Study of the sensitivity and stability of a landslide sensor based on magnetic amorphous wires

Cristian Zet
"Gheorghe Asachi" Technical University of Iaşi
Faculty of Electrical Engineering
Iaşi, Romania
czet@ee.tuiasi.ro

Cristian Foşalău
"Gheorghe Asachi" Technical University of Iaşi
Faculty of Electrical Engineering
Iaşi, Romania
cfosalau@ee.tuiasi.ro

Daniel Petrişor
"Gheorghe Asachi" Technical University of Iaşi
Faculty of Electrical Engineering
Iaşi, Romania
dpetrisor@ee.tuiasi.ro

Abstract — **The paper presents a study on the measurement stability of a landslide sensor based on four magnetic amorphous wire strain gauges used in an Wheatstone bridge configuration. The sensor is aimed for in-situ monitoring using a distributed sensor network. The experiment has been performed in the lab using a test stand, while a time step progressive deformation has been applied to the sensor. Results show a good stability of the measurement and a variable sensitivity with respect to the bending point.**

Keywords – landslide; sensor; magnetic amorphous wire; stability;

I. INTRODUCTION

Due to ambient degradation caused by the human activities, landslides became one of the most common natural hazards. They are triggered by various causes, but the main trigger is the moistening of an underground impermeable layer during heavy rain periods or after snow melting. Landslide starts with a very slow movement and after cracks develop onto the ground and weakens the resistance of the soil, the movement accelerates and finally triggers the landslide while a large quantity of ground glide on the tilted underground layer.

There are several monitoring methods available by measuring some parameters related to cause or related to effect. Atmospheric climatic parameters are easier to be monitored, while underground parameters are more difficult. Among the monitoring methods we can mention remote monitoring methods: radar satellite interferometry [1], laser scanning [2] and high resolution imaging via satellites [3] and local monitoring methods: tilt, acceleration, pressure or GPS [4]. Most of these alternatives are expensive enough to make their current use affordable. In a previous paper [5], the authors presented a cost effective strain gage based on magnetic amorphous wire. The purpose of this gage is to be used in the construction of a landslide sensor. Experimental data show a sensitivity of about 2000, value that makes this gage 10 times more sensitive than any other semiconductor or metallic gage [5].

Previous papers [5], [7] presented the construction and study of MAW strain gauges and the architecture of the landslide transducer, while the present paper is focused on the study of the sensitivity of the landslide transducer in respect with the direction of the landslide and the depth between the landslide layer and the measurement point and on the medium term stability of the transducer's output.

II. CONSTRUCTION AND TESTING OF THE STRAIN GAGE

The MAW gauge construction and behavior has been presented in detail in [5], therefore here will just shortly presented. The wire to be used in such application is a magnetic amorphous wire (MAW) with the composition $(Co_{94}Fe_{6})_{72.5}Si_{12.5}B_{15}$, with the diameter of 120 µm, having a magnetoimpedance effect. When the wire is subject to mechanical stress under constant magnetic field it shows a stressimpedance effect [6].

In order to choose the best dimensions and working conditions, pieces of wires with different length were tested (5mm, 10mm, 20mm). The wires were measured with an Agilent HP4285A automatic bridge, biased with AC currents from 4 to 15mA and frequencies from 100KHz to 10MHz. The wires were initially pre-stressed with different forces in order to move the zero working point approximately in the middle of the linear part of their characteristic, as shown in Fig. 1 [6].

The characteristic slightly changes, as the zero point moves towards the middle of the quasi-linear region for 55MPa pre-stress (the trace marked with diamond in Fig. 1). The wires were glued on the substrate with the stress applied and after the glue dried, the force is removed but the wires remain pre-stressed. Finally the optimal values were chosen: as shown in the Table I [6].

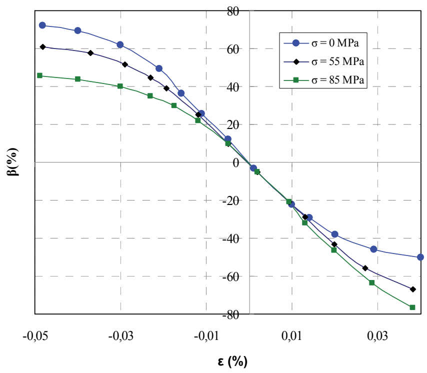


Fig. 1 The influence of the initial stress to the gage characteristic

TABLE I.

Parameter	Value
Length	20 mm
Frequency	1 MHz
Current	10 mA
Initial stress	55 MPa

The final device is presented in Fig. 2. The wires are bonded on a polyimide substrate with 0,075 mm thickness with cyano-acrylate glue, while the ends are soldered with normal Sn alloy used in electronics, after the wire ends were plated with Cu.

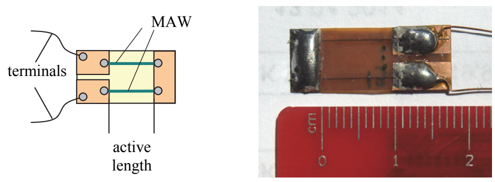


Fig. 2 The MAW gage construction

III. THE TRANSDUCER CONSTRUCTION

The transducer consists of 4 strain gauges mounted on the exterior wall of a flexible tube (PET). They are placed with an angular shift of 90 degrees between them along the tube's circumference (Fig. 3). The MAW is oriented along the tube axis in order to have the deforming force along the wire. Before being mounted, the gauges were carefully sorted in order to match their parameters (the initial electric resistance and the elastic constant). They are glued on the exterior of the tube, with 90 degrees shift between two consecutive gauges (Fig. 2), with a waterproof cover over them. Special glue has been used (Z70) for fixing the gauges on the tube's surface. For keeping the same exterior diameter of the tube and the planarity of the gage, the gauges were mounted in special hollows. The contacts with the electronics are realized gold spring pins through the tube's wall.

Because the MAW properties are effective at high frequencies, special conditioning circuits are necessary. The 4 gauges are connected in a Wheatstone bridge circuit, powered by a local oscillator with a sinus wave with the frequency of 1MHz. Because the gages behave as complex nonlinear impedances in respect with the deformation, extracting the information is difficult. The most convenient way is to consider only the resistive part of the impedance and to use only the linear zone of its characteristic [5].

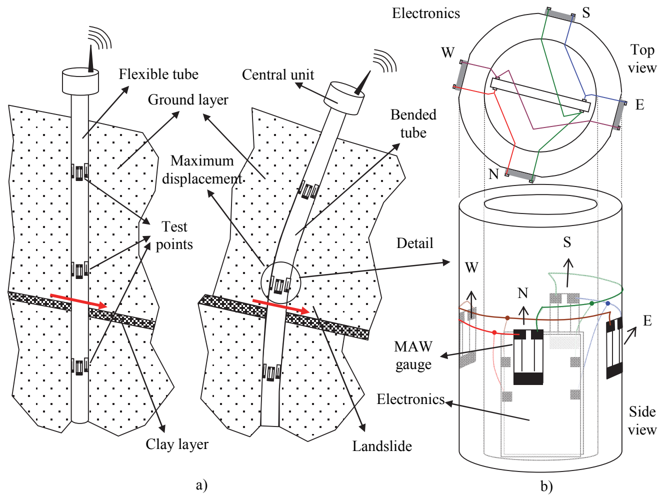


Fig.3 The transducer construction

The impedance modulus can be extracted from the amplitude of signal measured on the diagonals of the bridge. The block diagram of the electronic part of a test point [7] is shown in the Fig. 4.

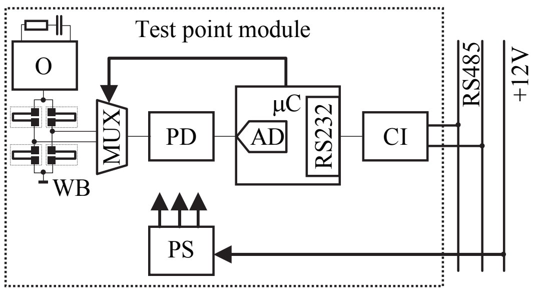
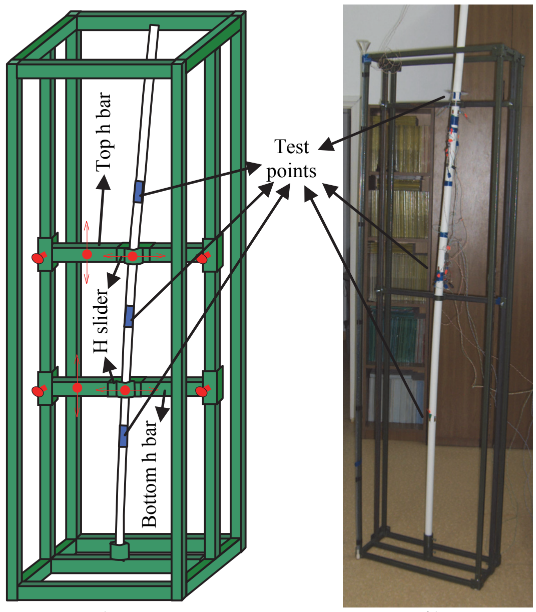


Fig. 4 The test point block diagram

Thus, a sinus excitation signal with the frequency of about 1MHz and the amplitude of 400mV is generated locally by an RC oscillator. The voltages on the two diagonals of the Wheatstone bridge (WB) are collected through a multiplexer (MUX) and peak detected (PD), one after another during a measurement cycle. They are converted into digital by the microcontroller (μC) internal A/D converter (AD) and thereafter sent via the communication interface (CI) toward the ground level to the central unit.

Because it is designed to monitor an area with high landslide potential, it has to detect tiny displacements of the ground with slow progressive rates. Thus, is very important to have a high sensitivity of the measurement and high long term stability without a fast response for step like displacements.



a) b)

Fig. 5 The experimental arrangement

IV. THE EXPERIMENTAL ARRANGEMENT

Before being installed in the field, the transducer must pass the test in laboratory conditions. In order to achieve this, a test stand has been designed. It consists of a metallic parallelepiped frame that allows fixing the bending point and the bending angle. Along two vertical bars (2.5 m tall), can slide up and down two horizontal bars (Fig. 5). Each horizontal bar has a slider with a circular hole through which the tube is mounted. The horizontal bars can be fixed in any position as well as the sliders on them. Thus, we can fix the slide level (the bottom horizontal bar position) and the slide displacement (the top horizontal bar and the slider on it) in respect with the test points positions. The distance between the test points is about 60 cm.

The experiment has been intended for testing the sensitivity of the device in respect with the slide level and the measurement stability. For determining the sensitivity the slide level (bottom h bar) has been varied between two test points in few steps, while the top slider on the top h bar has been displaced to left and to the right of the middle position. For the sensitivity measurement the slide level has been fixed to the midway between two test points and the slider on the top h bar has been displaced to the left and to the right of the middle position in small steps, while the data has been collected during day for one position. The NS slide direction has been chosen, in order to maximize the sensitivity of the gages on one arm of the bridge. The other arm will have the minimum sensitivity, but this scenario is the best one while, when installing the transducer in the field, it will be installed with the NS direction aligned with the hill-valley direction (the landslide direction)

The data has been recorded on a host computer via the RS485 communication network and processed in Excel.

V. RESULTS AND DISCUSSIONS

Using the test stand presented above, various tests were performed. The 4 MAW gages are used in a Wheatstone bridge configuration. In order to get the correct response the gages are connected like in Fig. 6. Opposite gages are connected in the same arm. The output voltages (U_{NS} and U_{EW}) are peak detected and recorded as a measure of the displacement.

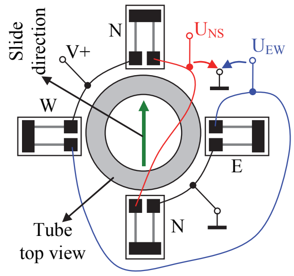


Fig. 6 The Wheatstone bridge wiring

For the sensitivity test, the bottom h bar has been fixed in different positions in respect with the test point: 15 cm, 30cm and 45 cm below the test point, considering the distance between test points of 60 cm. For each position, the slider on the top h bar has been moved to the left and to the right of the middle position with 20 cm in 2 cm steps. The voltage recorded on the NS arm (U_{NS}) is presented in Fig. 7. The sensitivity of the measurement decreases when the test point is located farther from the bending point. The curves trendlines show a decrease of about 1:2 in sensitivity (from 52 for 15 cm to about 33 for 45 cm) while moving away from the bending point.

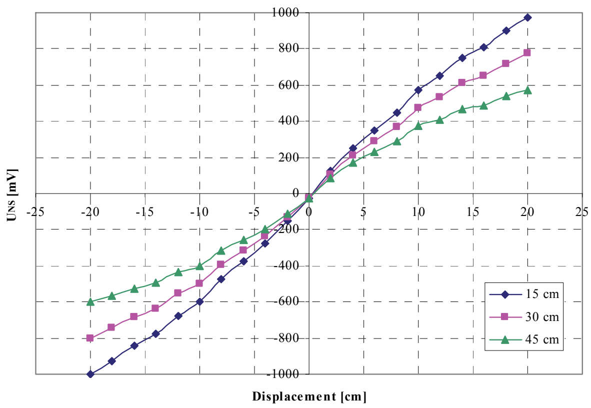


Fig. 7 U_{NS} sensitivity for different distances to the bending point

In Fig. 8 the voltage on the other arm of the bridge U_{EW} is represented. Due to the fact that the gages are not on the sliding direction, they are not affected by the tube bending. Still, the voltage shows a small variation due to the fact that there are 2 active wires are and they are physically shifted with about 2° from the 90° angle in respect with the sliding direction. The curves slopes are slightly different, but the difference is almost not detectable.

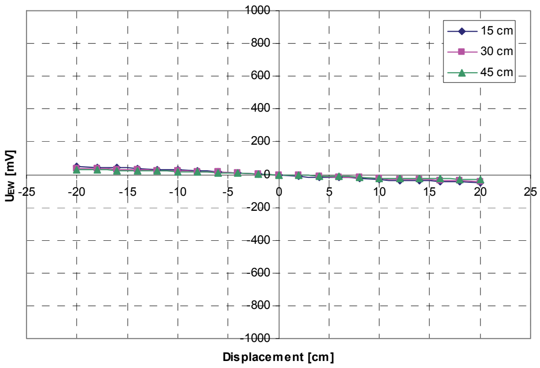


Fig. 8 U_{EW} sensitivity for different distances to the bending point

According to these results, we can conclude that the test point must be located as close as possible to the sliding layer in order to have a maximum sensitivity. When the hole for installing the transducer is drilled, the position of the sliding layer can be determined easily by the geologist by examining the structure of the material extracted from underground.

Another point to be considered is that the sliding direction must be the same with an arm of the bridge in order to have the maximum deformation for those gages, while the others will give no indication. The sliding direction is always toward the valley, so it is easy to properly install the transducer.

Regarding the stability of the landslide transducer, the measurement has been taken for about 100000 seconds. The gauges were kept for the above period under sustained load (slide displacement of 20 cm and slide level 15 cm under the test point)) and observed for the same period after unloading.

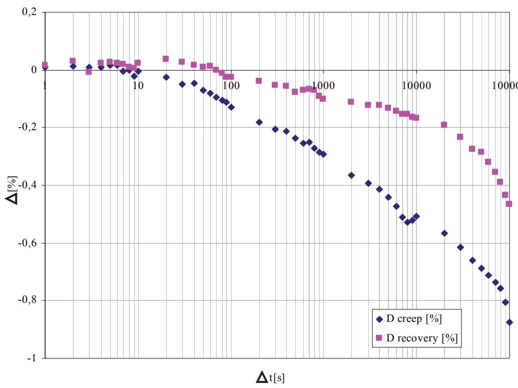


Fig. 9 Creep and creep recovery curves for landslide transducer

Collected data were used later on for computing the difference between the measured voltage at any time less than 100000 s and the initial reading after loading (creep). The same procedure has been applied for data taken after unloading (creep recovery). The results are presented in Fig. 9.

The following observations can be made:

- creep and creep recovery curves are not superposed. This shows an irreversible creep;

- creep signal is negative almost all over. This can be explained by the gage relaxation than to creep.

- the maximum value is under 1%, that makes the transducer suitable for the intended application.

VI. Conclusions

The aim of the experiments presented in the paper was to investigate the sensitivity and the medium term stability of landslide transducer (gages in association with their measuring system at ambient temperature). The landslide transducer is in the phase of lab testing and it is not yet installed in the field. We cannot make yet any appreciations regarding the robustness or the reliability of the transducer under real working conditions. The final landslide transducer will be insulated in order to stand the underground conditions (humidity and corrosion). The underground temperature conditions are almost constant all year around (10-15°C), keeping the gauges at constant temperature. As stated in [5], the temperature coefficient of the gauge is 0,11%/°C which gives an intrinsic variation of about 0.5% in respect with the temperature. Each test point has a built in temperature sensor for compensating the result.

The results show variable sensitivity of the output in respect with the distance with the distance from the slide level to the gauges level. The distance must be as small as possible.

Regarding the measurement stability, the transducer shows a good stability of the measurement (less than 1%). A slight relaxation of gages was noticed, its origin being supposed to be the gauges relaxation.

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