Data acquisition and control of a New electromagnetic Force-Displacement Sensor using National Instruments ''LabVIEW'' software

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Abstract: - A new electromagnetic force-displacement sensor is presented. Its operating principle is based on the fundamental laws of electromagnetism (Faraday-Lenz law) and the mechanical properties of a spring. The active elements are two coils made by a wire of 60 µm in diameter. The sensor signal is acquired using a high precision DAQ card, processed and stored on the computer using a LabVIEW Program. The average accuracy of the sensor is about $\Delta d=1\mu m$, and as a force sensor is about $\Delta F = 1\mu N$. This sensor could be successfully used for the manufacture of several measuring instruments.

Key-Words: - Electromagnetic force-displacement sensor, accuracy, measuring instruments, DAQ, LabVIEW.

1 Introduction

The principles used in magnetic sensors are numerous; applications are also very different, not only in terms of cost but also in terms of their measurement range and resolution [1-3]. Those inductive sensors which use the inductive effect were first used for historical reasons, but are still interesting because of their accuracy and robustness; Thus, inductive sensors are generally used for detection of position, pressure or flaw in mechanical structures.

There are many historical examples of the renaissance of various coil sensors. For example, the Chattock–Rogowski coil was first described in 1887 [4,5]. Today, this sensor has been re-discovered as an excellent current transducer [6] and sensor used in measurement of magnetic properties of soft magnetic materials [7]. An old Austrian patent from 1957 describing the use of a needle sensor (also called the stylus method) for the investigation of local flux density in electrical steel was revived several years ago for magnetic measurements [8,9].

The device we propose is an electromagnetic sensor based on the fundamental laws of electromagnetism and designed for manufacturing of different measuring instruments (Micro-balance, Micro-dynamometer, Density meter, Viscometer, Dilatometer, Tide gauge, Extensometer, Accelerometer, Seismometer, Gravimeter….)

During the sensor development experiences, it was necessary to monitor parameters, and save experimental data. Therefore, satisfactory results cannot be obtained without the automation of the instrument. Old approaches for automating instruments are based on text-oriented programming languages; unfortunately, this solution had many drawbacks as the long development time and the inflexibility and the difficulty to modify the program code as the speed of development of the experimental needs increases.

Therefore, we chose an approach using the graphical programming platform LabVIEW developed by National Instrument [10]. It was already proved that LabVIEW is an excellent tool for experiment automation [11]. In the last two decades, LabVIEW found wide applications in instrumentation in various fields, especially in physics, such as optics [12-14], thermodynamics [15, 16], plasma physics [17, 18], and microscopy [19, 20].

This paper is organized as follows: an presentation of the electromagnetic force-displacement sensor is presented in Section 2, the block diagram of the experimental device is presented in Section 3, the data collection and processing inter-faces are described in Section 4

2 Electromagnetic Force-Displacement Sensor

Our goal is to design and produce an electromagnetic sensor with a good accuracy of measurement, stability and specified measuring range and resolution.

The operating principle of the proposed sensor is based on the fundamental laws of electromagnetism (Faraday-Lenz law), which justifies its name “Electromagnetic force sensor”.

This sensor consists of two flat circular coils of 1.8 cm in diameter, placed in parallel. One of the flat coils (Fixed Coil) is fixed on an insulating horizontal support and the other flat coil (Moving Coil) is wound around an insulating cylinder, the lower end passes through the free surface formed by the fixed coil, and the upper end is connected to a spring which is itself attached to a fixed support. At the lower end of the cylinder that acts as a guide, we set a hook for hanging masses.

The entire system formed (fixed flat coil, guide cylinder, spring and moving flat coil) is aligned on the same vertical axis (Fig-1).

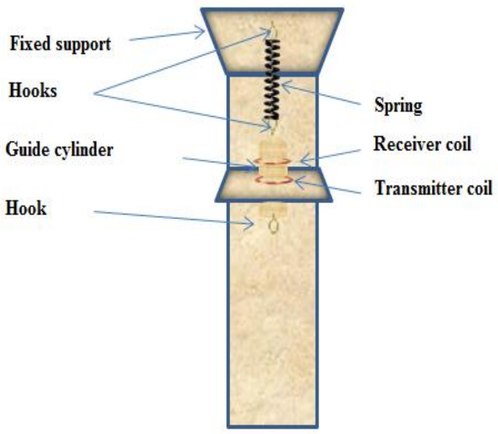

Fig.1. Electromagnetic sensor

The cylinder is movable vertically upwards or downwards virtually without friction, when we exert a force on its lower end, which has the effect of extending or compressing the spring, this action bring closer or away the guide cylinder (moving coil) from the fixed coil.

The fixed coil is supplied by a low frequency generator, and therefore it is traversed by a sinusoidal current which creates a sinusoidal magnetic flux along its axis, the latter creates through the moving coil a variable flow Φ and induced a measurable sinusoidal electromotive force, the value of the EMF induced depends on the distance x from the center of the transmitter coil, the flux Φ is proportional to the magnetic induction B that changes as a function of x by the following equation:

$$B(x) = \frac{\mu_0 I R^2}{2\sqrt{(R^2 + x^2)^3}} \qquad (1)$$

With I: Maximum amplitude of the current flowing through the coil, R: coil radius and x is the distance between the coil center and a point M on the coil axis.

The magnetic field created by the transmitter coil is at a maximum at the center of the coil (x=0):

$$B_0 = \frac{\mu_0 I}{2R} \qquad (2)$$

The second flat moving coil is the receiver coil; it acts as an inductive sensor that converts a magnetic field flowing therethrough to a voltage. This receiver coil situated at a distance x from the fixed flat coil will receive an electromotive force whose expression is given by the Lenz-Faraday law $e = -d\Phi/dt$. The magnetic flux Φ through the receiver coil is proportional to the magnetic induction B whose variations in terms of x are given by the relation (1), and therefore the induced electromotive force will have similar variations in function of x in a given frequency. The maximum amplitude of this induced current will be greater as the frequency is higher. Thus, we realized an electromagnetic displacement sensor, at each position x of the receiver coil corresponds a determined induced voltage, this voltage takes its maximum value when the two coils are juxtaposed and decreases as the receiver coil moves away from the transmitter coil. The use of the spring, which acts as a force-displacement converter, allows to use the sensor as a force sensor.

The induced signal is sinusoidal and its amplitude is low, so it has been necessary to introduce circuits for amplification, rectification and filtering to make this voltage usable.

2.1 Sensor response

By hooking hight precision masses in steps of 100mg, by converting the masse to a force and by using the spring that acts as a force-displacement converter, the characteristic curves of the sensor shown below are obtained.

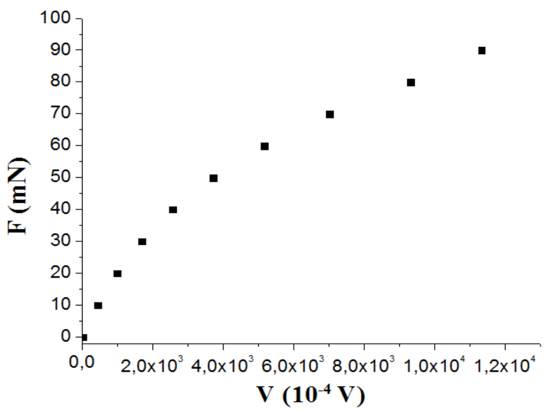

Fig.2. Output voltage variation as a function of force F

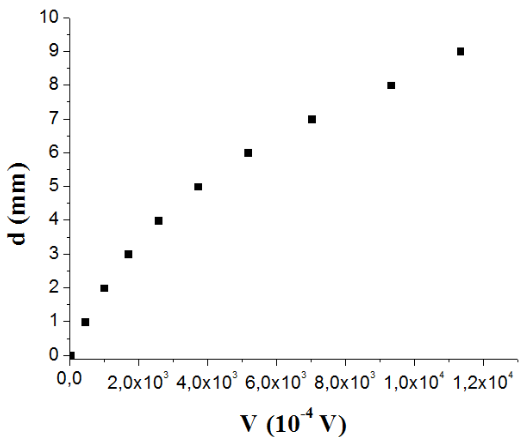

Fig.3. Output voltage variation as a function of displacement d

The sensor response is not linear, it is rather parabolic and follows a polynomial equation, the immediate consequence of this non-linearity is having a variable sensitivity which depends on the distance x between the two coils according to the equation (1).

2.2 Discussion

Since at the receiver side only small signals are expected, it is preferable to increase the number of turns in the pickup coil, even at the cost of a decrease of the cross section of the wire. According to Faraday's law, the number N of turns in the coil is the relevant factor for the induced voltage U [21], but by increasing the number of turns in the coil or the cross section of the wire, it also increases its size which has a negative effect on the signal-to-noise ratio or on the stability of the sensor.

Empirical studies have led us to the discovery of a crucial number of wire turns which is 30, and a crucial wire diameter which is 60 µm. That gives stability and a good sensitivity comparing to all experiences we made by changing each time the already mentioned parameters. And finally we got the following results:

Sensor drift : when we turn the sensor on, the output voltage decreases exponentially and after 10 to 15 minutes of operation, this voltage stabilizes at a characteristic constant of the experimental device.

Sensitivity : The average sensitivity of the sensor depends on the stiffness of the spring used and conditioning circuit. we achieved a sensitivity of $\Delta F = 1$ µN by using a spring of stiffness k=2 N/m. And as a displacement sensor the sensitivity is $\Delta d=1$ µm.

Measuring range: By using the sensor as a displacement sensor, the sensor is designed to work in a range of 0 to 1cm. and by using the sensor as a force sensor it's related to the mechanical properties of the spring (by using for example a spring of stiffness K=2N/m, we have $\Delta F = 1$ µN and the measuring range is from 0 to 1g).

Accuracy: The average accuracy of the sensor is about $\Delta d=1$µm, and as a force sensor is about $\Delta F = 1$µN.

Hysteresis: The results are perfectly reversible and there is no hysteresis cycle

3 Experimental device

The experimental device which allows taking readings of the voltage delivered by the movable coil according to the distance between the two coils and acquiring data is as follows:

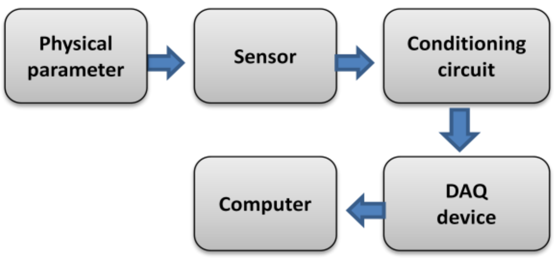

Fig.4. Experimental device

The conditioning circuit includes circuits for amplification, rectification and filtering to make the signal usable, to improve the signal-to-noise ratio and to ensure a better stability.

To isolate the sensor from the external perturbation, it was essential to cover it with a layer of copper to protect it from interfering magnetic fields.

4 The data collection and processing interfaces

LabVIEW is very powerful when it comes to creating DAQ applications. LabVIEW includes a set of VIs that let you configure, acquire data from, and send data to DAQ devices. Each DAQ device is designed for specific hardware, platforms and operating systems.

National Instruments, the inventor of LabVIEW, also makes DAQ devices, so the integration with the DAQ devices from NI and the LabVIEW software is seamless and makes it easy to do I/O operations from the LabVIEW environment.

The externe DAQ card used is NI usb-6281, its operational features are:

- 16 analog inputs at 18-bits, (software selectable per channel) with a ±10 V operating range.
- a successive approximation A/D converter with a 18-bit accuracy and a 625 kS/s maximum sampling rate.
- Two analog output channels with 16-bit accuracy.
- 24 digital input/output channels (8 clocked).
- Two timer/counters.
- Compatibility with LabVIEW, LabWindows™/CVI, and Measurement Studio for Visual Studio .NET.
- NI-DAQmx driver software and LabVIEW SignalExpress LE interactive data-logging software.

The block diagram of the developed LabVIEW program is as follows:

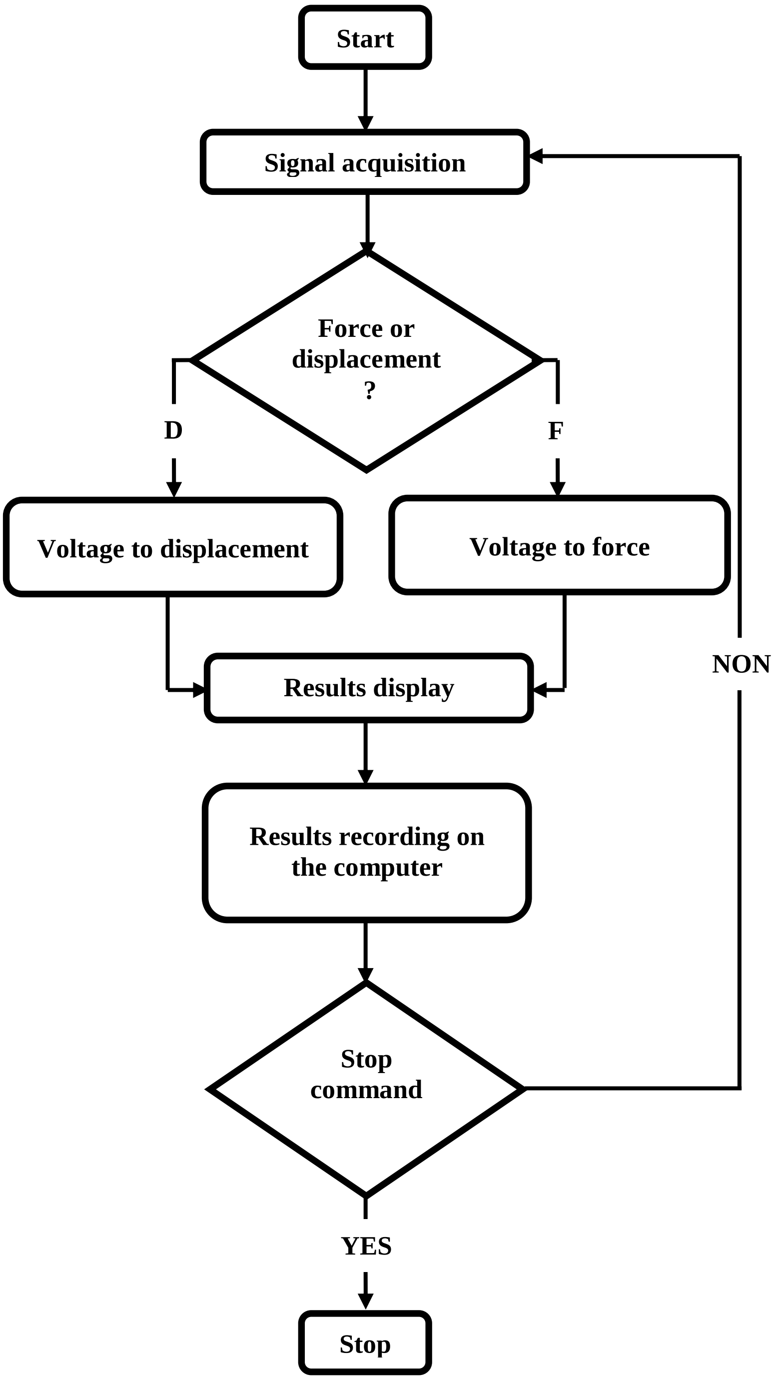

Fig.5. Block diagram of the developed LabVIEW program

The program contains a reset sub-program that can be illustrated in the following diagram :

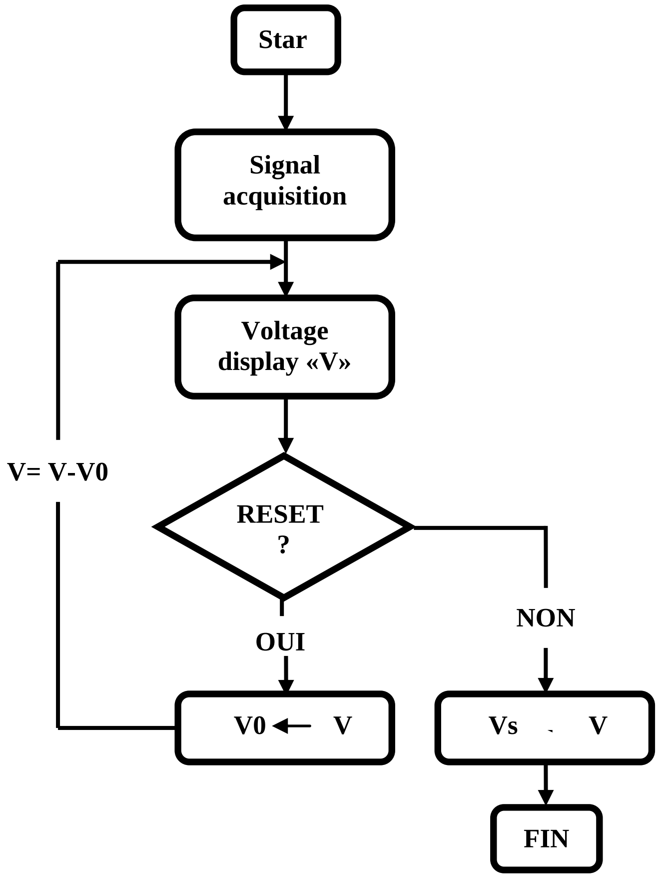

Fig.6. Block diagram of the reset LabVIEW sub-program

The data-acquisition card is controlled by a properly developed interface, using the LABVIEW software, running on the PC. It consists of two parts: (a) a graphical environment with components such as displays, buttons and charts in order to code, which provide a convenient-to-use environment for the system operator, and (b) the program is in block-diagram format and consists of built-in virtual instruments (VIs), performing functions such as analog channel sampling, mathematical operations,file management etc.

The main panel of the LabVIEW program to control the force-displacement sensor is shown in Fig.7

First, the signal is acquired using the DAQ assistant function, then, the signal is converted into force or displacement, depending on the type of acquisition selected, using the predefined polynomial adjustment of the sensor calibration curve.

Indeed, the first step is to choose the type of acquisition (force or displacement) with the icon shown on the top left (fig.7), the user has also the possibility to control the acquisition time step and to reset the voltage value using the icon “Reset”. The front panel of the program has two digital indicators for display of digital values, and two chart indicators to represent the selected parameter as a function of time. These data are stored on the computer.

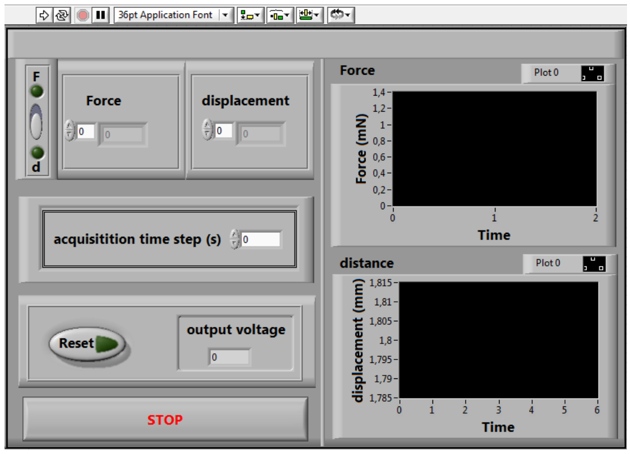

Fig.7. Front panel of the LabVIEW program

5 Conclusion

We realized a new force-displacement sensor with an important sensitivity and accuracy (Δd=1μm and ΔF = 1μN) which is based on two converters, the first is a spring which allows to calculate the displacement by knowing the value of the force applied and its characteristics.

The sensor characteristics depend on the two coils and on the spring. Thus, the effect of the turns number in the coil, the wire diameter and the spring stiffness k can rather modify the sensitivity and the measuring range of our sensor, and thus, the applications for which it is dedicated.

The flexibility of LabVIEW software offers the possibility of acquiring, displaying measurements and data storage. The numerous functions librairies and the relative simplicity of development allow to make complex programs in a short time.

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Biography

Z. ABBASSI received the specialized Master in microelectronics at the Faculty of Sciences, Kenitra,Morocco in 2012. He is currently a Ph.D. student at Department of physics and engineering, Faculty of Sciences Meknes, Morocco. His current field of study is the development of a new generation of electromagnetic force-displacement sensors and its applications.

A.BENABDELLAH received the master degree in 2012 in microelectronics at the university of Kenitra, Morocco. Currently he is pursuing his Ph.D. in physics and engineering in Moulay Ismail university of morocco, his work is mainly about the optimization of a new electromagnetic force-displacement sensor ,then the design and implementation of several measuring instruments based on this sensor for the study of liquid physical properties.

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