CILAMCE 2017
Florianópolis - Santa Catarina - Brazil

A consistent experimental approach for strain measurement: Two case studies

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Abstract. *This paper presents a methodology for the measurement of strain by means of strain-gauges, performing the data acquisition using an Arduino Uno board, due to the low-cost and the easy manipulation of this microcontrollers. The measured signal conditioning is performed by means of a Wheatstone Bridge and then discretized by an Analog-Digital Converter (ADC) external to the Arduino. For the validation of the proposed measurement system are performed experiments on a cantilever beam and on a cantilever-supported shaft, the experimental results are compared with those obtained analytically and by simulation using the finite element method. The results obtained are in agreement with the literature and demonstrate that the proposed system has satisfactory accuracy.*

Keywords: *Strain gauge, Arduino, Low-cost data acquisition*

1 INTRODUCTION

In many practical situations in engineering, the knowledge of the stresses and strains that are applied in a structure is of vital importance, since the predictability of the materials depend closely on these parameters. Besides, it is important to avoid deformations so large that they may prevent the structure from fulfilling the purpose for which it was intended (Popov, 1990). Generally, mathematical models or finite elements methods (FEM) are needed to predict the stresses in a structure. There are some situations, however, were the modeling is not possible or its results are rough approximations that do not agree with the real loads acting on the structure. In these cases, in order to avoid overdimensioning, the experimentation is the way around.

There are many experimental procedures aimed at measuring mechanical strain, such as using extensometers, which can be optical (Lalout et al., 2006) or mechanical (Lim et al., 2008); or using electrical strain-gauges, that can be based on resistive (Wen et al., 2001), capacitive (Cohen et al., 2012), inductive (Butler et al., 2002) and photoelectric (Lonsdale, 2001). One of the most common applied method is based on the use of resistive-based strain-gauges. These devices allow the strain to be measured directly by measuring the change in the electrical resistance of them as they are subjected to deformations, which is commonly done by using a Wheatstone bridge. The gauges can also be used to measure forces and torques acting on a structure, as these quantities are directly related to strain. However, since the strain-gauges are expensive and not reusable, the overall cost of the experimental procedure is generally high.

Taking into account the aforementioned, in this paper, a low-cost experimental setup is presented with the purpose of measuring strain using resistive-based strain-gauges. For such, the voltage output from the Wheatstone bridge was discretized by an Analog-Digital Converter (ADC) and then send to an Arduino Uno board, which was used as an acquisition system. The evaluation of the experimental apparatus was done by comparing its measurements with the data obtained using analytical and FEM models of a cantilever beam and a cantilever-supported shaft.

2 ANALYTICAL MODELS

The two models that were used to evaluate the experimental procedure proposed are static models of a cantilever beam subjected to pure bending load and a cantilever-supported shaft subjected to torsional load. The principal stresses in both cases are given by (Popov, 1990), respectively,

$$\sigma_1 = \sigma_{max} = \frac{6M}{bh^3}, \quad \sigma_2 = 0 \tag{1}$$

$$\sigma_1 = -\sigma_2 = \tau_{max} = \frac{16T}{\pi d^3} \tag{2}$$

where $\sigma_{1,2}$ are the principal stresses, which are acting in the sectional plane in the bending beam and at 45° from the section plane in the shaft; σ_{max} is the maximum bend stress, M is the bend moment applied in the beam, b is the beam width, h is the beam thickness, τ_{max} is the maximum torsional stress, T is the torque applied in the shaft, and d is the shaft diameter. Using Hooke Law, the strain for the beam and the shaft is given, respectively, as follows,

$$\varepsilon_1 = \sigma_1 E = \frac{6ME}{bh^3}, \quad \varepsilon_2 = 0 \tag{3}$$

$$\varepsilon_1 = -\varepsilon_2 = \sigma_1 G = \frac{16T}{\pi d^3}\left(\frac{1+\nu}{E}\right), \tag{4}$$

where $\varepsilon_{1,2}$ are the principal strains, E is the Young Modulus, ν is the Poisson ration and G is the shear Young Modulus. Therefore, knowing the loads acting on the beam and on the shaft, and also knowing their mechanical properties, the strain in both cases can be easily obtained using Eqs. (3) and (4).

3 EXPERIMENTAL SETUP

For the data acquisition it was utilized an Arduino board model Mega2560 and a module based on the chip ADS1230, that includes amplifier, filters and a 20-bit high-resolution analog-digital converter (ADC), configured for a sample rate of 80 Hz and gain of 128 times. The use of Arduino microcontrollers together with low cost sensors has been proved to be efficient on the tasks related to instrumentation, as shown in Varanis et al. (2018), where MEMS (micro-electromechanical Sensors) sensors were utilized with an Arduino microcontroller to analyze mechanical vibrations on multi-degree of freedom systems.

For the strain analysis preformed, it was utilized strain-gauges Model BF350-3AA with nominal electrical resistance of 350 ohm. To allow the reading of the gauges signals, a quarter-bridge of a Wheatstone circuit was mounted in a protoboard using 680 ohm resistors. It was used the quarter bridge circuit due to the use of one transducer for each mechanical system and, since the resistors used in the bridge has resistances of 680 ohm, a trimpot was used to balance the circuit by zeroing the output signal. The electric circuit was powered with 5 V by the Arduino's pins, while outputs from the Wheatstone Bridge signals were connected to the amplification module already mentioned, where the signal was amplified and discretized. In Fig. 1 one can see the connection diagram of the components used.

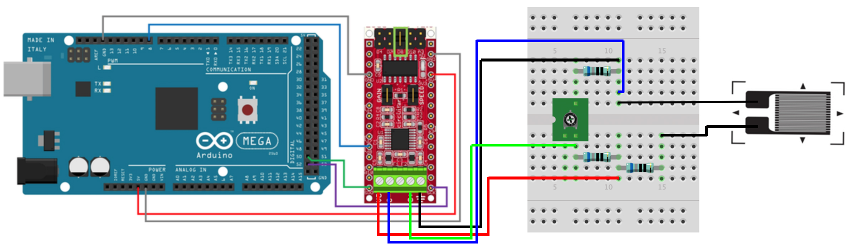


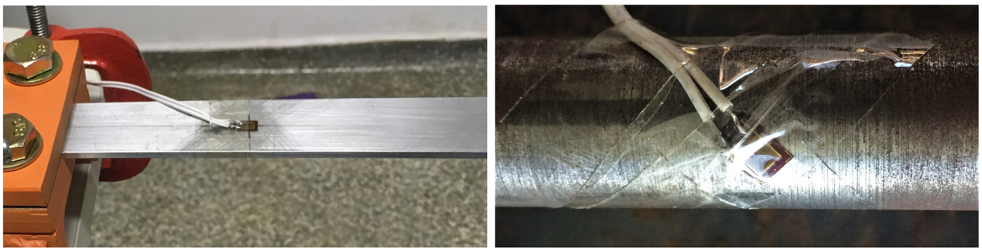
Figure 1: Connection diagram of the components for the data acquisition.

For the experiment of the cantilever beam a force of 0.981 N was applied by positioning a block with known mass at the free end of the beam. The strain-gauge was glued at 30 mm from the fixed end, on the center of the upper faceof the beam. In the shaft under torsion experiment a torque of 3.6 N/m was applied and the strain-gauge was glued at 45° of the axis of symmetry of the workpiece. In both experiments 256 points were acquired.

The experiments were performed in two stages for each system. First, the force or torque were applied and after a time taken off. As for the second stage, the described process was performed twice for each system, to analyze if the proposed measurement system has repeatability. The test benchs utilized for the experiments can be seen in Fig. 2 and in Fig. 3 the strain-gauges already glued in the mechanical systems analyzed are shown with more detail.

(a) (b)

Figure 2: Test benches for experimental validation of the proposed measurement system: (2a) Cantilever beam and (2b) Crimped-supported shaft under torsion.

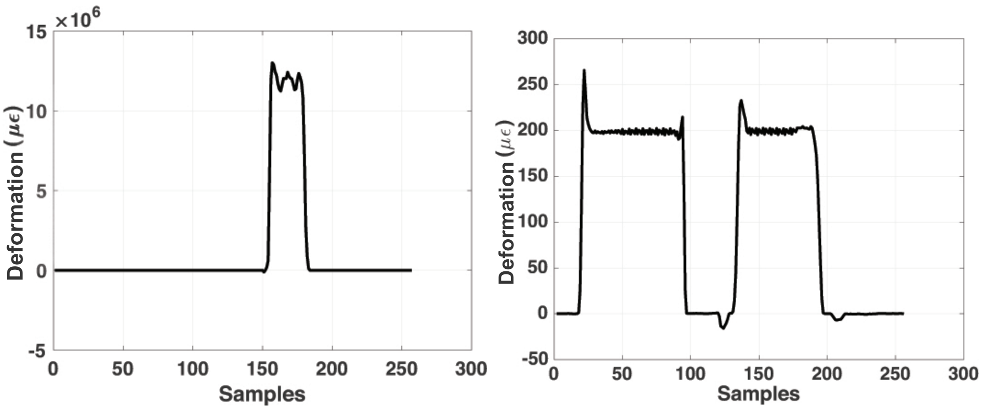


(a) (b)

Figure 3: Strain-gauges glued to the analyzed mechanical system (3a) in experiment 1 and (3b) in experiment 2.

4 RESULTS AND DISCUSSIONS

Five measurements using 256 points and a sampling frequency of 80 Hz were performed for each case analyzed. Two samples of the time domain signal acquired of deformation are shown in Fig. 4. In order to obtain the deformation value measured in the mechanical system, the average peak values of the time domain signal were calculated. The experimental results were very close to those obtained analytically and numerically for both experiments and they presented values with low dispersion, making the proposed methodology reliable for the measurement of deformation.



(a) (b)

Figure 4: Samples of the time domain strain signals acquired: (4a) First test, load applied once, and (4b) Second test, load applied twice.

In Table 1 the results obtained in the three analyzes performed are presented for comparison.

Table 1: Results Obtained.

Method	Experiment 1	Experiment 2
Analytic ($\mu\varepsilon$)	208.83	14.02
Numeric ($\mu\varepsilon$)	207.98	14.49
Experimental ($\mu\varepsilon$)	207.3	13.3

5 CONCLUSIONS

In this paper, it was presented the use of the Arduino microcontroller as a data acquisition system for the instrumentation of strain, aiming to introduce a methodology of measurement of strain to undergraduate students in a simple and intuitive way through the Arduino platform, which has easy-to-use hardware and software as well as low-cost. The results obtained are in agreement with the literature and indicate that the system has good precision for the intended purpose. In future works we intend to apply the methodology proposed in systems subject to dynamic loads.

ACKNOWLEDGEMENTS

The authors acknowledge the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for the support.

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