Development of Mechanical Sensors Based on Flat Coil Element

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Abstract: - Distance is a physical quantity that used in many applications. In the field of sensor, distance is a main physical quantity that can be used for many measurements. In this paper, we will show the use of flat coil element for measuring proximity. Based on this ability, sensors for measuring mechanical quantities such as pressure, vibration and torque have been developed. As a proximity sensor, the flat coil element is used to measure the position of an object (seismic mass) as a function of time. Its working principle is based on position change of a seismic mass that put in front of a flat coil element. The flat coil is a part of a LC oscillator. The change of seismic mass position will change its resonance frequency. Based on the developed flat coil element, an air pressure sensor has been successfully developed. The working area of the developed pressure sensor can be set by adjusting the membrane thickness. The flat coil element has also been developed for vibration sensor and earthquake sensor. For earthquake measurement, the sensor should measure vibration in very low frequency range. The developed earthquake sensor can be used to measure vibration until 0.2 Hz. We have also successfully developed a torque sensor with relative error under 3%.

Key-Words: - flat coil element, LC oscillator, mechanical sensor, pressure sensor, proximity sensor, vibration sensor.

1 Introduction

In general, the mechanical sensor can be defined as a sensor that measures mechanical quantities, such as position, acceleration, velocity, pressure, force, vibration, etc. Recently, the demand for these sensors has increased significantly because of the growing number of applications dependent on accurate measurements of physical quantities such as in plant and process control, monitoring systems, and medical applications. These sensors should provide high precision measurement data with low cost and low power consumption.

Some mechanical sensors have been developed based on different methods such as: electro-active polymers [1], p-type silicon [2], metal-oxide semiconductor [3], silicon nano-wire [4], lead zirconate titanates (PZT) [5], magneto-rheological elastomer [6], and flat coil element [7,8,9].

In this paper, we present mechanical sensors based on flat coil element that has been developed, like: proximity, vibration, pressure and torque sensors.

2 Flat Coil Element

Fig. 1 shows the developed flat coil element. The flat coil element is made from thin epoxy and silver mixed with number of coils 30, diameter 3 cm and inductance 9.2 μH.

Fig. 1. The developed flat coil element

The flat coil element has been used as mechanical sensors such as: proximity, vibration, pressure, and torque sensor.

3 Mechanical Sensors Based on Flat Coil Element

3.1. Proximity Sensor

In the field of sensors, distance is a main physical quantity that can be used for many measurements.

Physical principle of a flat coil sensor is based on inductance changes due to the perturbation of conductive material. Inductance element in the form of flat coil changes its inductance if a conductive object or disturber material placed close to the coil. The ac current that flow through the coil produces magnetic field and generate eddy current in the conductive material depend on distance between flat coil and the conductive material. The eddy current produces induced magnetic field. This induced magnetic field interfere strongly with the original field that generated by the flat coil element itself. Change in total inductance of the coil is used as part of inductance-capacitance oscillator.

Fig. 2 shows the developed proximity sensor. The total magnetic field is influenced by the magnetic field from the coil (self inductance) and the magnetic field induction from the conducting material (mutual inductance). The total inductance L can be calculated by summing up the self inductance L_j and the mutual inductance M_{jk} [10,11].

$$L = \sum_{j=1}^{N} L_j + \sum_{j,k=1}^{N} M_{jk} \ , \qquad (1)$$

with

$$L_j = 2\pi\left(D_j - \frac{d}{2}\right)\left[\left(1 + \frac{\left(\frac{d}{2D_j}\right)^2}{\left(1 - \frac{d}{2D_j}\right)^2}\right)K(k_j) - 2E(k_j)\right], \qquad (2)$$

$$M = \frac{2\pi\sqrt{D_1 D_2}}{k}\left[\left(2 - k^2\right)K(k) - 2E(k)\right], \qquad (3)$$

with,

$$K(k) = \int_0^{\frac{\pi}{2}} \frac{d\varphi}{\sqrt{1 - k^2 \sin^2 \varphi}} \ , \qquad (4)$$

$$E(k) = \int_0^{\frac{\pi}{2}} \sqrt{1 - k^2 \sin^2 \varphi} \ , \qquad (5)$$

$$k = \frac{\sqrt{D_1 D_2}}{\sqrt{\left(\frac{D_1 + D_2}{2}\right)^2 + a^2}} \ , \qquad (6)$$

where, *K(k)* is elliptic integral I, *E(k)* is elliptic integral II, *D* is diameter of the ring, *d* is diameter of the wire, and *a* is distance between two rings.

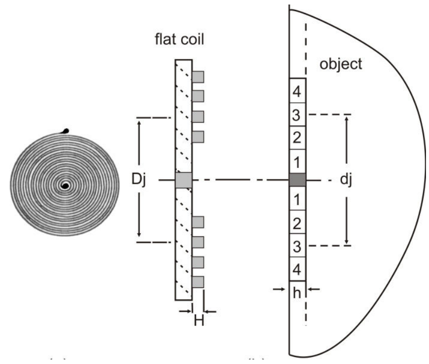

Fig 2. The developed proximity sensor (flat coil sensor in front of conductive material) [8]

The sensor system is constructed as a LC oscillator. The resonance frequency of the oscillator is a function of distance. Using a Phase Locked Loop the resonant frequency is converted into voltage.

The influence of temperature on the flat coil element has also been measured. Fig. 3 shows that temperature increase cause raise of the output voltage slightly. This can be corrected mathematically using a basic function [12].

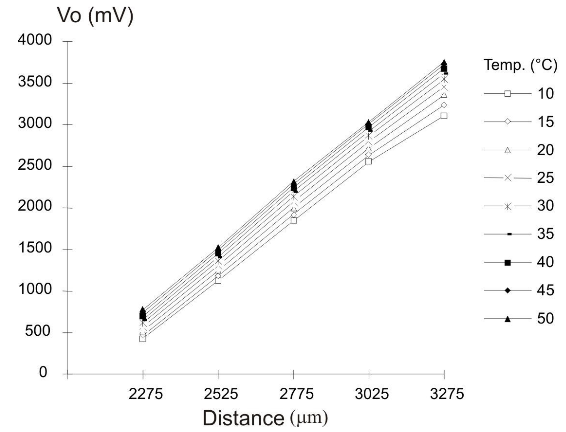

Fig. 3. Influence of temperature on the proximity sensor

For measuring static characteristic of the developed sensor an instrument calibration has been developed [8]. Fig. 4 shows its calibration system of flat coil as proximity sensor. Position of an object is determined by a micrometer, which works using a stepper motor. The stepper motor is controlled by a microprocessor. Sensor output voltage as a function of distance shown in Fig. 5. From Fig. 5 we can see that the sensor has a good sensitivity (~3mV/μm).

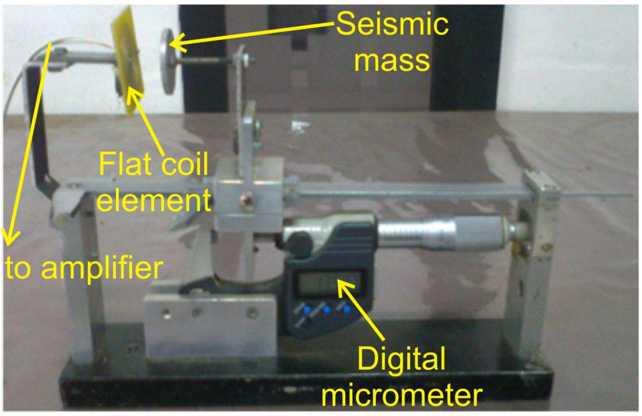

Fig. 4. Calibration system of flat coil as proximity sensor

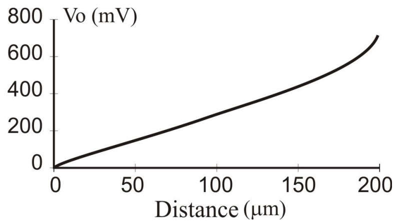

Fig. 5. Output voltage of the sensor as function of distance [8]

3.2. Vibration Sensor

In recent years, vibration measurement has become an important method in mechanical structural products like research, design and maintenance [13]. Vibration sensor detects the vibration parameter of an object through its mechanical structure and converting the vibration parameter into the electrical signal by physical effect to achieve transferring the non-electrical signal to electrical signal.

Based on the developed flat coil element, a vibration sensor has been developed [14]. The systems consist of a flat coil element, seismic mass, spring and body as shown in Fig. 6. Complete scheme of a vibration measurement system consists of flat coil element, analog signal processing, digital signal processing and display. Block diagram of the measurement system is shown in Fig. 7. Microcontroller controls the whole process included process in ADC and sends the data to a PC. The PC can be used for further data processing such as calculation of amplitude and frequency of vibration. Detailed information of this sensor can be found in Djamal, et.al [8].

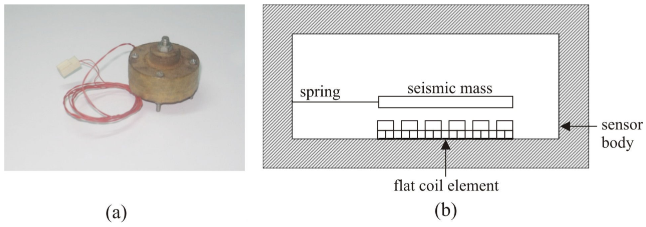

Fig. 6. The developed vibration sensor (a) and its block diagram (b) [8].

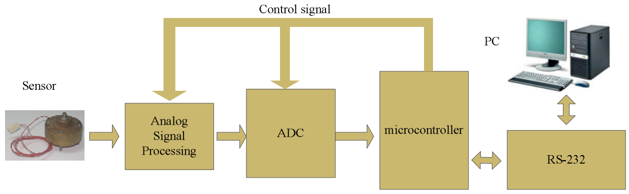

Fig. 7. Block diagram of the measurement system

We have also further developed the vibration sensor for measuring earthquake [15]. For this purpose a two dimensional (2D) low frequency vibration sensor have been developed (see Fig. 8). The sensor has a mechanical system using a simple pendulum. The developed sensor can detect vibration with frequencies below 1 Hz.

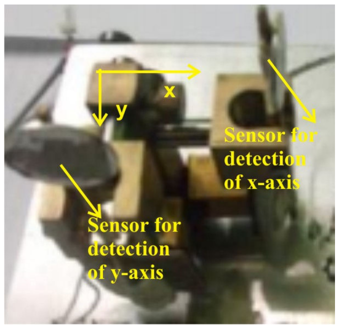

Fig. 8. The developed 2D low frequency earthquake sensor

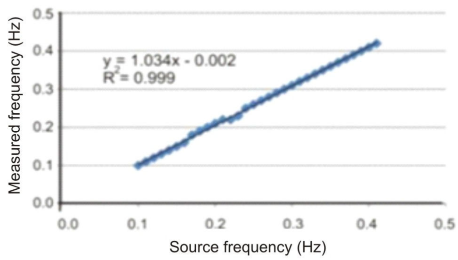

Fig. 9. Calibration of the developed earthquake sensor

Fig. 9 shows result of frequencies measurements ranging from 0.1 Hz to 0.5 Hz by 0.01 Hz intervals with constant amplitude. The relationship between the input and output frequency is linear, as shown in Fig. 9. A sensor model based on mathematical approach for determining frequency and amplitude of the sensor has been developed by Djamal, et.al [8]. The model shows a good result with relative error under 3%.

3.3. Air Pressure Sensor

Over the last decade there has been a rapid evolution of pressure sensing devices. It made possible by the dramatic advances in integrated circuit and microelectronics technology.

Actually, air pressure sensors have been developed based on semiconductors [16] and polymers [17]. In most cases the sensing elements in pressure sensors are based on strain-gauge, capacitive, piezoelectric or optical principles. We have developed a new air pressure sensors based on flat coil element (see Fig. 10) [18,19]. The sensor consists of flat coil element, membrane, seismic mass, gas inlet P1 and P2. In this sensor, the membrane plays a very important role. Thickness and elasticity of the membrane determines the deflection range of the membrane. If the membrane material is less elastic then the membrane deflection range decreases, and vice versa.

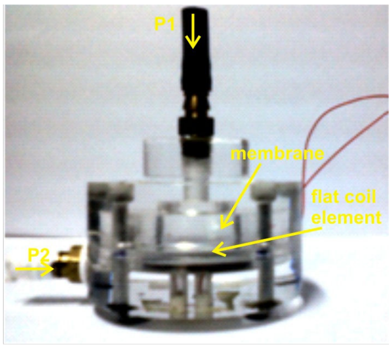

Fig. 10. Photograph of the developed air pressure sensor [18]

The flat coil element is used to measure the position of a membrane that changes its position linearly to the measured air pressure (see Fig. 11). Its working principle is based on position change of a seismic mass on the membrane that put in front of a flat coil element. The flat coil is a part of a LC oscillator. The change of seismic mass position will change its resonance frequency. The coil has 36 windings, 1.8 cm in diameter and 9.3 μH inductance.

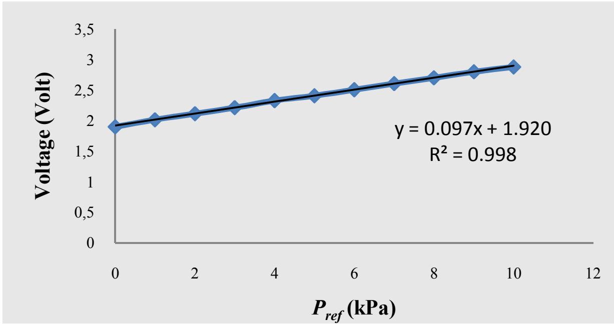

Fig. 11. Sensor output voltage as function of air pressure

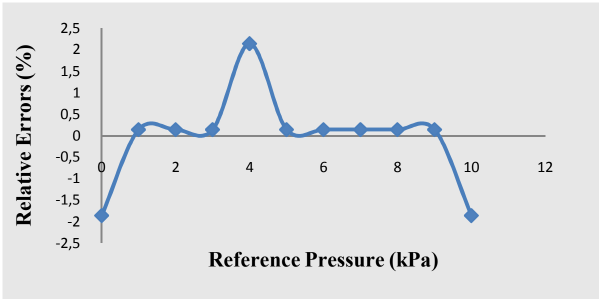

Fig. 12. Relative error of the developed pressure sensor

Calibration is performed using a reference pressure. Pressure is applied to the developed sensor with an increase every 1 kPa. The result of the calibration is shown in Fig. 12.

The developed sensor can measure air pressure in the range of 0 to 10 kPa with a relative error under 3% as shown in Fig. 12.

3.4. Torque Sensor

The design and construction of torque sensor can be developed based on different physical principles, which must be suitably selected to ensure that a sensor has the characteristics required. In a highly mechanized world, torque is among the most important of all measured quantities. They play a significant role in automotive and aerospace.

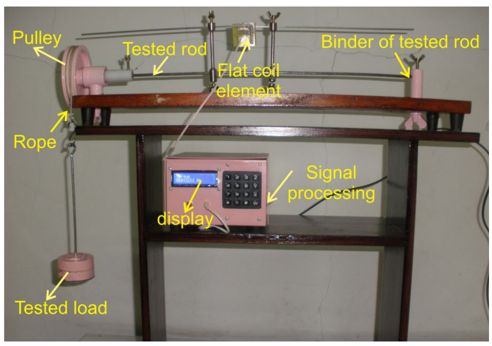

Fig. 13. Set up equipment for torque measurement

We have developed a torque sensors based on flat coil element [20]. Set up equipment for torque measurement is shown in Fig. 13. The instrument consists of flat coil element, tested rod, tested load, pulley, rope, signal processing with digital display. The tested load produces moment of force (torque) to the tested rod that makes the tested rod twisted. Through calibration, we get linier relation between the twisting angles and output voltage of the sensor system as shown in Fig. 14. Besides measuring the torque, the developed instrument can also measures the shear modulus of a material with relative error under 3% as shown in Fig. 15.

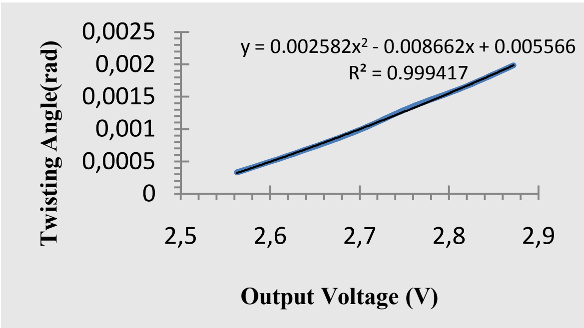

Fig. 14. Sensor output voltage as function of twisting angle

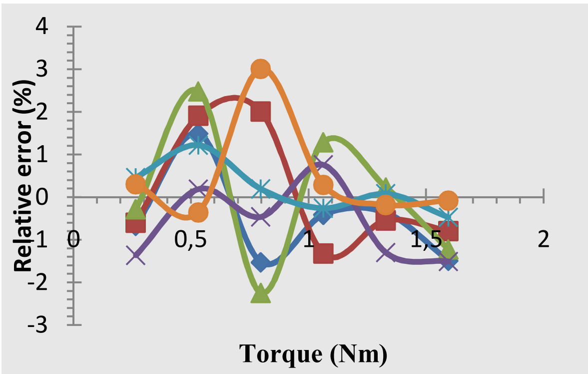

Fig. 15. Relative error of the developed torque-meter

4 Conclusion

Mechanical sensors based on flat coil element have been developed for measuring proximity, vibration, pressure, and torque. The research shows that the flat coil element can be successfully used for mechanical sensors with relative error under 3%.

References:

[1] G. Alici, G.M. Spinks, J.D. Madden, Y. Wu and G.G. Wallace, Response Characterization of Electroactive Polymers as Mechanical Sensors, *IEEE/ASME Transactions on Mechatronics*, Vol. 13 No.2, 2008, pp. 187 – 196.

[2] T. Toriyama and S. Sugiyana, Analysis of Piezoresistance in p-Type Silicon for Mechanical Sensors, *Journal of Microelectromechanical System*, Vol.11, No. 5, 2002, pp. 598 – 604.

[3] T. S. Chen and Y.R, Huang, Evaluation of MOS Devices as Mechanical Stress Sensors, *IEEE Transaction on Components and Packaging Technologies*, Vol. 25, No. 3, 2002, pp. 511 – 517.

[4] T. Toriyama, Y. Tanimoto and S. Sugiyama, Single Crystal Silicon Nano-Wire Piezoresistors for Mechanical Sensors, *Journal of Microelectromechanical System*, Vol. 11, No.5, 2001, pp. 605 – 611.

[5] D. Belavic, M. Hrovat, M. S. Zarnik, J. Holc, J. Cilensek, M. Jerlah, S. Macek, H. Ursik and M. Kosec. PZT Thick Film for Pressure Sensors: Characterization of Materials and Devices. *2nd Electronics Systemintegration Technology Conference*, Greenwich, UK, 2008, pp. 989 – 994.

[6] W. Li, K. Kostidis, X. Zhang and Y. Zhou, Development of Force Sensor Working with MR elastomes, IEEE/ASME International Conference on Advanced Intelligent Mechatronics, Singapore, 2009, pp. 233 – 238.

[7] M. Djamal, Flat Coil Sensor and Some of Its Applications, *Proceedings of the Tunisien-German Conference on Smart Systems and Devices*, March 27- 30 , Hammamet, Tunisia, 2001.

[8] M. Djamal, Ramli, S. Satira and Suprijadi, Development of Low Cost Vibration Sensor Based on Flat Coil Element, *International Journal of Mathematical Models and Methods in Applied Sciences*, Vol.5, 2011, pp. 550 – 557.

[9] R. Widanarto, M. Djamal, Design of Flow Meter Using A Flat Coil Sensor, *Proceedings of the Indonesian-German Conference on Instrumentation, Measurements and Communications For the Future*, July 11-13, 2001, Bandung, Indonesia.

[10] D. Kohn, W.Killar, H., R. Trankler, Smart sensor for measurement of displacements, *Proc. Of the 11th of the IMEKO*, Houston, Texas, 1988.

[11] M. Djamal, A Study of flat coil sensor for Measuring Displacements, *KFI*, Vol.7, No. 2, 1996.

[12] Traenkler, H.-R., Tachenbuch der Messtechnik, Oldenburg, 1990.

[13] XuJi, Choice and Installation of the Vibration Transducer, *Metrology and Measurement Technique*, 2010, Vol.1, pp. 45 – 46.

ISBN: 978-1-61804-099-2

[14] Mitra Djamal et.al: Sensor Getaran Menggunakan Koil Datar (Vibration Sensor Based on Flat Coil Element, Patent Number ID Nr. 0 021 804, 27 Agustus 2008.

[15] Mitra Djamal dkk (2011) :Alat Pengukur Getaran Frekuensi Rendah Menggunakan Koil Datar dan Pengolah Sinyal, Patent registered number P00201000542

[16] A. Druzhinin, E. Lavitska, I. Maryamova, Medical pressure sensors on the basis of silicon microcrystals and SOI layers, *Sensors and Actuators B*, Vol. 58, 1999, pp. 415–419.

[17] M. A. Fraga, H. Furlan, M. Massi, I. C. Oliveira, L. L. Koberstein, Fabrication and Characterization of a SiC/SiO2/Si Piezoresistive Pressure Sensor, *Proc. Eurosensors XXIV*, September 5-8, Linz, Austria, 2010.

[18] Sundari, E.M., Design and implementation of air pressure measuring instrument with flat coil sensor based on microcontroller ATmega 16, Graduate Thesis, Department of Physics, ITB, 2011**.**

[19] Mitra Djamal,et.al (2011) : Alat Ukur Tekanan Fluida Menggunakan Koil Datar, Patent registered number P00201000928.

[20] R. Kumalasari, Design and manufacturing Torque-meter based on flat sensor using microcontroller ATmega 16, Graduate Thesis, Department of Physics, ITB, 2012.