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# Study and realization of a torque measurement sensor based on strain gauges dedicated to bending and torsion

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**Abstract**—This We have chosen the most popular tool which is the strain gauge, which is the most suitable for the torsion and bending tests we performed. We have detailed the theoretical operation of torque sensors based on strain gauges as well as some difficulties related to this method of measurement. Then we analyzed the bending and torsion tests. A design of the torque sensor has been made.

**Keywords**—strain gauges, bending and torsion, sensor, diameter.

In the world of design and manufacturing, torque measurement is essential for defining assembly specifications and validating product characteristics such as motors. However, measuring torque is relevant for some applications especially with the improvement of mechanical equipment performance where the need to choose the measurement method that fits with the imposed specifications is critical. Therefore, many technological advances in the applications concerned require innovation in torque measurement where research and development in this area is ongoing and many advances have been made in the design of torque sensors [1][2]. Thus, the objective of the work carried out is to select and build a torque sensor with good sensitivity, which can measure up to 2N.m [3][4][5]. Firstly, a theoretical study of the adapted measurement technology will be presented. Finally, we start the practical part which consists in designing the torque sensor based on strain gauges by detailing the various stages carried out which enables us thereafter to carry out a prototype by exploiting the case of flexion and torsion. Torque is the tendency of a force to rotate an object around an axis; its measurement is a technology that began in the 17th century and has continued to develop to the present day [5]. This concept is present in the manufacture of a large number of products used daily. However, it is essential for manufacturers to measure the torque. For this purpose, there are several measurement methods: direct and indirect; static and dynamic. Four approaches can be used, including: - Torque measurement by gauges; - Torque measurement by torsion; - Torque measurement by reaction; - Torque measurement by current. Now that the advantages of using a strain gauge based torque transducer have been highlighted, we will present in detail its theoretical principle of operation as well as the origin of the faults appearing in practice.

## I. TORQUE MEASUREMENT IN AN INDUSTRIAL FIELD

### A. Torque measurement by gauge

Torque measurement can be done using strain gauges, by inserting a mechanical part between the part on which a torque is applied and another part that receives this torque[6].

Figure 1 the force is transmitted by the two perforated metal plates connecting the two sections of the part.

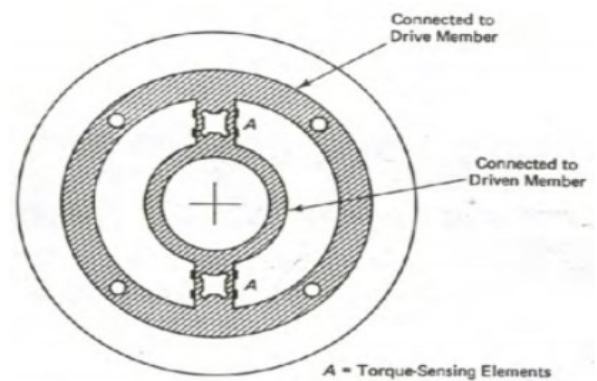


Figure 1. Mechanical part for torque measurement by gauge [8]

The measured stresses are proportional to the torque between the two elements connected to this mechanical part. Generally, this system does not allow for much rotation, as the strain gauges must be connected to an acquisition system (using a brush and ring system to transmit the gauge signals) [7].

### B. Torque measurement by torsion

The measurement of torque by torsion is based on the torsion undergone by a shaft subjected to a torque[8][9]. At each end of the shaft are installed metal gears and two inductive proximity detectors figure(II.3).When the shaft rotates and no torque is present, there is no torsion and the phase shift between the two detector outputs is equal to 0°. When the shaft experiences torque T, the shaft experiences torsion and a phase shift occurs between the two detector outputs. The relationship between the torque T (Newton-meter) and the phase shift  $\theta$  (in radians) is

$$T = GJ\theta / lN \quad (I-1)$$

Where T is the shear modulus of the shaft material; J is its moment of inertia; l is the distance between the sensors; and N is the number of teeth of the metal gears. What is interesting about this approach is that the measurement can be made on a rotating machine.

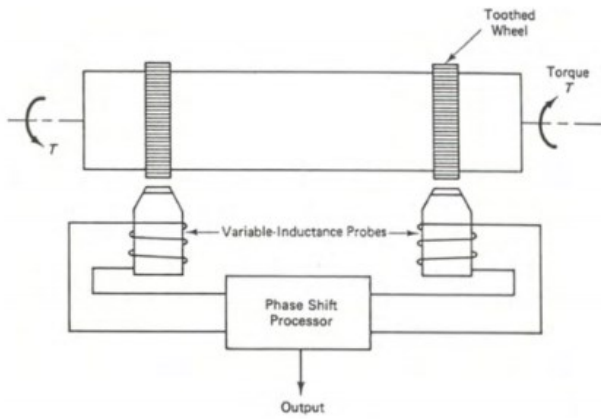


Figure 2. Torque measurement by torsion [9].

## II. TORQUE MEASUREMENT METHOD USING STRAIN GAUGES

Now that the interest of using a strain gauge based torque transducer has been highlighted, we will present the theoretical principle of operation. Afterwards, we will explain some basic notions useful to clarify our topic. This allows us to start the practical part in the following section.

### A. Definition of the strain gauge

Gauges consist of a resistive wire bent in an accordion-like fashion and are usually made from a thin metal foil ( $\mu\text{m}$ ) and an insulator, which is treated like a printed circuit board. The strain gauge (often called a strain gauge) figure (3) is based on the principle of elongation or shortening of a resistive wire attached to the deforming support. In a more detailed way, a strain gauge is a passive sensor that translates its own deformation into a variation of resistance: By acting by traction or compression on the wire, it lengthens or shortens. This variation in length modifies its electrical resistance. This change in resistance is measured between the resting state and the stressed state [10][11]. The wire is arranged in turns so that the deformation acts simultaneously on several sections of the wire to amplify the change in resistance electrical given by equation (II.1)

$$R = \rho L / S \quad (\text{II.1})$$

Where  $\rho$ ,  $L$  and  $S$  are the resistivity, length and cross-sectional area of the conductor. A change in length causes a change in resistance according to the essential formula of extensometry.

$$K\varepsilon = \Delta R / R \quad (\text{II.2})$$

Where  $k$  is the gauge factor whose value is close to 2 and  $\Delta R/R$  is the relative change in resistance.

### B. The basic circuit, the Wheatstone bridge

The basic circuit, the Wheatstone bridge A Wheatstone bridge is a measuring device invented by Samuel Hunter Christie. It is used to measure an unknown electrical resistance by balancing two legs of a bridge circuit, with one leg containing the unknown component.

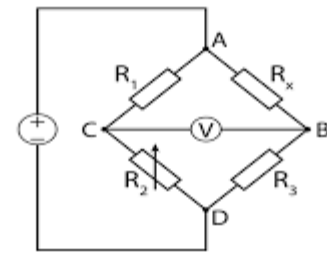


Figure 3. Wheatstone bridge[11].

The bridge consists of four resistors  $R_1$ ,  $R_3$ ,  $R_2$  which is a variable resistor and an unknown resistor noted  $R_x$ . Between points B and C, by symmetry, there is a zero potential difference. A measuring instrument, for example a G galvanometer, does not deviate when the symmetry is perfect (the value of  $R_x$  is fixed by varying the resistance  $R_2$  to have  $V_{BC} = 0$ ). If the resistance  $R_1$  varies slightly, the equilibrium is destroyed. We can either measure the variation of resistance by the current of the unbalance voltage, or restore the equilibrium by a known variation of one of the 3 other resistances. We can easily verify that  $R_1$  and  $R_3$  act in the same direction, while  $R_2$  and  $R_x$  act in the opposite direction, hence the first fundamental principle of extensometry : Two adjacent resistors act in opposite directions, while two opposite resistors act in the same direction. In practice, either one or more of these four resistors are gauges, the others being pure resistors. In measuring strain,  $R_1$  is an active gauge glued to the structure,  $R_2$  is an identical gauge glued to a part of the same metal, but not stressed.  $R_3$  and  $R_x$  are pure resistances. Under these conditions, the thermal effects are eliminated and only the deformations linked to the stresses are detected, the latter is interpreted in the form of a variation of potentials, which will then be used to measure the force or the torque[12][13].

Note: -Before carrying out a strain gage measurement, a choice must be made between different mounting and wiring solutions.-Full bridge, half bridge and quarter bridge mountings are not used under the same conditions and do not all require the same precautions.-In all cases, the wiring plays an essential role. A Wheatstone bridge for strain gauges is configured as either: - one (01) strain gauge en 1/4 bridge; - two (02) strain gauges en 1/2 bridge; - four (04) strain gauges in full bridge ; and in accordance with the measurement objective[14].

This step allowed us to choose the Wheatstone bridge as the ideal candidate for the gauge conditioning circuit and to define the arrangement of the gauges in it. Then we analyzed the bending and torsion cases, which allowed us to start the experimental part.

## III. TORQUE TRANSDUCER DESIGN BASED ON STRAIN GAUGES

The objective of this section is to describe the design of a sensor dedicated to the measurement of the torque based on strain gauges, to realize it, two principals were exploited: the first one consists in using a test body equipped with strain gauges which contributes to measure the bending force and the second one is based on the torsion where strain gauges will be glued on an Aluminium rod to detect it. In order to evaluate the performance of the sensor realized, a comparison of the obtained results must be carried out, for this reason we used this type of sensor at the level of the

laboratory of the solid and structure at the university as a reference of validation of our results. Finally, we will conclude with the exposition of the experimental results obtained.

### A. Measurement chains

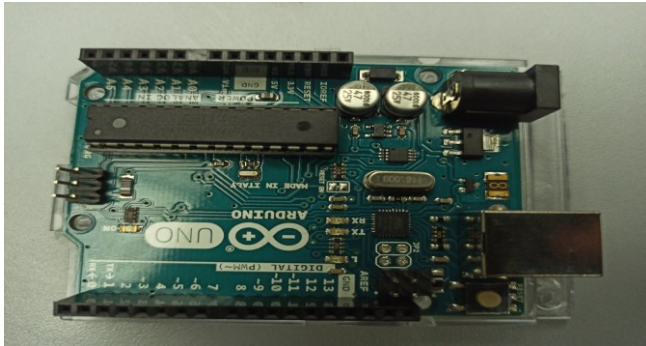


Figure 4. Arduino uno used cards.

### B. The approach followed

#### B.1 Bending case

A sensor based on strain gauges has been made to measure the bending, this force will be exploited later to find the values of the applied torque. In this case, we have a test body in rectangular form whose strain gauges are mounted in a complete bridge; the latter is connected to a module HX711 to amplify the output signal which will be connected in turn to an arduino board to make the acquisition.

In this part, we describe the different steps to design the desired sensor: We start by connecting the HX711 module on the one hand, to the arduino board and on the other hand to the test body equipped with strain gauges. As it is illustrated in the figure (4), load cell is equipped with four wires red, black, green and white, constituting a complete bridge of Wheatstone these last ones will be connected to the module HX711.

The strain gauges are placed on the upper and lower part of the test body in order to maximize the sensitivity of measurement and linearize the bridge, these are mounted in a region where the deformation is maximum and which is not affected by the phenomena of extremity so that all the gauges undergo the same deformation simultaneously such that those which are opposite undergo the same phenomenon of traction or compression ( $R_1$  and  $R_3$ ) or ( $R_2$  and  $R_4$ ).

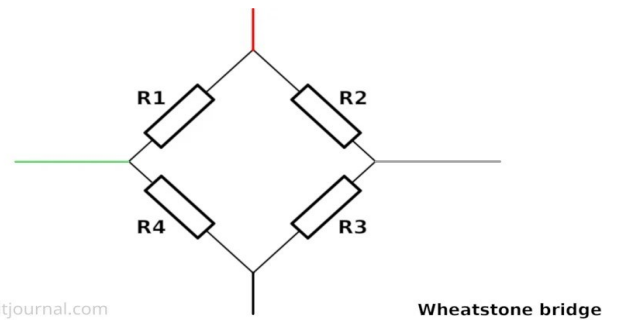


Figure 5. Wheatstone Bridge

Figure 5 below is a simplified diagram that illustrates the wiring described above:

Once this step is completed, we obtain the following assembly:

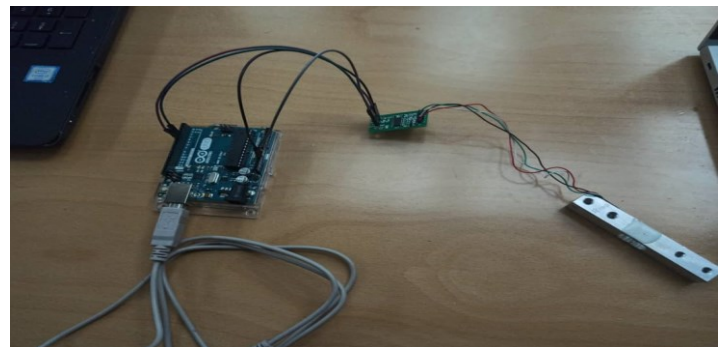


Figure 6. HX711 Module wiring

Once we connect this assembly to the PC, we can easily obtain the variation of the resistance of the strain gauges.

#### C. Torsion case

In this case, the body of test is a hollow cylinder in Aluminum, or the gauges of constraints are stuck to  $45^\circ$  with regard to its axis constituting a complete bridge which allows the conversion of the deformations in variation of the electrical resistances. Figure (7). once this step is completed which is the most delicate task of the process, we connect our test body to a HX711 module which allows amplifying the level of the output signal, and then we connect it to an arduino board in order to obtain torque measurements in real time.

In order to evaluate the performance of this sensor, we use the one at the level of solid mechanic's laboratory to validate our results. By using a complete bridge of strain gauges we ensure:

- A linearity of the measuring bridge;
- A better sensitivity to the torque to measure;
- Compensation of the effect of parasitic forces.

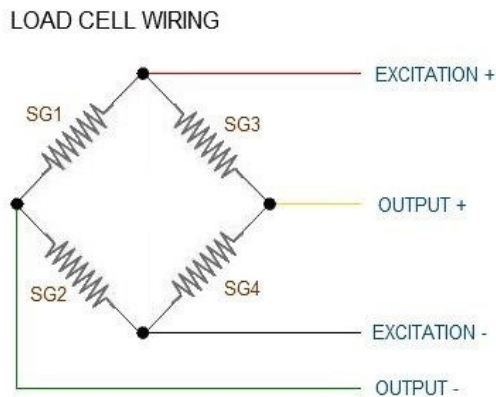
The figure below shows the rod and the support used:





Figure 7. The stem and the support used

As in the case of bending, we connected the four wires of the strain gauges to the terminals A+, A-, E- and E+ of the HX711 module so as to form a Wheatstone bridge, and the terminals Gnd, Sck, Dt and V cc to the arduino board as previously explained.



The figure below illustrates the final assembly obtained

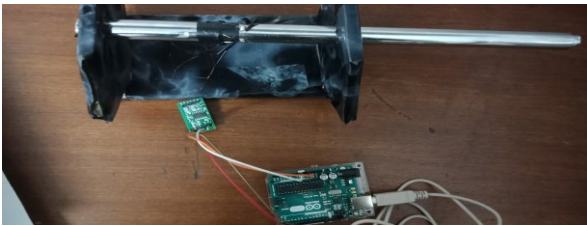


Figure 8. The final assembly

The solid mechanics laboratory reference device is made up of two parts: the first is the torsion one where the gauges are mounted on the cylinder at  $45^\circ$  and the second presents the bending case, connecting it to an acquisition card we can read directly the deformation value that corresponds to the force or torque applied. It has a maximum weight of 0.5 Kg for this value the acquisition card displays a value of deformation of 30 which presents the calibration of the system.

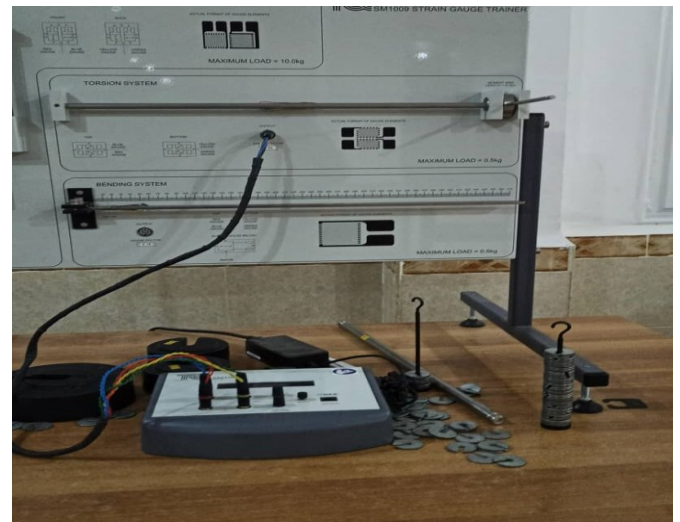


Figure 9. The stem and the support used.

In this section, we were able to study and design a sensor to measure the torque based on strain gauges by exploiting the case of bending and torsion. First, we presented and described the hardware used, such as the arduino board and the HX711 module that allows amplifying the output signal of the Wheatstone bridge, and then we explained the approach followed by describing the steps of realization of the sensor in the two cases mentioned. Finally, we ended by exposing the device of reference that of laboratory of mechanics of solid and structure by specifying its calibration.

#### IV. CONCLUSION

We have chosen the strain gauge method which is the most suitable for the torsion and bending tests we have performed. We detailed thereafter the theoretical operation of the sensors of torque based on the strain gauges. Thereafter we analyzed the tests of flexion and torsion; that allowed us to begin the experimental part. A design of the torque transducer was made.

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