, a 2250AMI-10 Endveco piezoceramic accelerometer (0.3 grams' mass), Brüel & Kjaer cables, a 2034 dual channel signal analyzer Brüel & Kjaer, 9.93 mV/g sensitivity and a 102 Endveco signal amplifier and conditioner.

The accelerometer was fixed at the surface of the force platform, which was attached at the vibrating table. The range of vibration chosen was from 0 to 6.4 kHz, with the accelerometer also fixed at the vibrating table, and the output signals were sent to the signal analyzer.

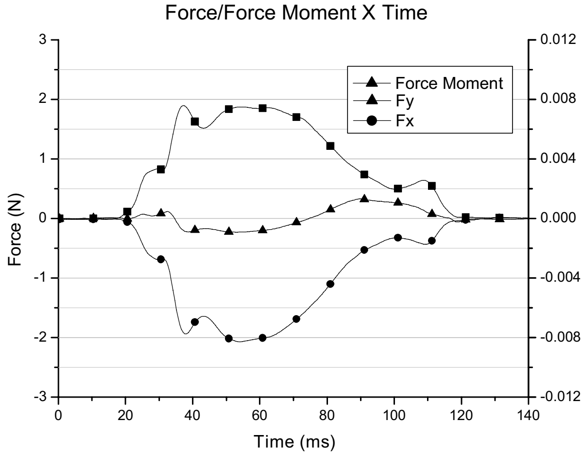
The dynamic calibration showed that the first fundamental mode of the force platform is superior to 2300 Hz. This result allows the equipment to be used safely in order to analyze events where the frequency does not exceed 750 Hz.

MEASUREMENTS

The desks used for typing can be adjusted to the keyboard's height, in order to achieve a comfortably position according to the anthropometric characteristics of each typist. However, these tables are not rigid enough for simulations. For that matter, a 0.70 m high masonry table has been specially made for mechanical measuments, where the keyboard with the force platform (H-shaped) has been placed. Fig. 5 shows the force components in three different time moments during typing.

Fig. 5
Force components on key button's surface

● Fz ▲ Fy ■ Mx



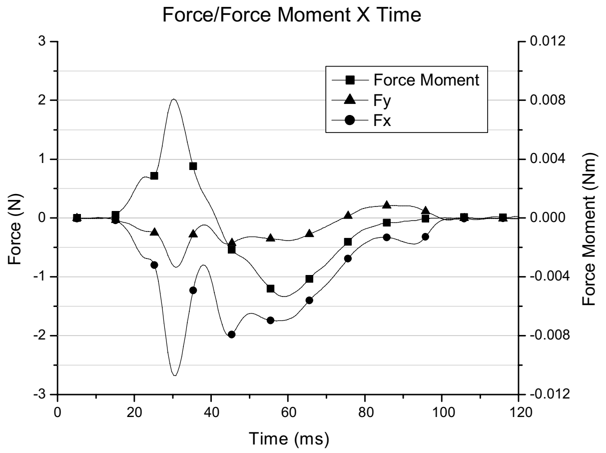
A representative model of the force components refering to three different moments during key button fingering can be seen in Fig. 6. It can be noticed that the pressure center on the surface of the force platform is initially placed at the furthest half from the typist's body. However, when the key button reaches its course end, the pressure center changes position, moving over the surface to the nearest half from the typist's body.

Maybe this fact can be explained because: (a) first, the finger movement on the surface of the key button and (b) second, because the pressure center of the fingertip's contact area changes position as the applied force increases.

Initially, the pressure center is at the center of the finger's contact area on the surface, when only skin tissues are being pressed; however, when the applied force increases, the pressure center moves to the edge of the finger, due to fingertip bone load (distal phalanx tuberosity).

Fig. 6
Force components on key button's surface

● Fz ▲ Fy ■ Mx



Analyzing the results, one can assume that the force platform developed for this experiment displays accurate characterization of the applied force on the surface of computer key buttons.

In 1994, at the presentation of his innovative load cell, Rempel (a) stated that, at that point, there was not solid information on load force during typing, so it was useful to develop mathematical models with experimental data to be used in the analysis of upper limbs (hands and fingers), as it has been proposed by Chao (1976).

Later, more complex models were created by Leijnse (1995, 1996 and 1997) and Biggs (1999). The information generated by the load cell developed in this work is more adequate to supply these models with experimental data. Also, moving the key button to a 90 angle, it is possible to measure force at the keyboard's longitudinal axis.

CONCLUSIONS

The force platform produced in this work displayed enough sensitivity, sampling rate, repetition, mechanical uncoupling and precision, in order to measure two force components (and one force moment) of the applied force at the surface of a key button during typing with great accuracy.

The force at y, Fy direction, denotes significantly representative level. By determining that, it is possible to observe important aspects concerning the key button triggering characteristics from a typist. This force must not be taken for granted, as well as x, Fx direction force.

It has not been found any better equipment to describe the characteristics of the applied force at a key button than the one presented in this work.

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2D MINIPLATFORMA PRO MĚŘENÍ SÍLY VYVÍJENÉ NA KLÁVESNICI POČÍTAČE

(Souhrn anglického textu)

V souvislosti s používáním počítačů v zaměstnání i doma se začínají objevovat zdravotní problémy související se psaním na počítači, způsobené většinou držením těla jednotlivce, opakovanými pohyby horních končetin, jimi vyvíjenou silou atd. Od začátku 90. let 20. století již bylo provedeno několik studií s cílem pochopit příčiny těchto zdravotních problémů. Hlavním cílem této práce je vytvoření silové platformy pro měření síly vyvíjené prstem na klávesnici při psaní na počítači. Tato platforma bude využívána v aplikacích biomechaniky a motorické kontroly. Byla vyvinuta a vyrobena za účelem měření vertikální síly Fz (směr z), horizontální síly Fx (směr x), transversální síly Fy (směr y) a momentu aplikovaného v horizontální (a podélné) ose Mx (směr x). Jako senzory byly použity odporové tenzometry umístěné na konzolovém nosníku. Tyto senzory jsou za účelem nezávislého měření Fx, Fy a Mx připojeny na plný Wheatstonův můstek. Pro účely rozvoje byla silová platforma vyhodnocována a testována pomocí numerického modelu (metodou konečných prvků). Systém získávání dat se skládá z (a) počítače pro sběr a další zpracování informací získaných pomocí (b) měniče proudu, (c) zařízení upravujícího signál a (d) softwaru SAD 2.0. Statická kalibrace silové platformy vykazovala lineárnost v rozmezí 3 %. Dynamické zkoušky prokázaly, že platforma má základní frekvenci vyšší než 2300 Hz a že tudíž může být použita pro analýzu sil vyvinutých při psaní.

Klíčová slova: biomechanika, motorická kontrola, dynamometrie, silová platforma, klávesnice, psaní na počítači.

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