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Development of Ground Displacement Sensor based on Flat Coil Element for Detection of Landslide

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Abstract: *This paper presents the development and characterization a low cost, robust and reliable ground displacement–based flat coil sensor for application of landslide detection. Flat coil element has been made from a thin epoxy and silver mixed with a number of coils 30, diameter of 3 cm and inductance 9.2 μH. The measurement static characteristic of sensor showed that the sensor output voltage increases with increasing distance between the seismic mass to the sensor and vice versa. Flat coil-based sensors have a working area between 0.6 to 10 mm with the absolute and the relative error of 0.035 mm, 0.81 %, respectively. The dynamic characteristic of sensor system is able to detect the ground shifting in the direction of the horizontal and vertical in the range (0-15) mm and (0-20) mm, respectively.*

Keywords: *Flat coil, ground displacement, landslide, induction sensor, seismic mass*

I. INTRODUCTION

Indonesian countries are exposed to numerous geological hazards, such as landslide, earthquake, volcanic eruptions, and floods. Landslide is an important geological hazard that causes damage to natural and social environment. According the National Agency for Disaster Management in Indonesia had an average of 236 events of landslide in 2013 [1]. The frequency of their occurrence seems to be on the rise every year. The main reasons for the observed increase in landslide disasters are a greater susceptibility of surface soil to instability as a result of overexploitation of natural resources and deforestation, and greater vulnerability of the exposed population as a result of growing urbanization and uncontrolled land-use [2].

Landslide causes very complex to change the form of the land and the environmental conditions that exist on the land. Recent research estimated that more than 4,500 people are killed and thousands of others are injured in landslides around the world every year [3]. Landslide is one of the most costly catastrophic events in terms of human lives and infrastructure damage, early warning monitoring for landslides becomes more and more important. Early warning systems are becoming one of the main pillars of disaster prevention in natural hazards especially landslide. Warning is the most economical risk-reduction measure for rapid landslides, and development of early warning systems for mitigating natural risks is a topic of much research around the world.

Currently existing monitoring systems for early warning are available in terms of monolithic systems. This is a very cost-intensive way considering installation as well as operational and personal expenses.

In this study, a new type of flat coil sensor system has been developed to predict the likelihood of a landslide. The flat coil element being developed is an inductive proximity sensor for detection mass of soil movement. The simple method of flat coil manufactures and low cost, is an attraction that is still inspired to develop flat coil sensors. Moreover, flat coil sensors are reliable, rugged, and easy to handle. The electronic system can be easily designed for the processing of the signal from the sensor with low energy consumption.

The flat coil sensor based on eddy current technology has been developed in our laboratory for the purpose of low frequency vibration sensor [4] and can measure vibration frequencies between 0.2 to 1 Hz. In this paper, we present the development of flat coil sensor for landslide monitoring. In order to achieve this goal, we have performed a set of measurements in laboratory. Later, we have performed a verification process to ensure that our sensor system is working correctly. Particularly, the characterization of the flat coil sensor with respect to its static and dynamic characteristics is in the focus of attention.

II. FLAT COIL SENSOR AND ITS APPLICATION TO GROUND DISPLACEMENT

2.1. Flat Coil Sensor

The working principle of flat coil sensor is based on inductance changes from flat coil due to the disruption of the conductive material (seismic mass). Magnetic field around a flat coil element arises when an electric current flowing through it and its inductance will change if a conductive material is placed in its local magnetic field. This is due to eddy currents arise in a conductive material so as to produce its own magnetic field and interfere mutually reinforcing with inductance generated by the flat coil element itself. A change in the total inductance of a flat coil element is used as part of a series LC oscillator. Each winding of the coil is considered as a circle coaxial with radius approximately equal to radius of winding. Figure 1a shows the developed of flat coil sensor and Figure 1b shows a flat coil element in front of conductive material (seismic mass). The total magnetic field is influenced by the magnetic field of the coil (self-inductance) and the induction magnetic field of the conducting material (mutual inductance). The total inductance *L* can be calculated by summing up the self1inductance L_i and the mutual inductance M_{jk} [5,6].

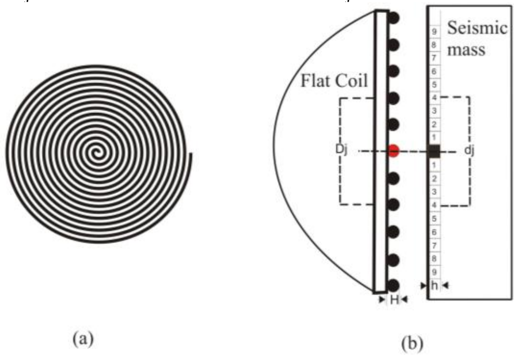


Figure 1. Flat coil sensor (a). flat coil element, and (b). flat coil element in front of conductive material (seismic mass) [7]

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

with,

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

$$M_{jk} = \frac{2\pi\sqrt{D_1 D_2}}{k_{jk}}\left[\left(2 - k_{jk}^2\right)K(k_{jk}) - 2E(k_{jk})\right] \tag{3}$$

with,

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

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

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 *l* is distance between two rings.

2.2. Ground Displacement

Ground motion is defined as the mass transfer of soil and rock in the direction of upright, horizontal or inclined from its original position. Type of ground movement is creep, flow and landslide. Landslides are consists of fall, topple, slides, slump, flow, or lateral spread, creep and avalanche compound [8]. The cause of the landslide is usually associated with instability in the slopes. There are several causes of slope instability, making it possible to identify one or more landslides causes and landslides trigger. One of them is water content in the soil and cause weight of the soil increased. If water penetrates the soil impermeable layer that acts as a slip plane, the ground became slippery so land on it will move to follow the slope and off the slopes, as shown in Figure 2.

The basic formulation of the safety factor of the slope (ground material) was introduced by Fellenius and then developed by [9, 10] is:

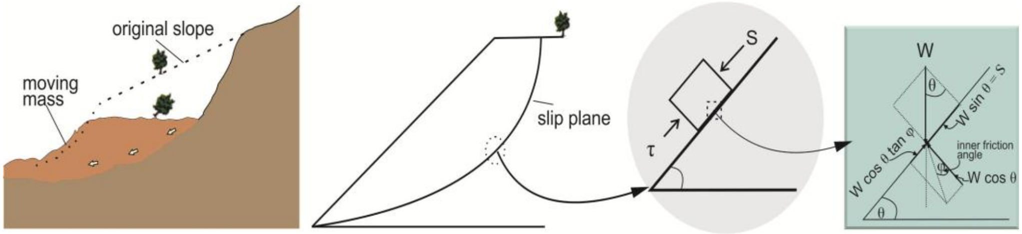


Figure 2. The forces acting on landslides; retaining force (τ) and driving force (s)

$$F = \sum [\tau / s]$$
$$\tau = cL + [(W + V)\cos\theta - \mu]\tan\varphi \qquad (6)$$
$$s = (W + V)\sin\theta$$

where: F, τ, s, L, c, φ, W, V, μ, and θ are safety factor of the slope , sliding resistance force / shearing resistance along the L (N/m^2), thrust shear (N/m^2), segment length field slip (m), slope mass cohesion (N/m^2), the mass sliding slope angle(degrees), the weight of the mass in the upper segment (N), external load (N), pore pressure (γ_{air} x h x L), and the angle formed by the slip plane with the horizontal plane(degrees), respectively .

Generally, according to Terzaghi [11] the dynamics of the landslide was preceded by a gradual decline in the ratio of the retaining force of the driving force is called the safety factor, which is characterized by a downward slope occurs/deformation. Varnes [8] classifies the type of landslide velocity in seven classes, namely: 1). Extremely Rapid; {> 5 m/sec}, 2). Very Rapid; {5 m/sec – 3 m/min}, 3). Rapid; {3 m/min - 1.8 m/h}, 4). Moderate; {1.8 m/h - 13 m/month}, 5). Slow; {13 m/month – 1.6 m/year}, 6) .Very Slow; {1.6 m/year - 16 mm/year}, 7). Extremely Slow; {< 16 mm/year}.

III. MEASUREMENT SYSTEM

Flat coil element has been made with print circuit board (PCB) technology from a thin epoxy and silver mixed with a number of coils 30, diameter of 3 cm and inductance 9.2 μH. Distance calibration is performed on flat coil element to determine the static characteristics of the sensor. The static characteristics of the sensor were tested using the sensor calibration tools that can set the distance to the object of a flat coil. The working principle of these tools is to rotate a digital micrometer then there is a shift of the object, where object approached the flat coil element. System calibration tool consists of a micrometer as rangefinders, aluminum (2 mm thick and 30 mm diameter) as seismic mass, stepper motor, and microprocessor as shown in Figure 3.

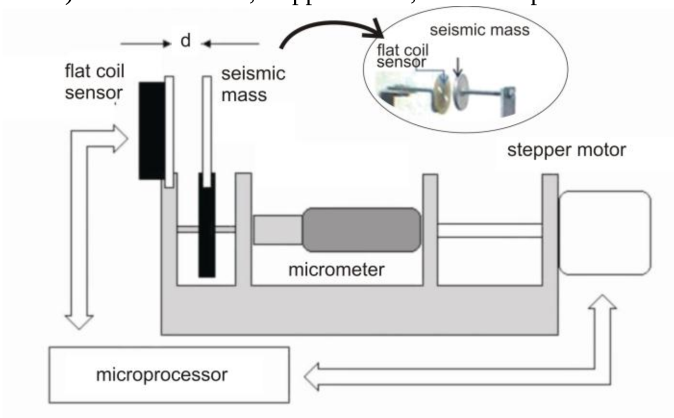
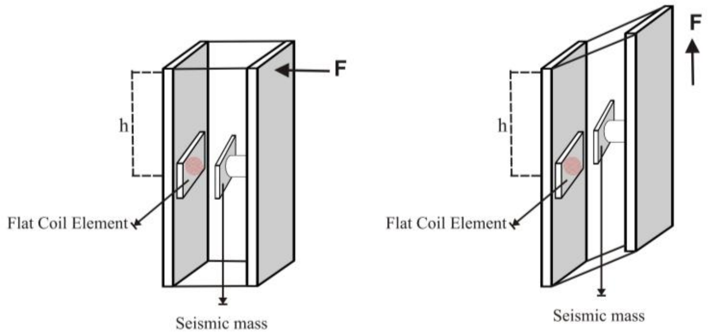


Figure 3. Calibration system of a flat coil as a ground displacement sensor [7]

Development of ground displacement sensor system based on flat coil element containing a flat coil sensor, seismic mass, and two plates with a distance of 40 mm, as shown in Figure 4. The variables are varied is the distance between the tip of the plate to the center of a flat coil sensor. To determine the dynamic characteristics of the sensor, the sensor system tested in two manners, namely: 1) By pressing one end attached to the end of the plate to another plate. The distance between the two plates and measuring intervals adjusted for variables that have been raised. 2) By pulling / shifting one end of the plate to the vertical direction.



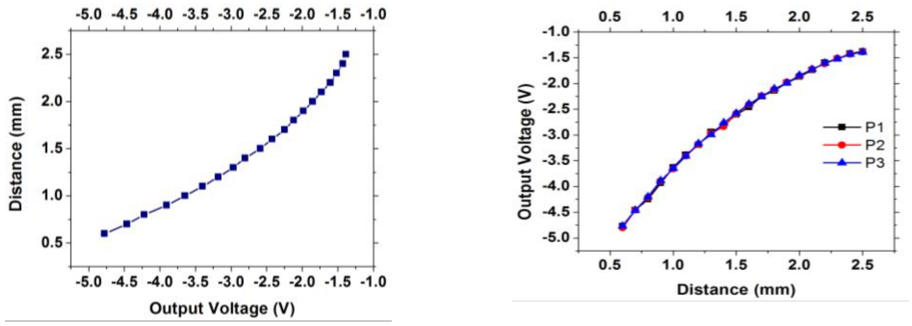
(a) (b)

Figure 4.The developed of ground displacement-based flat coil sensor system.

IV. RESULT AND DISCUSSION

Measurement of the static characteristics of a flat coil sensor carried on the range (0-25) mm with 0.05 mm intervals. The measurement results showed that the sensor output voltage increases with increasing distance between the seismic mass to the sensor and vice versa. Flat coil-based sensors have a working area between 0.6 to 10 mm. The sensor sensitivity is very high when the distance of the sensor closer to the seismic mass and low when the sensor farther from the seismic mass. Thus, the sensitivity of the sensor is different for each distance. The sensitivity of the sensor output is very good in the region 0.6 to 2.5 mm due to output changes in this area is large for slight change in each input, as shown in Figure 5.(a). Reproducibility test of flat coil sensor performed 3 times (P1, P2, P3) on area measurements of 0.5 to 2.5 mm with interval of 0.05 mm, as shown in Figure 5.(b) and we found the absolute error of 0.035 mm and the relative error is 0.81 %, as shown in Figure 6 (a) and (b) .

In first manner, measurement of dynamic characteristics of a flat coil sensor is done by pressing one tip of plate attached to another plate. The measurement results show for distances greater than 15 mm that the sensor output voltage reaches saturation, both for experiment A and experiment B, as shown in Figure 7. These results are consistent with the static characteristics of a flat coil sensor, wherein the region (10-25) mm is outside the work area of the sensor. If the distance between the tips of plate to the center of the sensor increases, the output voltage approaches the saturation. This is due to the distance between the sensor with the seismic mass has not been entered into the working area of the sensor, but the tip of pressed plate is attached to one tip of another plate. So, there are limitations on the distance between the seismic mass to the center of the sensor.



(a) (b)

Figure 5. Distance calibration of flat coil sensor; (a) sensor sensitivity and (b) reproducibility of sensor

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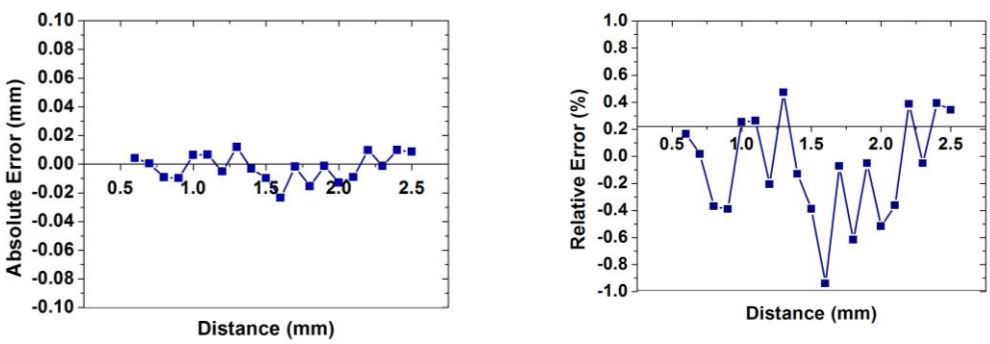
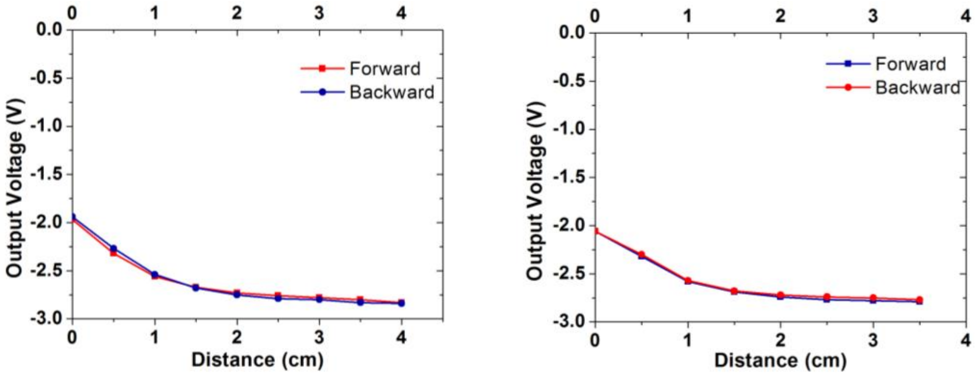


(a) (b)

Figure 6. (a) Absolute error and (b) Relative error of reproducibility of flat coil sensor



(a) (b)

Figure 7. Relation of distance to output voltage of developed sensor (a) Experiment A: Distance of tips seismic mass to sensor center is 150 mm and (b) Experiment B: Distance of tips seismic mass to sensor center is 250 mm.

*Forward = tip of the first plate is pressed to attach to the tip of the second plate.

*Backward = position of the plate that pressed is shifted slowly to the starting position.

In the second manner, measurement of dynamic characteristics of a flat coil sensor is done by shifting one tip of the plate to the vertical direction by 20 mm. The measurement results show the output voltage of the sensor is increase with increasing shift distance, as shown in Figure 8. The calibration results showed that ground displacement flat coil-based sensor system that has been developed, able to detect a shift in the range of 0-20 mm. Before the landslide, firstly soil movement occurred several millimeters in a few seconds. In cases where the landslide types moderate [8] which landslide velocity of less than 0.5 mm/sec, the ground displacement sensors that have been developed is still able to detect it.

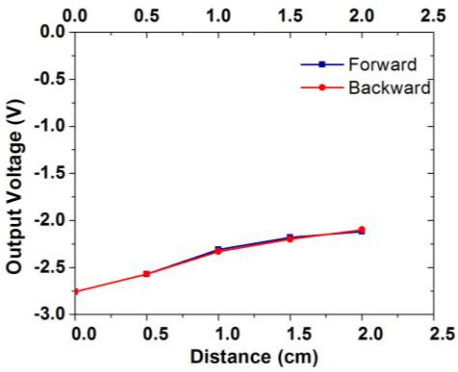


Figure 8. Relation between shift distance to output voltage for tip of plate shifted by 20 mm.

V. CONCLUSION

Development and calibration of a flat coil-based sensor system to detect landslides have been successfully carried out. Flat coil sensor is able to detect a very small shift of ground movement, because he has a work area in the range of 0.6-10 mm. This sensor system is able to detect the ground shifting in the direction of the horizontal and vertical in the range (0-15) mm and (0-20) mm, respectively. Thus, the sensor system has the potential to be applied as sensors for early warning of landslides. Further work, we will develop the deployment of landslide sensor based on flat coil around an active landslide zone. We also have been developed a ground displacement sensor based on coil (solenoid) sensor. This sensor consists of a wire in diameter of 1.2 mm, number of windings of 2.4, solenoid diameter of 50 mm and height of 80 mm, and has a working area of 0-60 mm.

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