XVII IMEKO World Congress
Metrology in the 3rd Millennium
June 22–27, 2003, Dubrovnik, Croatia

ABSOLUTE ANGULAR AND INCREMENTAL POSITION SENSOR BASED ON THE MAGNETOSTRICTIVE DELAY PRINCIPLE

E. Hristoforou[a], *I. Darie*[b]

[a]Laboratory of Physical Metallurgy, School of Mining and Metallurgy Engineering, National Technical University of Athens, 9 Iroon Polytechniou, Athens, Greece
[b]National Institute of R&D for Technical Physics, 47 Mangeron Blvd. 6600 Iasi, Romania

Abstract – In this paper we present a new sensor able to detect absolute and incremental angular position, having a simple construction. The sensing technique is based on the magnetostrictive delay line principle. The dependence of the sensor on the sensing core rotation was measured and filtered. Thus, a sinusoidal response with an uncertainty of 0.05% was realised. We also demonstrate the ability of this principle idea to be used as a dynamic displacement sensor in the range of 15mm.

Keywords: Position sensors, magnetostriction

1. INTRODUCTION

Developing and manufacturing sensors for absolute and incremental position measurement reflects an important problem for many automated systems and robots. Related to that, a wide range of sensors and transducers for angular position has been developed in the past, based on different principles, namely photoelectric, capacitive, resistive, magnetoresistive, magnetostrictive etc.

The complexity of manufacturing of these transducers regarding its processing circuitry and wiring, as well as the technological process required for the electronic material involved increase considerably their price. Adding other problems, like hysteresis and temperature instability, results in significant drawbacks.

Therefore, the motivation of this research work was the development of relatively inexpensive and accurate rotation sensors able to be installed and used in given industrial environments. The operation of the sensor of absolute and incremental angular position is based on the magneto-strictive delay line principle and can be used in laboratories and in industrial environments.

Magnetostrictive delay lines (MDL) have been employed for many kinds of displacement sensors in the past [1], illustrating significant advantages with respect to the given state of the art. According to this technique, the generation, propagation and detection of elastic waves can be modified by the modification of the excitation and biasing fields, as well as by the mechanical stress, pressure or torsion applied on the magnetostrictive element.

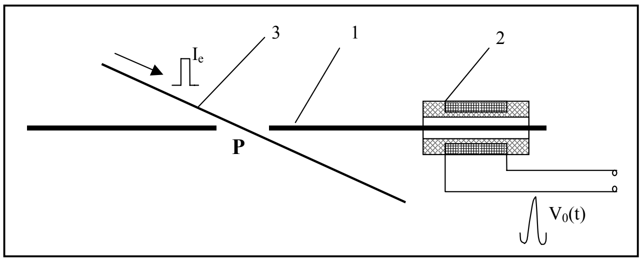

Fig. 1. Basic arrangement used in the construction of the angular position sensor: 1 – Magnetostrictive delay line; 2 – Receiving coil; 3 – Copper wire supplied with rectangular current pulses for the excitation of the magnetostrictive delay line.

The basic set-up for the MDL operation is illustrated in Fig.1. According to this figure, pulsed current is transmitted through the conductor, generating elastic pulsed within the MDL at the intersection of conductor – MDL, due to the magnetostriction effect. The elastic pulse propagates along the length of the MDL and is detected as an induced pulsed voltage at the search coil due to the inverse magnetostriction effect.

2. THE SENSOR

The sensor is illustrated in Fig.1. A $Fe_{77.5}Si_{7.5}B_{15}$ amorphous ribbon is used as magnetostrictive delay line (1). A 750 turns receiving coil (2), located at the end of the magnetostrictive delay line is used to detect elastic pulses in the form of a pulsed voltage. Two parallel copper wires, (3) and (4) respectively, are used to transmit equal amount of rectangular current pulses for the delay line excitation. A magnetoelastic ribbon (5), having a typical surface of 15x5 mm^2, is used as the active core of the sensor.

The operation of the sensor is as follows: Pulsed current is transmitted through the parallel conductors. Since the MDL is set at the middle of the distance of these two conductors, the induced puled fields from the two conductors are opposing each other and the resulting elastic pulse is almost zero. Placing a soft magnetic tape on top of the conductor – MDL intersection results in a break of the symmetry of the above mentioned pulsed fields.

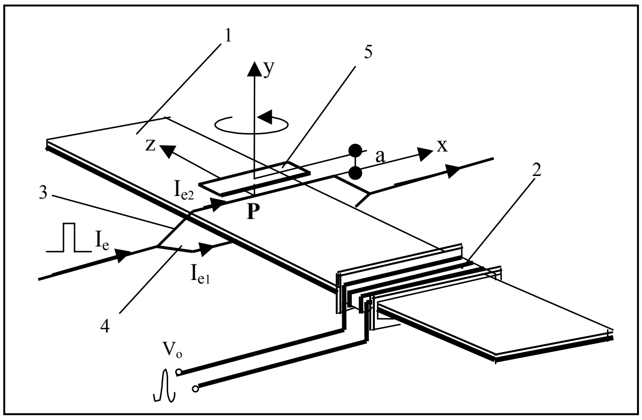

Fig. 2. Basic diagram of the absolute and incremental angular position sensor working according to the MDL principle: 1 – Magnetostrictive delay line made of $Fe_{77.5}Si_{7.5}B_{15}$ amorphous ribbon; 2 – Receiving coil; 3,4 – Parrallely coupled copper wires used for the excitation of the magnetostrictive delay line with rectangular current pulses; 5 – Soft magnetic tape.

Therefore, an elastic pulse is generated in the MDL, propagating along the length of it, which is detected as a pulsed voltage at the search coil. The magnitude of the generated elastic pulse is dependent on the relative position of the soft magnetic material set on top of the pair of the pulsed conductors. The more length of the pulsed current conductors is covered by the soft magnetic tape the larger the pulsed output signal is.

This happens because the magnetomechanical coupling factor between the excitation conductors and the delay line changes by the rotation of the soft magnetic tape acting as a sensing core. Hence, considering the soft magnetic tape as the sensing core and the rotation of it as the input of rotation in the system, the pulsed voltage output corresponds to the rotation sensor output.

3. EXPERIMENT

The basic principle of the experimental set-up is illustrated in Fig. 3.

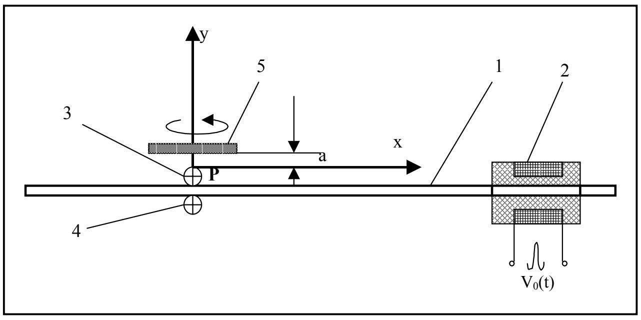

Fig. 3. Principle of operation of the experimental set-up. A certain distance between soft magnetic tape and MDL arrangement is valid for the repeatability of the measurements. 1 - MDL; 2 – Receiving coil; 3,4 – Parrallely connected copper wires supplied by rectangular current pulses for the magnetostrictive delay line excitation; 5 –Passive core.

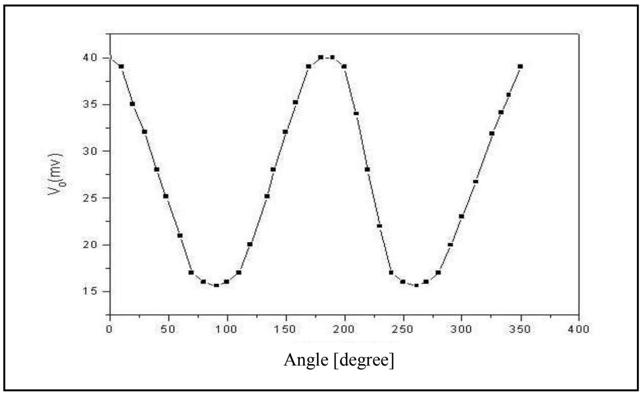

Fig. 4. The response of the absolute and incremental angular position sensor.

Details of the experimental set-up can be found in [2]. The response of the sensor is illustrated in Figure 4. The rotation of a passive core around the Y axis of the Cartesian coordinate system with the origin in P, produces a permeability modulation resulting in a sinusoidal variation of the output voltage of the sensor of the type presented in this figure.

The mathematical function obtained by filtration and approximating the response characteristic of the sensor is given by relation:

$$V_0(x) = A \sin \frac{\pi(x - x_c)}{w} + A_0 \qquad (1)$$

The dependence of the response of absolute and incremental angular position sensor on the position sensor of the passive core displaced along the X axis with respect to point P, is illustrated in Fig. 5. One can see that the maximum value V_0 of the sensor output voltage is obtained when the sensing core is placed above the point P.

By analyzing the bell shape characteristic presented in Fig. 5 one can notice that within the displacement range of (0 – 15) mm, the above mentioned sensor of absolute and incremental angular position can be also used as a displacement sensor.

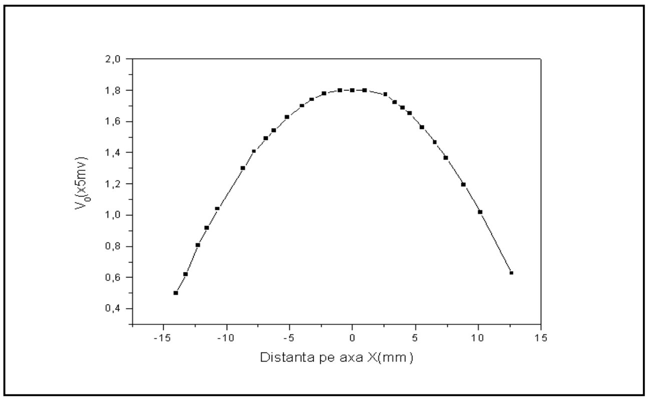

Fig. 5. The dependence of the sensor on the position of the passive core displaced along the X axis, with respect to point P, regarded as the middle sensor point.

In this case, the function approximating the characteristic obtained by filtration is a 2nd order polynomial given by relation:

$$V_0(x) = A + B_1x + B_2x^2 \quad (2)$$

where A = 1,937; B_1= - 0.00392; B_2 = - 0.0689. Such a response can result in using such a sensor arrangement as displacement sensor or dilatometer.

4. DISCUSSION

In order to make such a sensor idea market applicable, a number of problems should be solved to optimise the sensor characteristics, which mainly are the linearity and repeatability of the sensor response.

Regarding the problem of the sensor linearity, the λ(H) function must be tailored in order to obtain a linear (or quasi-linear) response of the voltage output with respect to the applied field. Linearity is improved by using amorphous ribbons after heat and field annealing. Thus, the uncertainty of the sensor response becomes better than 0,05%. Furthermore, using amorphous wires after heat and field annealing improves even more the sensor uncertainty.

Experiments under various values of ambient magnetic field detected a small amplitude signal change, which affects the sensitivity of the sensor. These signals are explained as magnetic noise, due to the presence of the magnetic domains as well as the non-uniformity of the tested wires. A first approach to solve this problem is the use of low pass filtering system.

The influence of the angle of the biasing field with respect to the MDL axis on the pulsed voltage output of the sensor was test using the set-up of Fig. 6, where the biasing field was applied through a 5 cm diameter, 10 cm long Helmholtz pair, rotation of which permits application of DC field at an angle with respect to the MDL axis. Amorphous ribbons and wires have been tested and preliminary observations indicate that for a DC field H, applied at an angle α to the axis of the delay line, the received voltage output becomes equal to the voltage output under a field H'=Hcosα, applied on the direction of the MDL, indicating that the component of the field perpendicular to the plane defined by the MDL axis and thickness could also be measured.

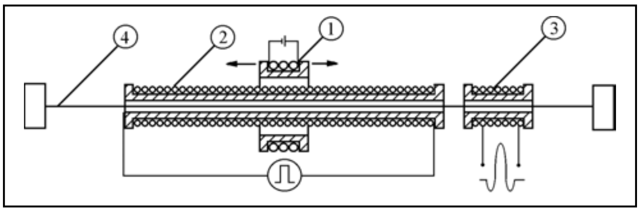

Fig. 6. Set-up for detecting the influence of magnetic field on the sensor.

It has been reported that MDL non-uniformity response, determined as the fluctuation of amplitude of readings along the length of the line, is a non-standardized function [1]. For the case of ribbon MDLs, it has been established that a first solution to this is the normalization process. Such a problem has been eliminated for the case of amorphous wires even in the as-cast form, while heat and magnetic annealing greatly improves their sensitivity and magneto-elastic uniformity. They are also to perturb the measured field less, as their cross section is much smaller.

5. CONCLUSIONS

An simple but highly reliable absolute and incremental angular position sensor based on the MDL technique was constructed, and its basic characteristic are here reported. The obtained results show a sinusoidal response of the absolute and incremental angular position sensor, the accuracy being 0.05%. Moreover we analysed the possibility to extend of application this sensor as displacement sensor for short distances (0-15) mm.

REFERENCES

[1] E. Hristoforou, "Array sensors based on amorphous alloys", *Ph. D. Thesis, University of London,* 1991.

[2] E. Hristoforou, "Magnetostrictive delay line and their applications", *Sensors and Actuators*, A59, pp. 183-191, 1997.

[3] E. Hristoforou and R. E. Reilly, "New mechanical stress transducers based on amorphous alloys", *IEEE Trans. Magn.*, Vol. 26, pp.1563- 1565, 1990.

[4] T. Meydan, "Application of amorphous materials to sensors", *J. Magn. Magn. Mater*. Vol. 133, p. 525, 1994.

[5] K. Mohri, *IEEE Trans. Magn.*, Vol. 20, p. 942, 1984.

[6] E. O. Doebelin, "Measurement Systems: Applications and design", 4th Edition, *McCraw-Hill,* 1990.

Authors: Dr. Evangelos Hristoforou, School of Mining and Metallurgy Engineering, National Technical University of Athens, 9 Heroon Polytechniou Street, Zografou Campus, Athens 15780, Greece
Phone: +30210-7722178
Fax: +30210-7722119
e-mail: eh@metal.ntua.gr
Dr. Iulian Darie, National Institute of R&D for Technical Physics, 47 Mangeron Blvd, 6600 Iasi, Romania
Phone: +4032-130680
Fax: +4032-231132
e-mail: iulian_darie@yahoo.com