

# Accurate Position Electromagnetic Sensor Using Data Acquisition System

Z. Ezzouine, A. Nakheli

**Abstract**—This paper presents a high position electromagnetic sensor system (HPESS) that is applicable for moving object detection. The authors have developed a high-performance position sensor prototype dedicated to students' laboratory. The challenge was to obtain a highly accurate and real-time sensor that is able to calculate position, length or displacement. An electromagnetic solution based on a two coil induction principal was adopted. The HPESSE converts mechanical motion to electric energy with direct contact. The output signal can then be fed to an electronic circuit. The voltage output change from the sensor is captured by data acquisition system using LabVIEW software. The displacement of the moving object is determined. The measured data are transmitted to a PC in real-time via a DAQ (NI USB -6281). This paper also describes the data acquisition analysis and the conditioning card developed specially for sensor signal monitoring. The data is then recorded and viewed using a user interface written using National Instrument LabVIEW software. On-line displays of time and voltage of the sensor signal provide a user-friendly data acquisition interface. The sensor provides an uncomplicated, accurate, reliable, inexpensive transducer for highly sophisticated control systems.

**Keywords**—Electromagnetic sensor, data acquisition, accurately, position measurement.

## I. INTRODUCTION

**S**ENSORS are essential components of electronic control systems. Sensors are defined as [1] devices that measures physical quantities such as pressure, speed, etc., and converts them to an output electrical signal that serves as inputs for measurement or operating a control system.

A position can be defined as the variation with time of a position, the first derivative relative to time gives the displacement, and the second derivative gives acceleration. These two quantities are indeed accessible from the signal provided by a position sensor. The position sensors are thus grouped in two groups: linear position sensors and angular position sensors [2]-[8].

Induction coil method is widely used. The important advantage of this method is simplicity in operation and design [9]-[11]. In this paper, a novel application of an induction coil sensor is proposed. The application for position measurements of a moving object system presented in this paper shows an improvement of the real-time response of an inductive displacement sensor. The system operation of this sensor is

simple. As the moving object approaches the distance the inter coils decreases, the flux increases, and consequently, the voltage output begins to increase. As the distance inter coils becomes null, the voltage output peaks to its highest level. As the moving object further away to the mobile coil, the voltage output decreases. As the moving object approaches, the same sequence occurs. Thus, the motion of the moving object feature results in a time-varying flux that induces a proportional voltage in the coil. The amplitude of the induced voltage is proportional to the position of the moving object. This voltage signal is fed to the electronic card that processes it to output the signal in the desired format. After, the out signal of the sensor is acquired by the acquisition system, consisting of the interface for the analogue signal (induced voltage) conditioning, AD converter and PC with adequate software. The HPESSE described in this paper is simple, low-cost and is an easy way to introduce students to the position measurements of a moving object.

The aim of this article is limited to measuring the relative positions (that is to say relative to a reference linked to a solid reference considered as fixed). The rest of this paper is organized as follows. Section II presents the design and basic principle of the inductive sensor. The developed interface and the calibration of the system are presented in the same section. Section III presents the results and discussion, while Section V concludes this paper.

## II. SETUP OF THE SENSOR SYSTEM

An overview of the sensor system is shown in [12]. Fig. 1 illustrates the setup of the proposed HPESSE sensor. The position measurement system consists of an inductive sensor, electronic card and a computational system developed to acquire and analyze the out signal of the sensor.

The principle operation of the new sensor is based on the fundamental laws of electromagnetism (Faraday's law). The proposed sensor is a displacement sensor, consisting of two identical flat coils (fixed and mobile coil) of the same diameter 2cm, and each formed of 30 turns, which are conductive wires of copper of section 0.05mm, a calibrated elastic spring, a solid insulating cylinder, and two hooks which are fixed to the centers of the two bases of the insulating cylinder and a fixed support [13]. The movable part is fixed a hook, to which the upper end of the spring is connected, and at the other lower end of the spring, the cylinder is suspended by means of a hook. The measuring coil is attached to the cylinder.

The excitation coil is fastened to the contour of the orifice. A protocol was also developed for manufacturing.

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The fabrication is done in a very delicate and careful way to design two detection coils that have the same number of turns. The spring and cylinder are aligned on the same vertical axis (Fig. 1).

The cylinder acts as a guide and allows the moving coil which is fixed to it to approach or move away from the fixed coil. The cylinder is therefore capable of moving vertically upwards or downwards, practically without friction when exerting a force at its lower end, which has the effect of lengthening or compressing the spring.

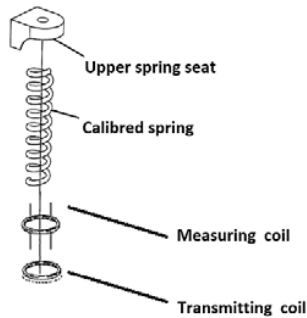


Fig. 1 Diagram of the electromagnetic displacement sensor prototype

The two flat coils are connected by connection wires to the conditioning circuit, as seen in Fig. 1 [12], [13].

The principle of the operation is described by the phenomenon of influence of the magnetic induction between two flat coils of the same diameter and having the same number of turns situated at a certain distance, one from the other, on the same axis passing through their centers.

One of the coils is fixed on a horizontal support and fed by a frequency generator, with precise phase and amplification conditions (sinusoidal voltage of 16 of frequency and amplitude 2). The winding of the fixed coil is driven by a sinusoidal signal, it is therefore traversed by a variable current (a variation of the velocity of the electrons), and consequently, an electric field must exist in the direction of the coil wire creating a variable magnetic induction along its axis given by the equation [12], [13]:

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

$I$  is the current flowing through the coil,  $R$ : coil radius,  $z$  is the distance between the fixed coil and the moving coil.

The magnetic field created by the transmitter coil is at a maximum at the center of the coil ( $z=0$ ) [12]:

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

One should be able to verify quickly that (1) reduces to (2) for  $B$  at  $z=0$ . This induction produces a variable flux  $\Phi$  and an electromotive force (fem) that is variable and measurable on the electrons of the other coil (mobile coil). By a direct application of Lenz's law, the flux variation of the magnetic

field) Through  $N$  turns induces an electrical voltage ( $e$ ):  $e = -d\Phi/dt$ .

The maximum value of this induced electronic voltage  $e$  depends on the distance  $z$  separating the two coils. The flux  $\Phi$  is proportional to the magnetic induction  $B$ , whose variation, as a function of  $z$ , using Biot-Savart Law is given by the relation (1), and therefore, the induced electromotive force will have similar variations in function of  $z$ . The maximum amplitude of the induced current increases proportionally if the frequency increases [13]. Thus, when an object of a given weight is placed on the hook, the spring elongates, the cylinder moves downwards, and the distance between the two coils decreases, resulting in an increase in the maximum induced voltage the terminals of the voice coil. The spring plays the role of a force-displacement converter, allows [12], [13] using the sensor as a force sensor, detailed information about the architecture and working principles of the sensor can be found in [12].

Good elasticity properties of the spring and electronic circuit permit designing transmitters of displacement with high accuracy. As a result, the mechanical property of calibrated spring is a good measuring element when we measure its displacement  $x$  as a function of the voltage:

$$d = f(V), \quad (3)$$

where  $d$  – measuring displacement,  $V$  – out voltage of sensor system.

The difference in distance between the moving coil and the fixed coil (measured between two coils) is used in the position or displacement calculation:

$$d = x_m - x_f, \quad (4)$$

where  $d$  is the position,  $x_m$  and  $x_f$  are respectively the position of the moving coil and the fixed coil position.

The position measurement system consists of an inductive sensor, electronic card and a computational system developed to acquire and analyze the output signal of the sensor. Fig. 2 shows the experimental setup based on the (HPESS).

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

#### B. Electronic Card

The induced signal from the inductive sensor is sinusoidal and its amplitude is low, so it has been necessary to introduce an electronic card includes circuits for amplification, rectification and filtering to make this voltage usable, to improve the signal-to-noise ratio and to ensure better stability.

The electronic circuit shown in Fig. 3 is an operational amplifier type LM318 which is characterized by an operating voltage ranging from 10V to 40V, a current of input polarization: 0.5uA at +/- 20V, and a tension input offset of 10 mV at +/- 20V.

### A. Data Collecting

The data acquisition system is normally electronics based, and it is made of hardware and software (see Fig. 4).

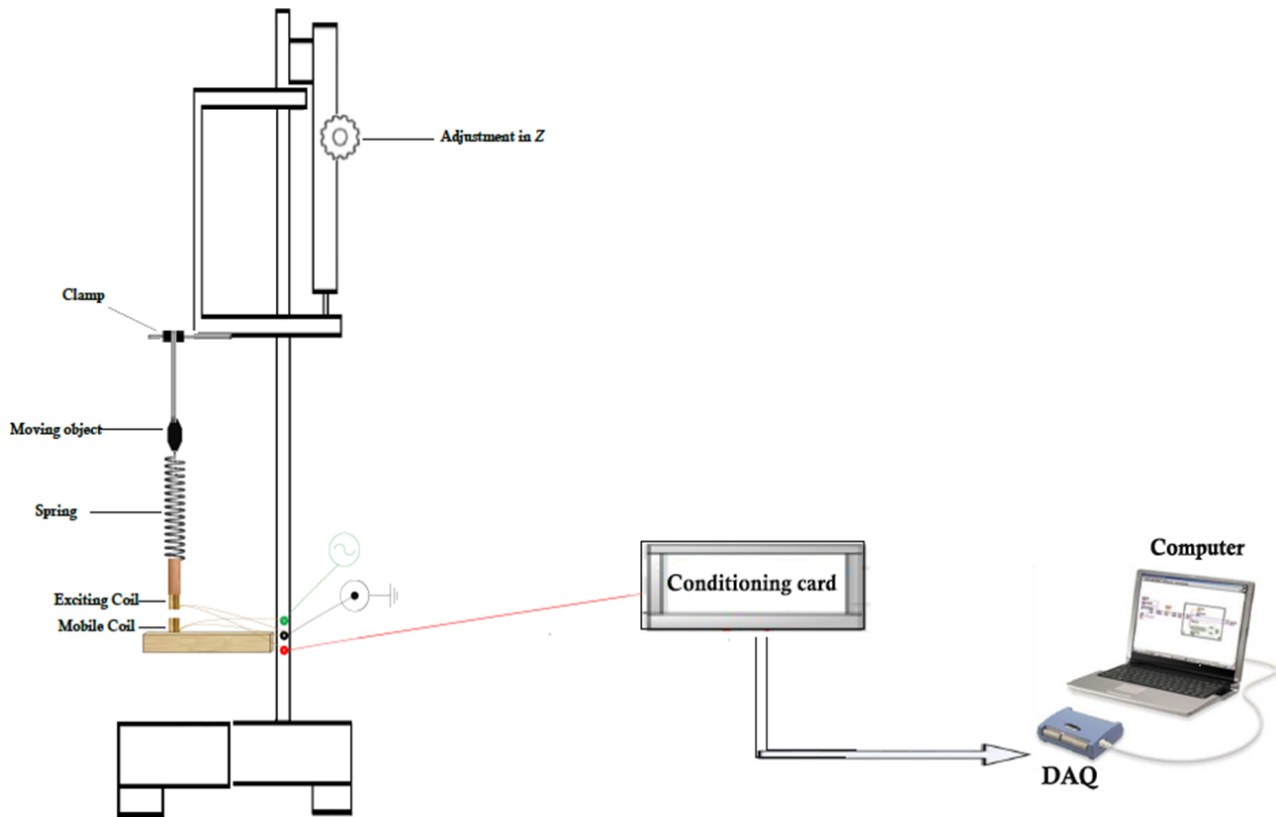


Fig. 2 Prototype of the HPESS system

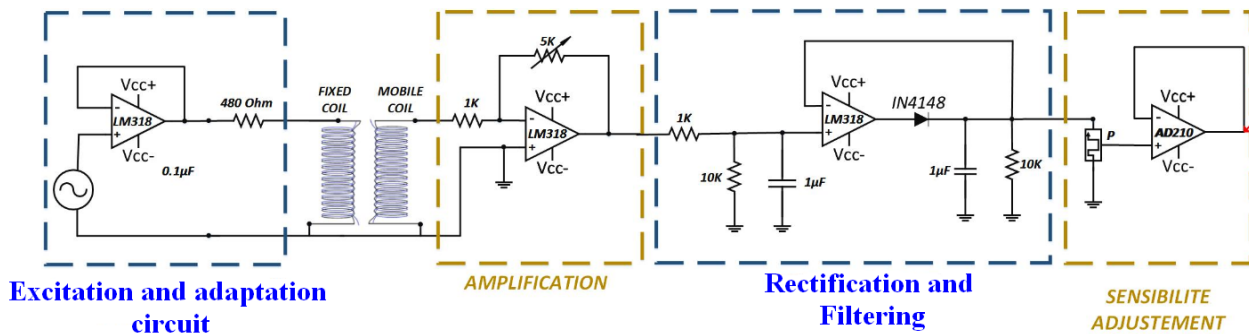


Fig. 3 Electronic card

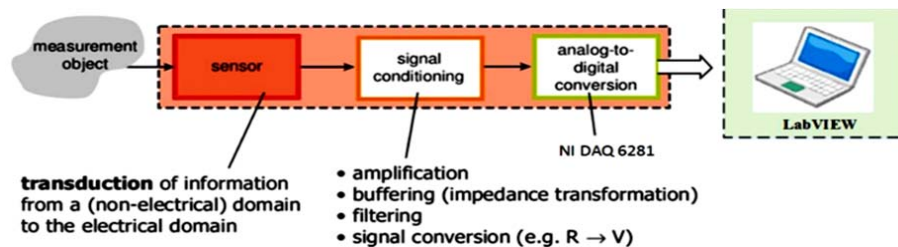


Fig. 4 Signal acquisition block diagram

The hardware part is made of sensors, cables and electronics components. The software part is made of the data acquisition logic and the analysis software. The data acquisition system in this experimental setup system is implemented using NI USB 6281 DAQ card (National Instruments). The data acquisition device can acquire the out sensor signal and send them to the PC to analyze and process them by software.

The National Instruments USB-6281 DAQ card was used in this study, it offers 16 analog inputs; a 625 kS/s single-channel sampling rate (500 kS/s aggregate), a resolution equivalent to more than  $5\frac{1}{2}$  digits for DC measurements, with an absolute accuracy of  $980\text{ }\mu\text{V}$  at the  $\pm 10\text{ V}$  range and  $28\text{ }\mu\text{V}$  at  $\pm 10\text{ mV}$ .

### III. RESULTS AND DISCUSSION

#### A. Measurement and Data Analysis

The structure of this system is shown on Fig. 5. The operating principle of this speed measurement system will be explained in this content. When the system starts, the sensor sends a signal to electronic circuit, which sends it into a DAQ card; the card handles this signal and then sends them to the computer through PCI-bus. Next, the LabVIEW program in the computer first acquires the data, and then calculates, displays, and finally records it. At last, the position curve can be obtained by the Straight-line of speed as a function of time. These data can test the accuracy of the system and analyze the characteristics of speed further.

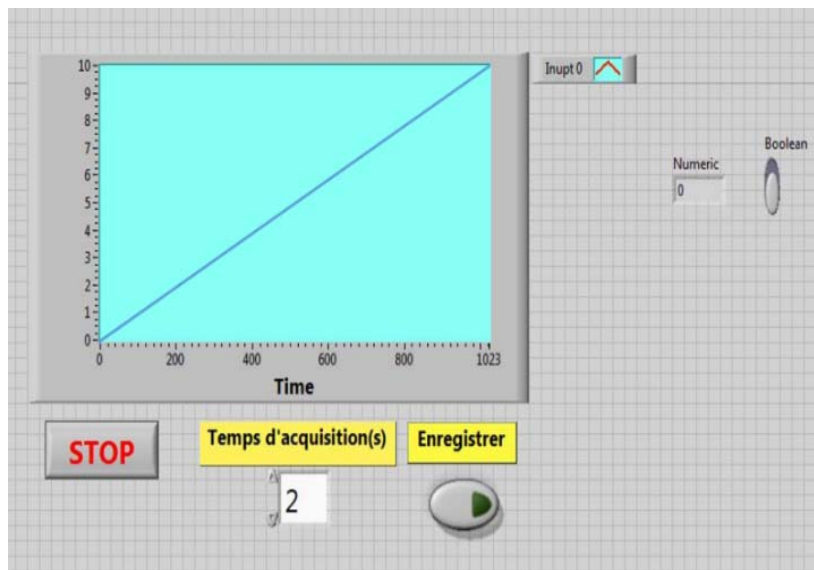


Fig. 5 Interface of the measurement system

TABLE I  
MEASUREMENT OF THE OBJECT DISPLACEMENT AS A FUNCTION OF VOLTAGE

Time $t$	(ms)	0	1	2	3	4	5
Voltage $V$	(mv)	451.2	501.2	551.2	601.2	651.2	701.2
Displacement $d$	( $\mu\text{m}$ )	6.826108	6.185608	5.545108	4.904608	4.264108	3.6608

A program was design to measure speed based on LabVIEW. Fig. 5 shows the interface of this measurement system which can display voltage of sensor, speed of moving object clearly in real time. When the program is running, the DAQ card acquires out sensor signal, and sent them to PC. For each time ( $T=1\text{s}$ ), the program calculates the displacement (revolutions per minute)  $d$  and moving object speed  $v$  based on time and displacement. Finally, speed  $v$  and displacement are displayed on the interface.

#### B. Calibration of the Speed Inductive Sensor System (HPSS)

The speed measurement has been carried out by the HPSS. The calibration has been done by this procedure, the speed

measurements have been performed for several different induction coil distances. The calibration curve of the sensor is obtained by slip carefully the moving object every second from 6 mm to 1mm in steps of  $1\text{ }\mu\text{m}$ , as seen in Table I, and we note the voltage values corresponding to each displacement. The curve response in Fig. 6 is not linear; rather, it is parabolic in relation with the sensor sensitivity as a function of the distance between the coils.

Measured distances  $d$  of the induction coil various out voltage of sensor are marked in Fig. 6.

The fit polynomial to the curve is shown in Fig. 6; the equation describing this relationship between the inter coil distance and the out voltage of sensor can be expressed by:

$$d(\mu\text{m}) = -12.81 \times 10^{-3} \times V + 12.60598 \quad (5)$$

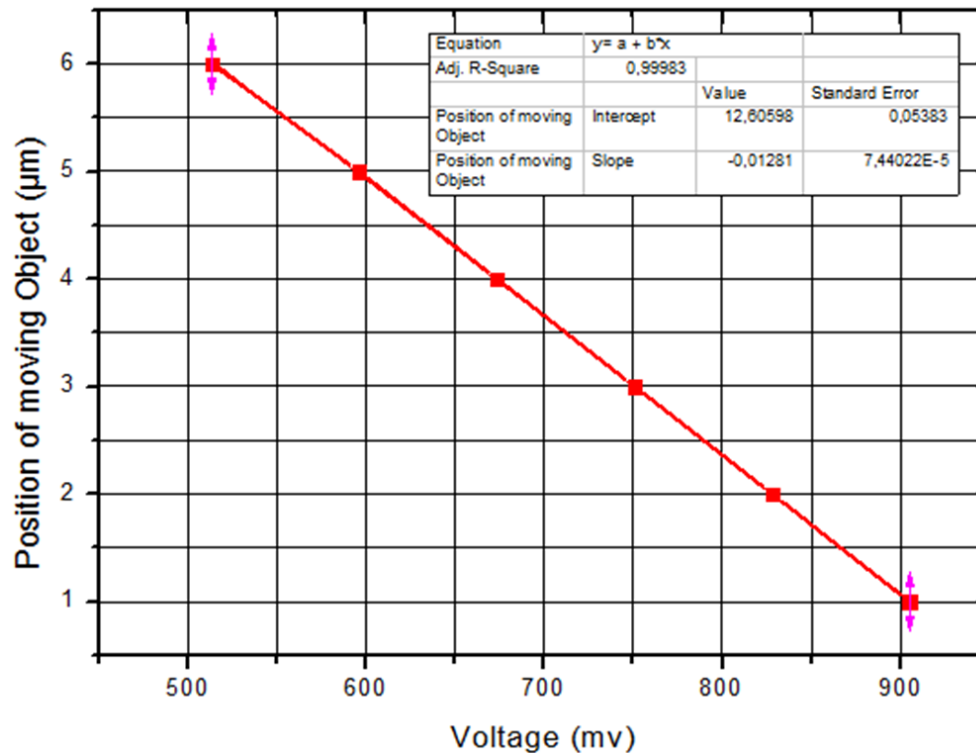


Fig. 6 Calibration curve of the inductive sensor:  $d = f(V)$

#### IV. CONCLUSION

In this paper, a high accurate performance position electromagnetic sensor system (HPESS) of moving object has been realized by using the two coils induction method, and spring, which allows to calculate the displacement (the choice of a perfectly elastic spring is important to get a reversible and precise measures), card electronic and data acquisition system. This system provides important sensitivity and accuracy ( $\Delta d = 1 \mu\text{m}$ ).

This position sensor system uses LabVIEW software program as the Graphic user interface (GUI). This program facilitates the user to implement the following functions; starting and stopping the measure, monitoring the real-time events of out sensor voltage and calculate the position of moving object materials, etc. This system can be used for many industrial applications (the measurement of position of gear tooth (in a crankshaft, camshaft) and sensing the turbine position of a jet engine), and by using this present experimental setup, the displacement or force can be extracted accurately. A general advantage of this experimental setup is the ability to be easily modified and adapted to application-specific systems.

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