# Development of a Low Cost Vibration Sensor Based on Fluxgate Element

Mitra Djamal, Yulkifli, Agung Setiadi, Rahmondia N. Setiadi

***Abstract*—T**his paper explains an application of fluxgate element as a low cost vibration sensor. The fluxgate element is a low field magnetic sensor. Because the magnetic field strenght of a position is a function of its distance to the magnetic source, so the magnetic field strenght of a position can be used for determining its distance to the magnetic source. In this research, the fluxgate element is used to measure the position of a vibrating object as a function of time. Magnetic mass is lying on a cantilever which acts as a spring. Due to periodical external force which applied to the magnetic mass, the cantilever will vibrate with the same frequency as the frequency of the vibrating object. As the magnetic mass vibrates, it will also change its distance to the fluxgate element. The fluxgate element will measure this distance as a function of time. By using a good mathematical sensor model the amplitude and frequency of a vibrating system can be determined. With this model, it has been obtained a vibration sensor with relative error under 4.39%.The developed vibration sensor has resonance frequency close to 38 Hz.

***Keywords*—**cantilever, fluxgate, resonance frequency, vibration, sensor model.

## I. Introduction

VIBRATIONS like earthquake, vibration of a bridge or vibration of machinery are physical phenomena that could be found everywhere in our daily life. Vibration characteristic of these phenomena can be used as utility for an early warning system that could reduce the loss or damage. For measuring of vibration, one needs a vibration sensor.

There are some kinds of vibration sensor, such as proximeter, seismic-velocity pick-up and accelerometer. These kinds of sensor are differentiated by its measurement principle. Proximeter measures position shift, seismic-velocity pick-up measures velocity and accelerometer measures acceleration of vibration [1]. Some of them which recently used in industry or laboratory has expensive price.

This paper describes the development of vibration sensor based on fluxgate element. Fluxgate element is a magnetic sensor that has low manufacturing cost. Magnetic sensor with fluxgate principle has high sensitivity. [2] found that the sensitivity of fluxgate sensor is about 2700V/T. This sensitivity is much better than other magnetic sensors e.g. 0,5V/T for Hall effect and 100V/T for magnetoresistive sensor. The other benefits of fluxgate sensor is its small size, low power, high temperature stability (ca. 30 ppm/$^{o}$C) and low offset coeficient (0.1 nT) [3].

In last few years we have developed the manufacture of fluxgate elements [4] and some its applications[5,6,7] . One of the applications is the used of fluxgate element for vibration sensor.

## II. Theory

### A. Analytical Model of Vibration System

Let's consider a mass lying on a cantilever. The cantilever acts as a spring in vibrating system. The systems consist of a seismic mass, spring and body that shown in Fig. 1

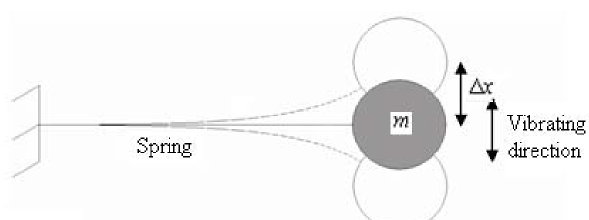


Fig. 1. Vibration model.

Manuscript received July 15, 2010. This work was supported partly by the Directorate of Higher Education, Indonesian Ministry of Education under grant "Hibah Bersaing" no 080/H35.2/PG/HB/2009 and Research KK-ITB No.: 262/K01.7/PL/2009 .

Mitra Djamal is chief of the Theoretical High Energy Physics and Instrumentation Research Group, Faculty of Mathematics and Natural Sciences, Institut Teknologi Bandung, Bandung, Indonesia (phone: +62-22-250 0834; fax: +62-22-250 6452; e-mail: mitra@fi.itb.ac.id).

Yulkifli is a member of Electronics and Instrumentation Research Group, Faculty of Mathematics and Natural Sciences, Padang State University, Padang, Indonesia (e-mail: yulkifliamir@yahoo.com).

Agung Setiadi is a member of the Theoretical High Energy Physics and Instrumentation Research Group, Faculty of Mathematics and Natural Sciences, Bandung Institute of Technology, Bandung, Indonesia (e-mail: agung102@gmail.com).

Rahmondia N. Setiadi is a member of the Theoretical High Energy Physics and Instrumentation Research Group, Faculty of Mathematics and Natural Sciences, Bandung Institute of Technology, Bandung, Indonesia (e-mail: rahmon@gmail.com).

The mass will vibrate if there is any external force applied to the system. The equation of this motion is [9]:

$$\frac{d^2 y}{dt^2} + \frac{b}{m}\frac{dy}{dt} + \omega_0^2 y = Fe^{i\omega t} \quad , \qquad (1)$$

where $b$ is friction coefficient, $m$ is seismic mass, $\omega_0$ is the resonance frequency of the system, and $F$ is external force. According to [10], resonance frequency of this system is

$$\omega_0 = \sqrt{\frac{3EI}{ml^3}} \quad , \qquad (2)$$

where $E$ is Young's modulus, $I$ is inertia, $m$ is seismic mass, and $l$ is the length of cantilever.

General solution of equation (1) is

$$y(t) = A\sin(\omega t) \qquad (3)$$

Near its resonance frequency, the system resonates with very high gain. This area must be avoided because it can disturb the measurement. From (1), gain at resonance area can be derived become [11]:

$$|G| = \sqrt{\frac{1}{\left(\omega_0^2 - \omega^2\right)^2 + 4\omega^2\gamma^2}} \quad , \qquad (4)$$

where $\omega$ is vibration frequency, and $\gamma = \frac{b}{2m}$

### *B. Fluxgate as Vibration Sensor*

Vibration is a dynamic mechanical phenomenon that involves periodic oscillatory motion. This motion provides position changing of an object to a reference position. Vibrating object is chosen which has magnetic characteristic. Magnetic material can be made from permanent magnet or ferromagnetic material. Magnetic material is placed on the vibrating object. If the object moves closer or farther from the sensor, so the sensor detects higher or lower magnetic field intensity [12,13]. If the magnetic field strength of a magnetic material is B, so the magnetic field strength that detected by the sensor at the distance $x$ is [5]:

$$B_x \propto \frac{B}{x} \qquad (5)$$

It can be seen that the magnetic field decrement is proportional to $1/x$

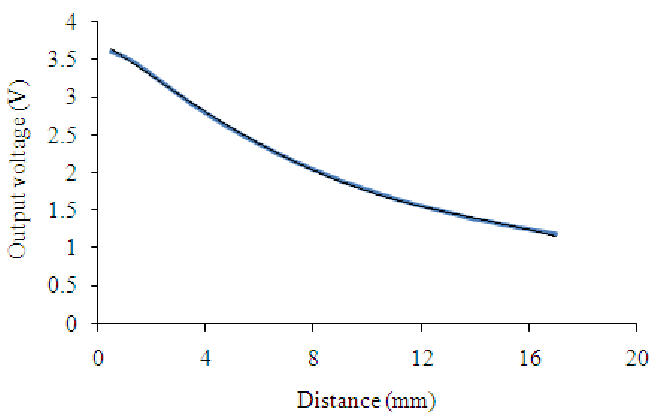


Fig. 2. Curve of distance measurement result [5]

Fluxgate sensor can measure this motion if the object can change magnetic field around the sensor. The output of the sensor is inversely proportional to the position of the object (Fig. 2). To determine vibration frequency and amplitude, Fourier Transform is performed [13]. This measurement principle is shown in Fig.3.

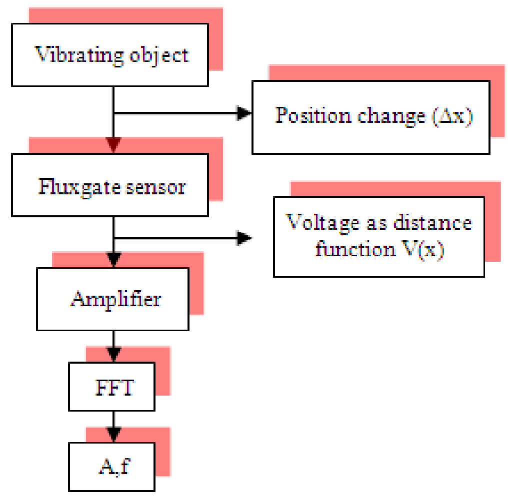


Fig. 3. Working principle of vibration measurement [13].

## III. Sensor Design

The developed vibration sensor works based on indirect measurement. The vibration of the measured object will vibrate the magnetic mass on cantilever. Beam made from copper-beryllium alloy is used as cantilever. This vibration sensor is shown in Fig. 4.

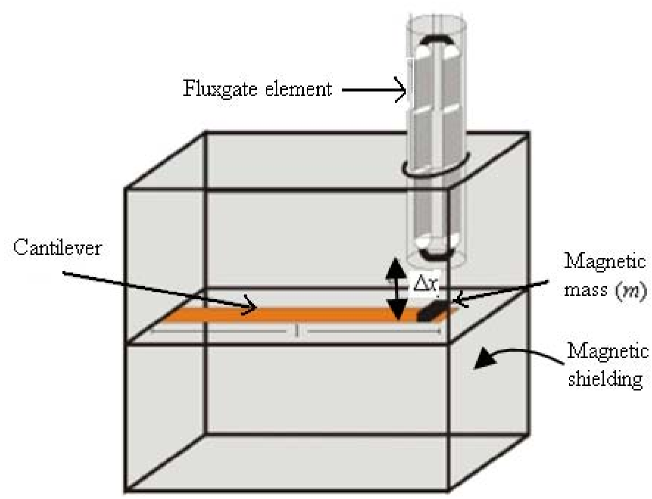


Fig. 4. Design of the developed vibration sensor.

The distance between fluxgate sensor and magnetic mass are adjustable. This variety can be tuned according to the requirement of measurement. All the sensor body is covered by magnetic shielding to avoid unwanted magnetic field from external.

## IV. Calibration

Calibration is carried out to determine the sensor characteristic. As calibrator, a calibrator system from Bruel and Kjaer Type 1047 is used. In this calibration, the acceleration is varied from 0.5 g to 2.5 g, where g is acceleration unit ($1g \approx 10 \, {}^{m}\!/_{s^2}$), and the frequency is varied from 25 to 48 Hz. Measurement data is acquired using Multichannel Signal Analyzer (MSA). Set up of calibration is shown in Fig. 5. To find the sensor characteristic of the developed sensor, a sensor modeling based on mathematical approach is used.


Fig. 5. Set up of calibration.

## V. Result and Discussion

### *A. Characteristic of the developed sensor*

To know the dependency of the developed sensor to frequency, a measurement system is carried out by measuring the output voltage as function of frequency (Fig. 5). The result shows that the developed sensor is influenced by frequency changing with resonance frequency close to 38Hz.

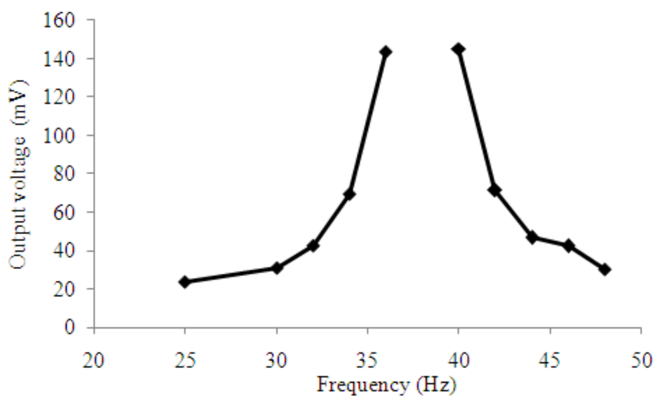


Fig. 6. Measurement result around resonance frequency at 1g acceleration.

### *B. Sensor Modeling*

The developed sensor is used to measure low frequency. Fig. 7 shows the dependency of output sensor to acceleration on different frequencies.

It can be seen that there is a linear depedency between acceleration and the sensor output voltage on each frequency. By using linear approximation (least square), the mathematical model of the sensor can be calculated in the form of (see Fig. 8).

$$V_o(a, f) = m(f) \cdot a \qquad (6)$$

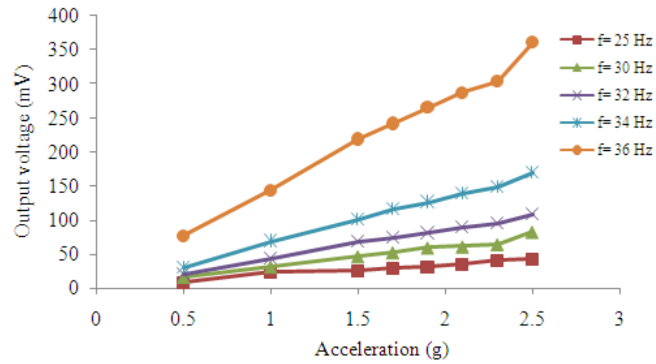


Fig. 7. Amplitudes as a function of acceleration on difference frequencies.

where *a*, *f*, and *m* are respectively acceleration, frequency of the vibration, and sensor sensitivity. The parameter *m* is a function of frequencies (Fig. 8)

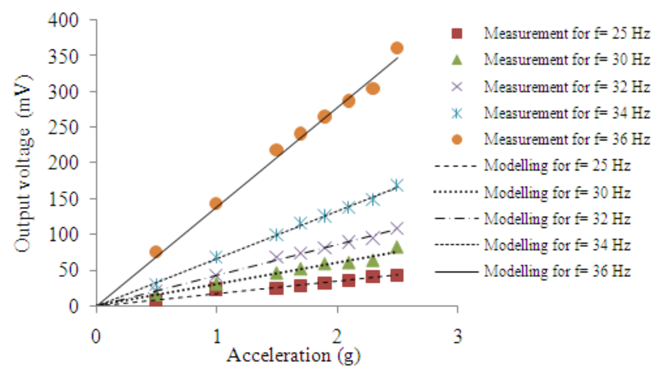


Fig. 8. Mathematical model of the developed sensor.

To find coefficient of *m(f)*, each gradient of the curve are plotted into a curve of sensitivity as a function of frequency. By using a mathematical approach we can find the most suitable equation. Each gradient value from Fig. 7 is shown by Tabel 1.

Table 1. Gradient in every frequency.

| Frequency (Hz) | Sensitivity (mV/g) |
|---|---|
| 25 | 17.28 |
| 30 | 30.41 |
| 32 | 42.82 |
| 34 | 66.76 |
| 36 | 139 |

These gradients are equal to sensitivity of the sensor. It can be seen that sensitivity increases while frequency toward to resonance frequency.

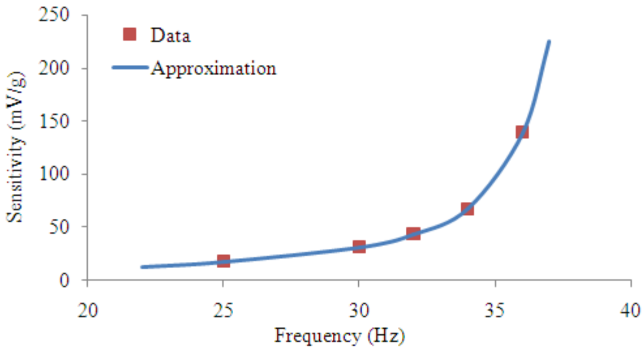


Fig. 9. Sensitivity as a function of frequency.

The continuous line in Fig. 9 is the most suitable equation to approximate relationship between sensor sensitivity and frequency. This equation is

$$m(f) = 1.97 \cdot 10^{-9} \exp(0.6792 f) + 1.09 \exp(0.11 f) \quad (7)$$

The final equation of the output voltage as a function of frequency and acceleration is

$$V(a, f) = \left[1.97 \cdot 10^{-9} \exp(0.6792 f) + 1.09 \exp(0.11 f)\right] a \quad (8)$$

The absolute and relative errors of the developed vibration sensor is calculated using equation (8). The result can be seen in Fig. 10 and Fig. 11 respectively.

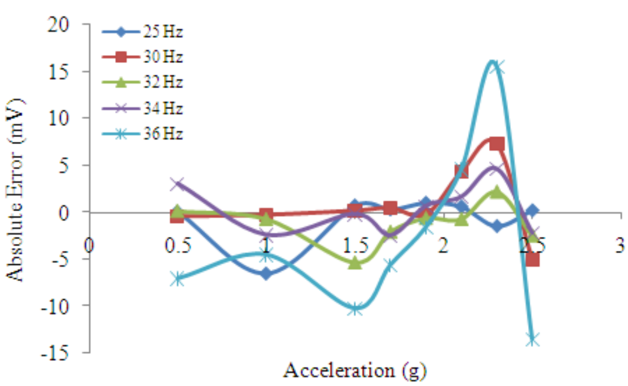


Fig. 10. Absolute error of the developed vibration sensor.

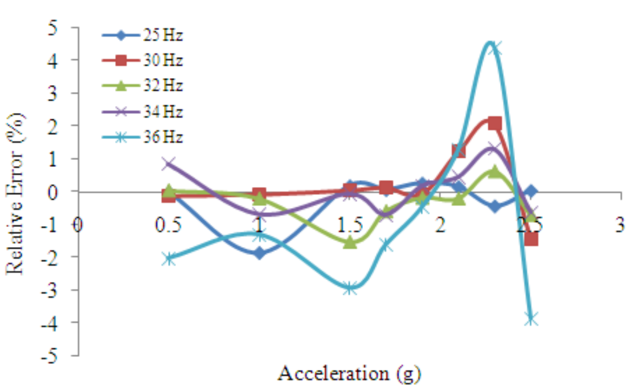


Fig. 11. Relative error of the developed vibration sensor.

The maximum absolute and relative errors are 15.5 mV and 4.39% respectively at 36 Hz and 2.3 g. It is shown that the maximum error occurs at the resonance frequency of the sensor system.

## VI. Conclusion

It is shown that the fluxgate element can be used well as vibration sensor. There is a linear dependency between amplitude of vibration system and the sensor output signal. The sensitivity of the sensor is different for different frequencies. It depends on the characteristic of the sensor material and the form of magnetic mass and the cantilever as spring. By using corrected mathematical model, a good sensor model as function of acceleration and frequency of the vibration can be determined. With this model, we find relative error under 4.39%.


## Acknowledgment

The work was supported by the Directorate of Higher Education, Indonesian Ministry of Education under grant “Hibah Bersaing” no 080/H35.2/PG/HB/2009 and Research KK-ITB No.: 262/K01.7/PL/2009.


## References


[1] S. Goldman, *Vibration Spectrum Analysis*, New York: Industrial Press Inc., 1999.

[2] S. Kawahito, A. Cerman, K. Aramaki, and Y. Tadakoro, "A Weak Magnetic Field Measurement System Using Micro-Fluxgate Sensors and Delta-Sigma Interface," *IEEE Transaction on Instrumentation and Measurement*, vol. 52, 2003, pp. 103-110.

[3] P. Ripka, *Magnetic Sensor and Magnetometers*, USA: Artec House, 2001.

[4] M. Djamal and R.N. Setiadi, "Pengukuran Medan Magnet Lemah Menggunakan Sensor Magnetic Fluxgate dengan Satu Kumparan Pick-Up," *Journal Proceedings ITB*, 2006.

[5] Yulkifli, Suyatno, M. Djamal, and R.N. Setiadi, "Designing and Making of Fluxgate Sensor with Multi-Core Structure for Measuring of Proximity," *Proceedings of The Conference Solid State Ionic (CSSI)*, Tanggerang: 2007, pp. 164-170.

[6] M. Djamal and R.N. Setiadi, "Sensor Magnetic Fluxgate dan Aplikasinya untuk Pengukuran Kuat Arus," *Jurnal Sains dan Teknologi Nuklir Indonesia*, vol. III, 2007, pp. 51-69.

[7] Yulkifli, Z. Anwar, and M. Djamal, "Desain Alat Hitung Kecepatan Sudut Berbasis Sensor Magnetik Fluxgate," *Jurnal Sainstek*, vol. 1, 2009, pp. 79-90.

[8] I. Irodov, *Problems in General Physics*, MIR Publisher, .

[9] K.R. Symon, *Mechanics*, Massachusetts: Addison-Wesley Publishing Company, 1960.

[10] A.K. Singh, *to I.E. Irodov's Problem in General Physics*, New Delhi: CBS Publisher & Distributors, 2005.

[11] D.E. Thompson, "Harmonic Response of Second Order Systems," 2006.

[12] M. Djamal and Yulkifli, "Fluxgate Sensor and Its Application," *Proceedings of ICICI-BME*, Bandung: 2009.

[13] M. Djamal, R.N. Setiadi, and Yulkifli, "Preliminary Study of Vibration Sensor Based on Fluxgate Magnetic Sensor," *Proceedings of ICMNS*, Bandung: 2008.