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Landslide transducer based on amorphous wire strain gauges

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Abstract-The paper presents a landslide transducer based on amorphous wire strain gauges. Four such strain gauges are mounted on a flexible tube and connected in a Wheatstone bridge powered with a 1 MHz sine wave. The voltages from the mid points of the two arms of the bridge are amplified and further peak detected. The transducer is build around a low power microcontroller. The voltages from the peak detector are converted into digital data and the displacement and the direction are computed and corrected. The result is sent via a serial interface toward a central unit.

The originality of the paper consists of the use of such strain gauges as sensitive elements and processing of the signals for landslide detection. The results show higher sensitivity than classic strain gauges and the possibility to detect the direction of the displacement.

I. Introduction

Nowadays, large-scale natural phenomena with catastrophic consequences are more frequent (hurricanes, floods, extreme temperatures or geomorphological changes like landslides or earthquakes), especially due to the influence of human activities on climate. Landslides represent one of the most common natural hazards on the planet. The causes of landslides events are various, based on the geological conditions, tectonics, terrain, climate changes and human impact [1]. The landslide is mainly triggered by the moistening of the underground layer (clays, sands or grits) during the rainy seasons or after snow melting. The superficial layers on tilted surfaces slip on this low resistance layer under the gravitational force, displacing large quantities of ground

Landslide monitoring is usually done by looking after some parameters related to cause or related to effect. If monitoring of atmospheric climatic parameters is quite easy, monitoring the changes underground is more difficult. Currently, there are some methods that provide information about them, but they provide average results: remote information systems or local based sensors systems. Among the first category we can mention radar satellite interferometry [2], laser scanning [3] and high resolution imaging via satellites [4]. These systems have high costs, low resolution and discontinuity in data acquisition. The best of them is the 3D laser scanning technique which reaches a resolution of 3 mm. The second category is based on local sensors (tilt, acceleration, pressure) or GPS [5]. The techniques based on local sensors networks are based on measurements taken from geotechnical sensors (inclinometers, extensometers, piezometers, geophones, tiltmeters, crackmeters).

Inclinometers are instruments placed in wells made in the sliding mass. They measure the tilt of the whole ground mass, the initially tilt being nil. As configurations, there are many different types, depending on the transducer used: vibrating wire transducers, transducers with differentially connected wires, servoaccelerometers and gravity activated electrolytic cells.

Extensometers are used to measure displacement or soil compaction. Usually, these sensors are mechanical type but, in order to allow the automation of the measurement, potentiometers, differential transformers or inductive resonant circuits can be attached. These tools can be placed in wells or on the surface.

Piezometers and pore water pressure sensors are used to determine the slope stability. In order to identify the alarming situations, critical preset levels must be imposed. Piezometers consist of vibrating wires that convert water pressure into a frequency transmitted by a diaphragm toward an electromagnetic coil. This type of sensor is reliable, accurate and can detect rapid changes of the value of water pressure.

Tiltmeters are used to determine a deviation of a surface from the horizontal, the movement direction and to signal the sliding speed. There are many constructive variants (liquid based, electrolytic, with vibrant wire and pendulum type).

Crackmeters are very common in landslides surveillance systems because they are very simple devices that determine the distance between two points.

The paper presents a cost effective sensor, easy to maintain and independent from the power point of view.

II. Amorphous wire strain gauges

The main component of the landslide transducer is the strain gauge. The sensitive elements are two amorphous wires, 10 mm length with stressimpedance effect [6], [7]. The wires are bonded on a thin FR4 substrate, like in Figure 1. The wires are soldered onto the pads using the normal hot soldering use din electronics. The transfer characteristic of the wires shown that, using a initial axial tensile stress pretension of σ_{a0} = 55 MPa in order to move the operating point on the middle of the characteristic $\Delta Z/Z_0 = f(\Delta l/l_0)$, where the sensitivity and linearity are most convenient [7]. The resulting characteristic is symmetric with respect to the origin, allowing equal excursions in both directions (elongation and compression).

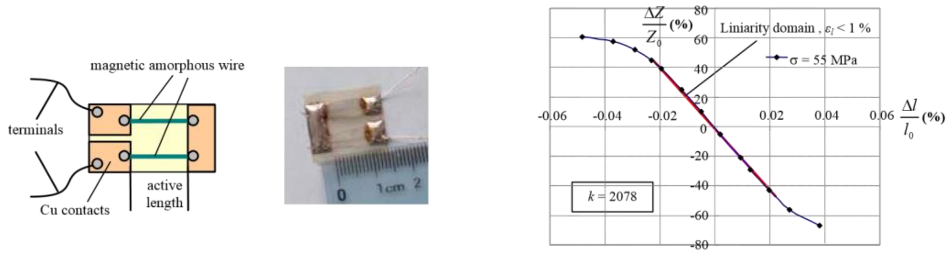


Figure 1. Strain gauge: left – the front view, right – the transfer characteristic [7]

The above characteristic is measured at 1MHz and shows a gauge constant of k=2078, much larger than conventional strain gauges [7]. The gauges are built from the same longer wire sample, pretensioned with the same force. Two such wires were vertically suspended, and the many gauges were glued using a special adhesive onto the FR4 support. After cutting the wires and the gauges were separated, the wires were soldered to their contacts. Some tests have been previously performed for determining the wire impedance dispersion. We noticed a quite large dispersion of the impedance along the wire (Z_{2cm} = 15,28 Ω, standard deviation 2,75 at σ = 55 MPa) that asks for the necessity of pairing the gauges.

III. Sensor construction

The sensor consists of 4 such gauges mounted on a flexible tube (PET). Before mounting the gauges were carefully sorted in order to match their parameters. They are glued on the exterior of the tube, with 90 degrees shift between two consecutive gauges (figure 2), with a waterproof cover over them. Special glue has been used (Z70) for fixing the gauges on the tube. For keeping the same exterior diameter of the tube, the gauges were mounted in hollows.

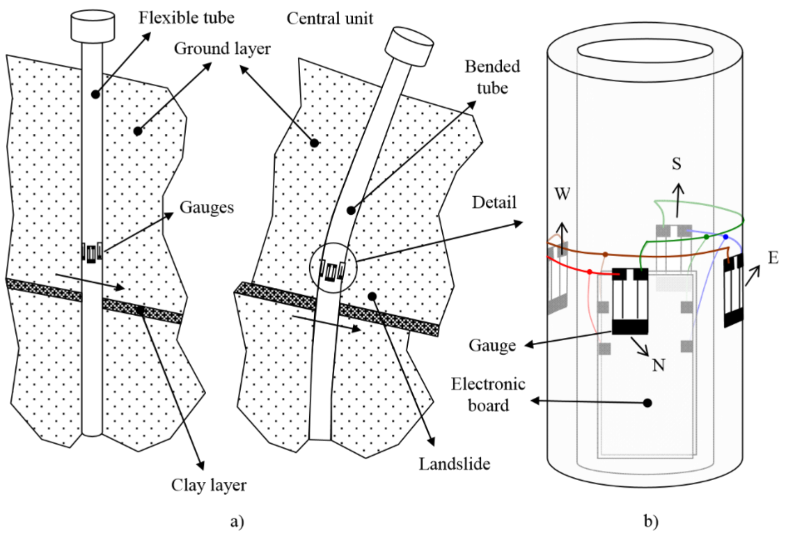


Figure 2. a) Landslide sensor emplacement and the mode of action; b) Sensor construction – detail

The sensor is mounted inside a well that must cross the sliding clay layer. The gauges level is located were the landslide will create the tube maximum bending. The four gauges are connected in a Wheatstone bridge. The opposite gauges are connected in the same arm (N with S and E with W) in order to get the maximum of sensitivity. Inside the tube, the bridge is connected to an electronic board. This is very close to the bridge and it collects the signals through short wires. Thus, noises and interferences are avoided. The above ground part of the tube contains an electronic box for remote control. Data is sent to the surface to be sent further to a data center.

IV. Transducer architecture

The transducer is build around a low power MSP430 microcontroller [8], as shown in figure 3. It was chosen because it has low power consumption, a built-in multichannel ADC, temperature sensor and serial interface. The electronic board is located underneath the gauges, inside the tube.

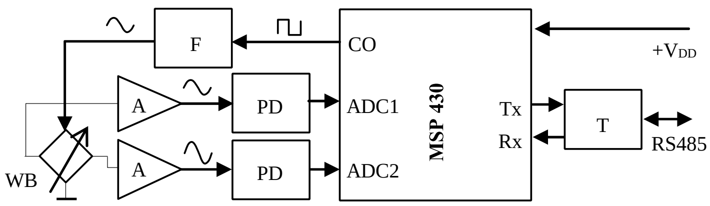


Figure 3. The landslide transducer architecture

Figure 4. The WB construction

The Wheatstone bridge (WB) is realized from 4 strain gauges mounted on the elastic pipe as presented above, physically shifted with 90□ like in Figure 4. The bridge is powered from the MSP430 [8], using a counter output (CO) to create a square wave of 1MHz, filtered by a bandpass filter F. This signal generator feeds the bridge with an about 1mA current, creating unbalancing voltages, ranging from a few mV to 20…30mV. When the pipe is bended, the signals at the midpoints of the two arms are modified with respect to the equilibrium ones, increasing or decreasing according to the bending direction and arrow. These low signals are amplified with two high speed amplifiers LT1805 (A) [9] and their peak values are extracted with 2 peak detectors (PD). These DC values are converted using the internal ADC into digital signals. The displacement amplitude and direction are computed inside the microcontroller. The temperature sensor is used to compensate the gauges temperature coefficient (□□ □ 0.11 %/ºC). Data are collected at fixed time intervals. The intervals can be usually large enough if no changes are detected, but they are reduced when changes in the signals are detected. The result is sent via RS485 toward the ground level unit which collects the data. We have chosen this solution because it allows communication between more such transducers using two wires.

IV. Results

The bridge is mounted on a flexible PET pipe as shown in Figure 4. The pipe was bended with different arrows, as shown in Figure 5. The strain gauges were carefully paired before mounting. An offset has been observed from the beginning. This is due to the initial bending of the tube during gauges mounting and due to the gauges unpairing and other stresses during the glue drying.

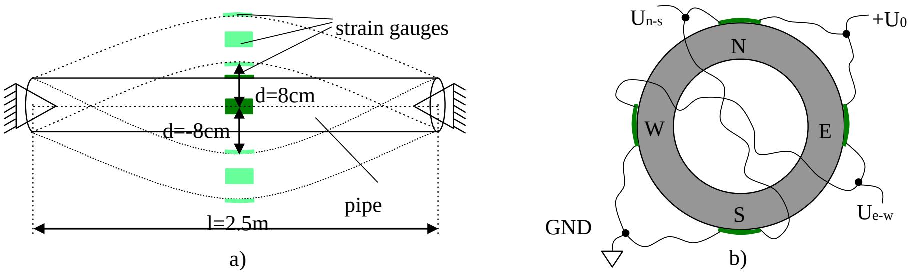
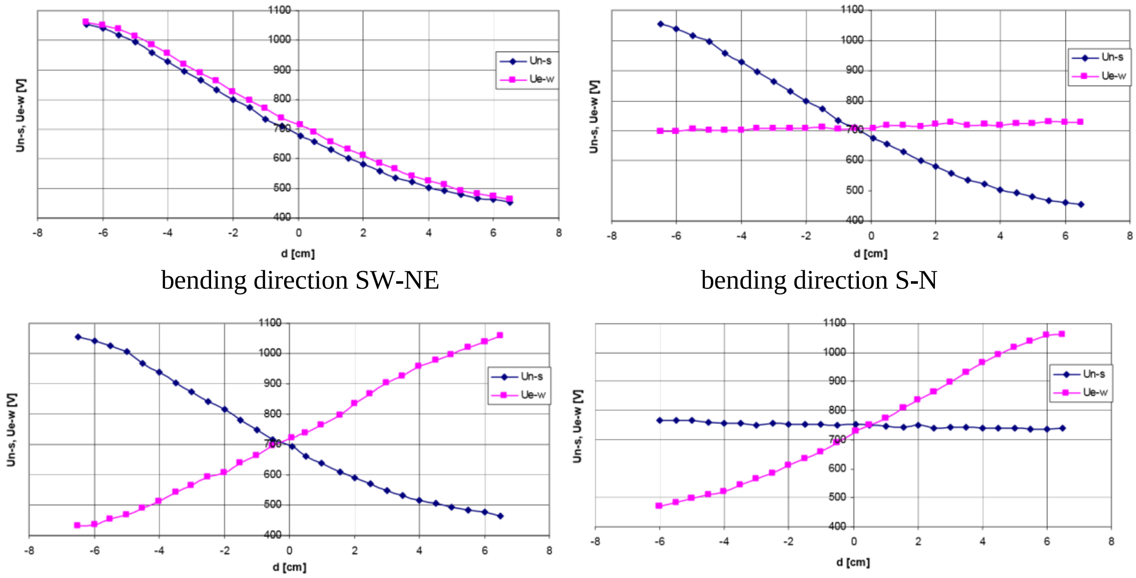


Figure 5. Testing the landslide transducer: a) mechanical arrangement; b) electrical arrangement

In order to test the sensor, the bending direction has been changed from SW-NE, S-N, SE-NW and W-E (S, E, N, W are the name of the gauges) and the voltages on the NS (U_{n-s}) and EW (U_{e-w}) diagonals were measured referenced to the ground. The maximum arrow has been varied from – 8 cm to + 8 cm, while keeping the ends of the pipe fixed. The pipe was lying on a horizontal table, and the bending direction was always in horizontal plane, so that the earth magnetic field pointed in the same direction. We monitored the magnetic field and found that the only magnetic field present during tests has been the earth's field, whose magnetic parallel induction was

42.5 µT. The results of the experiment are presented in Figure 6. The graphs show the measured voltages versus the displacement *d*.



bending direction SW-NE bending direction S-N

bending direction SE-NW bending direction E-W

Figure 6. Experimental results

By analyzing the experimental data, we can observe that the linear domain is restricted between – 4.5 cm to 4.5 cm. The total usable domain is around 9 cm, large enough for such applications, where the displacements, until the landslide is triggered, are of millimeters per day. The output characteristics are different depending on the direction of the displacement. If the direction of the movement is along the direction S-N (N-S) or E-W (W-E), meaning collinear with the gauges from the same arm, the output voltage on the other arm is constant (or almost constant). If the direction is 45□ from the arms, the output voltages can have the same variation or opposite variations (SW-NE and SE-NW). An offset of about 0.5 cm and a hysteresis of the same magnitude were recorded. These are static errors and they can be corrected. Further studies regarding the computation of the displacement and direction will be presented in future papers.

Aknowledgement

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