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Development of a Bench for Deformation Measurement

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Abstract: This paper refers to the construction of a didactic bench for the study of strain in an anodized aluminum clamped beam through strain gage. To the free end of this clamped beam an external concentrated load is applied through standard weights. The analytical method provides the necessary equations for programming the softwares used. The strain data obtained are sent to the HX711 module, which amplifies, filters, and converts the analog signal to digital in order to send it to Arduino®, where there is a code that reads and sends the data to the supervision station (LabVIEW®), where they will be stored. Graphs were generated for strain analysis, experiment validation, and relative errors between the results from the analytical calculation and those from the experiment.

Keywords: Strain gage; Strain measurement; Arduino; HX711; LabView.

Desenvolvimento de uma Bancada para Medição de Deformação

Resumo: Este trabalho refere-se à construção de uma bancada didática para estudo de deformação em uma viga engastada de alumínio anodizado por meio de extensômetro piezorresistivo. À extremidade livre desta viga engastada é aplicada uma carga concentrada por meio de pesos-padrão. O método analítico provê as equações necessárias à programação dos *softwares* utilizados. Os dados de deformação obtidos são enviados para o módulo HX711®, o qual amplifica, filtra e converte o sinal analógico em digital para encaminhá-los ao *Arduino*®, onde há um código que lê os dados e envia-os para a estação de supervisão (*LabVIEW*®), onde serão armazenados. Geraram-se gráficos para análise de deformação, validação do experimento e erros relativos entre os resultados provenientes do cálculo analítico e os do experimento.

Palavras-chave: Extensômetro; Medição de deformação; Arduino; HX711; LabView.

Introduction

Strain measurement systems are present in the most varied branches of industry, especially the oil and gas, automotive and aeronautical sectors [1]. Therefore, methods of obtaining and interpreting stresses and deformations are widely used to evaluate components. Works based on extensometry have become an important area of deformation analysis, based on the reading of signals from deformations in equipment coupled with the elements under analysis (strain gages), when subjected to loading [2]. The branches related

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to the application of extensometry are directed towards the reduction of errors, measurement procedures, in addition to the instruction on the correct use of the sensor, as well as the measurement calibration and reduction of errors, through the connection of the extensometers in circuits with Wheatstone bridges. HOFFMANN 1989 [3] covers basic areas, such as the selection of strain gages, the connection of circuits on the bridge and its interaction with the acquisition equipment, explaining the influence of Hooke's Law in determining the mechanical stresses. In MAGALHÃES 2016 [6], the reliability of a weld was analyzed with the aid of strain gages, using the measurement of residual stresses. These stresses are among the determinants of the quality of the welded joints, and may also influence the performance of the parts subjected to this procedure. There are designs based on extensometry for the creation of electronic sensors that measure force. The work carried out by GUADAGNINI et al. 2011 [1], where the design, construction and performance testing of an electronic sensor based on extensometry was performed for measuring force. Additionally, there are still applications in the areas of physiotherapy and biomechanics, for the assessment of musculoskeletal strength. Transducers, signal conditioners and a data acquisition system were used [5]. In this context, this paper deals with the integration of a Strain Gage connected to a Wheatstone bridge, together with a signal amplifier module and analog to digital converter (HX711®). The deformation signals from the HX711® are sent to an Arduino prototyping platform, where there is a code to handle these signals and transmit them via serial communication to a supervision station (LabView®). These data were analyzed statistically to consolidate the proposed project regarding the deformation studies.

Objective: The main objective of this work is to present the physical infrastructure for reading strain from a clamped beam subjected to a concentrated load from standard weights.

Material and Methods

The project design consists of two divisions, i.e. a physical and an electronic structure. Regarding the physical structure, there is a bar made of anodized aluminum performing the function of a clamped beam, on whose free end a concentrated load is applied. The loads are represented by four standard weights of 0.050 kg each, then encompassing 0.05, 0.10, 0.15 and 0.20 kg. The strain gage model chosen for the project was the BX120−3AA. The selected aluminum bar is anodized and has the dimensions of

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200 mm long, 30 mm wide and 2 mm of height. The electronic apparatus is composed of the strain gage connected to the HX711®, an analog to digital converter (which amplifies and filters the deformation signals), and an Arduino® (for which the signal is sent). In this platform, there is a code that reads the strain data from HX711® and sends the signal to the supervisory station, which consists of a notebook with National Instruments *LabView*® supervisory development software. The entire physical and electronic structure can be seen in Figure 1.

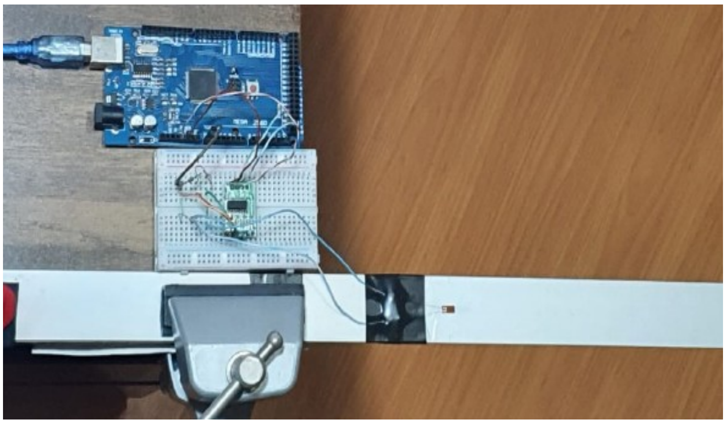

Figure 1 – Clamped beam and electronic structure (Arduino, HX711).

Results

For the correct installation of the strain gage on the specimen, the procedure developed by MURRAY and MILLER 1992 [6] was applied. When the association of the electrical input and output voltages, respectively, V_i *and* V_o , are made to the strain ε, Equation 1 yields:

$$\varepsilon_{EXP} = \frac{4}{k}\frac{V_o}{V_i}, \tag{1}$$

where, ε_{EXP} is the experimental strain, k is gage factor and the electrical input of HX711 is V_i. Moreover, in the case studied in this paper, the theoretical strain is given by Equation 2:

$$\varepsilon_T = \left(\frac{6\left|L_p - L_{sg}\right|}{Ebh^2}\right) m\, g\,, \tag{2}$$

where ε_T is theoretical deformation, E is the elasticity modulus of the material, *b* is the cross-sectional width, *h* is the cross-sectional height, L_p is the distance from the strain gage to the point of load application, L_{sg} is the distance from the strain gage to the support, *g* is

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gravity acceleration, and *m* is the mass of the standard weight. The values of the constants used are shown in table 1.

Table 1. Values of the constants.

Constants	Value
Gage Factor k	2.1
Width of the base in the cross section b	0.03 m
Cross-section height h	0.002 m
Distance from the strain gage to the support L_p	0.077 m
Distance from the point of load application to the support L_{sg}	0.277 m
Modulus of elasticity of the aluminum bar E	68.0987 GPa
Gravity acceleration g	9.81 m/s^2

To validate the experiment, the value obtained experimentally from Equation 1 was compared to the theoretical value from Equation 2. The results, as well as the error analysis and standard deviations that serve as metrics to validate the experiment will be presented in the following. For this purpose, five measurements were made with each standard weight, in which the results are shown in table 2. In order to evaluate the relative errors associated to the experiment, Equation 3 was used.

$$\phi(\%) = \frac{\left|\varepsilon_{EXP} - \varepsilon_T\right|}{\varepsilon_T} 100\,\%\,. \tag{3}$$

Table 2. Theoretical x Experimental values.

Theoretical Value			Experimental Value					
Mass (kg)	Electric voltage (V)	Theoretical Strain (ε_t)	Mass (kg)	Relative Error (%)	Electric Voltage (V)	Relative Error (%)	Experimental Strain (ε_{EXP})	Relative Error (%)
0.00	0.0000000	0.00000000	0.0002341	0.00	0.000009	0.00	0.000030	0.00
0.05	0.0001935	0.00007200	0.0511540	2.30	0.000198	2.29	0.000074	2.77
0.10	0.0003870	0.00014401	0.1024870	2.48	0.000397	2.56	0.000148	2.76
0.15	0.0005806	0.00021601	0.1493620	0.42	0.000578	0.45	0.000215	0.46
0.20	0.0007741	0.00028802	0.2010030	0.50	0.000778	0.49	0.000289	0.34

Discussion

Based on the results obtained in table 2, regarding the relative error values, the didactic bench behaves in a linear manner, which is in accordance with the functioning of the strain gage, when in an elastic strain range. By observing Equation 3, it is possible to analyze the accuracy taking into account an ideal result within 3% relative error. In addition, the small difference between the theoretical and experimental values is due to some steps of the experimental process. The probable causes are, for example: the

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replacement of Arduino cables, using it next to the protoboard, with ethernet cables, which optimized the transfer of information without constant bad contact, once interfering with the results of the circuit. In addition, there was a need for updates, including inserting the library for communication between the Arduino® and the HX711®, a patch to interface with MATLAB® script. Finally, the communication of the entire system with the supervision station (LabVIEW®), where the data was exported to Excell® to conduct all the static analyses. An oscillation in the results was also observed when the standard weights were not inserted, probably due to the ambient conditions such as temperature and vibrations where the experiment was carried out. However, the error values are within the study goals, since it is not a high precision bench. Therefore, the results proved to be satisfactory, since the experimental results showed certain linearity, corresponding to the desired by the application of the extensometer in the project.

Conclusion

The general objective of building an infrastructure capable of measuring and recording deformation has been achieved. Additionally, a piece of software was developed to be capable of associating the resistance variation suffered by the strain gage (in the acquisition system data) to a corresponding voltage, and converting it to the desired quantity. In the project, experimental values were compared with the theoretical ones, obtaining errors considered acceptable, observing a specified criterion.

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