International Journal of Civil & Structural Engineering– IJCSE
Volume 1: Issue 2 [ISSN: 2372-3971]
Publication Date : 25 June 2014

Accuracy and Reliability of a MEMS Inclinometer in Civil Engineering

Dae Woong, Ha · Jong Moon, Kim · Jin Gi, Kim· Hyo Seon, Park

Abstract—**Inclinometers are used in various industries such as aviation and consumer electronics. They are also used in the civil engineering field to measure the horizontality and verticality of structures. An improvement in micro-electromechanical systems (MEMS) techniques in recent times has led to the development of a MEMS inclinometer. Interest in the MEMS inclinometer is increasing because of the many merits of the MEMS technique. In this paper, we report on an inclinometer that employs MEMS techniques for measuring structures and we investigate its usability on sites through experimentation. The test results prove the accuracy of the measurements obtained, and indicate that the proposed inclinometer can be beneficially applied as a measurement tool in the civil engineering field.**

Keywords—**MEMS inclinometer, Experiment, Civil engineering**

I. Introduction

Owing to recent improvements in micro-electromechanical systems (MEMS), many new sensors have been developed. One of the most representative sensors is the accelerometer. The accelerometer that is used in MEMS is known to have highly precise measurement values. This paper focuses on a MEMS inclinometer that puts an accelerometer into practical use.

In general, an accelerometer is a sensor that measures dynamic acceleration and static acceleration at the same time. Especially in a stationary state, an angle is formed between the static acceleration and the gravitational acceleration.

Dae Woong, Ha
Yonsei University
Korea

Jong Moon, Kim
Dstek.ltd
Korea

Jin Gi, Kim
Yonsei University
Korea

Hyo Seon, Park
Yonsei University
Korea

And this angle defines the inclination of the sensor. An inclinometer based on MEMS was developed based on these principles

Inclinometers are used for divers reasons in many industries. They provide efficient measurements in civil engineering field, in particular, as a tool for measuring horizontality and/or verticality during construction works.

The existing inclinometer is not only large in terms of its volume and weight, but also offers a relatively low degree of precision. An inclinometer based on MEMS, on the other hand, is small and produces relatively precise measurement values. Thus, it is deemed to be appropriate as an alternative for the existing sensor.

Hence, in this paper, we report on the design and production of a small MEMS inclinometer, and we assess its accuracy and reliability. Our ultimate goal is to examine the applicability of the MEMS inclinometer in the civil engineering field, and to verify the merits it can be expected to offer.

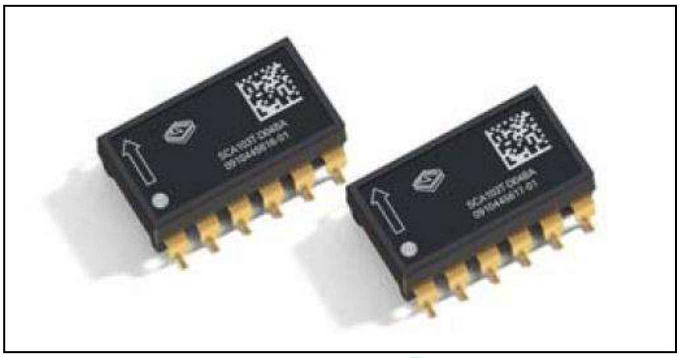
II. MEMS inclinometer

In this paper, we report on an inclinometer based on the MEMS technique that was designed and developed to realize the goal stated above.

In designing the inclinometer, a SCA103T chip was used for the sensing element. A SCA103T chip, with a surface micro-machined polysilicon structure built on top of a silicon wafer, is manufactured by VTI technologies.

The SCA103T is a MEMS based single axis inclinometer that uses the differential measurement principle. The high calibration accuracy combines extremely low temperature dependency, high resolution and low noise together with a robust sensing element design.

Figure 1. SCA103T Chip



SEEK DIGITAL LIBRARY

The SCA103T chip is shown in Figure 2.

The principle of the inclinometer is as follows. The accelerometer based on MEMS has a property of reacting sensitively to gravity. Inclination are measured using this property. In short, an angle is formed, depending on the position, between the stationary acceleration, which is measured when the MEMS accelerometer is in a stationary state, and the gravitational acceleration. This angle represents the sensor's inclination.

The relationship between acceleration of the X-axis (a_x), which takes place owing to the position change of the sensor, and gravitational acceleration (g), is shown in Equation (1). Here, (〈) denotes the inclination.

$$a_x = g \times \sin\alpha \quad (1)$$

$$\alpha = \sin^{-1}(a_x/g) \quad (2)$$

The interior of the inclinometer sensor was designed by dividing it into two layers, considering the size of the sensor. The upper layer constitutes a tilt sensor module, and the lower layer constitutes a process module. For the layer of the tilt sensor module, two sensing elements were installed - one each on the upper and lower part of the circuit board.

The two sensing elements were installed orthogonally so that they would be able to measure the sensors' X-axis and Y-axis gradients

In addition, signal devices such as an ADC converter, which converts the analog signals coming from the sensing element to digital signals, were installed. In the Process module shown below, a chip device is installed that controls all the operations of that the microprocessor has to carry out as it processes the information of the tilt sensor module.

The interior structure of the inclinometer is shown in Figure 2.

Figure 2. Interior structure of inclinometer

III. Experiment

An experiment was performed to demonstrate the accuracy and the reliability of the output values produced by the developed MEMS inclinometer.

A linear variable differential transformer (LVDT) sensor strain gauge, whose efficacy has been already verified, was used as a reference sensor. Next, the experimental frame was produced, as shown in Figure 3.

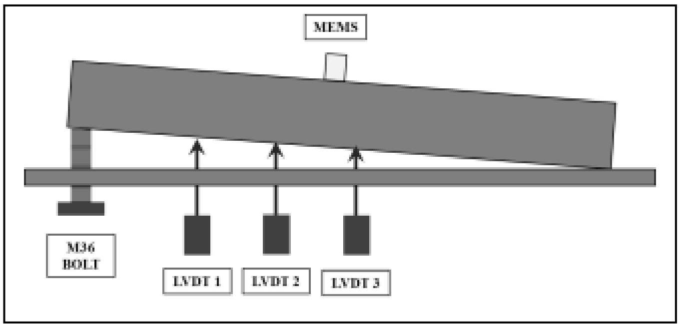


Figure 3. Experimental frame model

The experimental frame is fixed at one end to the lower plates, in a way that allows it to rotate, and an M36 bolt is installed on the other end to control the height. A four-pitch height control bolt was produced that accommodates the experimental frame's length and inclination. This means that the bolt rises vertically 4 mm in the course of one rotation.

An linear variable differential transformer(LVDT) was installed to compare it with the MEMS inclinometer. The inclination that is experienced by the member can be calculated using the vertical displacement that takes place at the LVDT.

In this experiment, three LVDTs were installed at 300 mm intervals, with the aim of providing precision. The calculation of the inclination experienced by a member by using the vertical displacements that take place at LVDT1 and LVDT2 is the same as Equation (3). In (3), h1 and h2 are the measured values for each LVDT.

$$\emptyset_1 = \tan^{-1}\left(\frac{h_1 - h_2}{300}\right) \quad (3)$$

Using the same equation as (3), the average value was calculated after finding the three values for each pair.

Equation (4) is the reference angle.

$$\emptyset_{ave} = \left[\tan^{-1}\left(\frac{h_1 - h_2}{300}\right) + \tan^{-1}\left(\frac{h_2 - h_3}{300}\right) + \tan^{-1}\left(\frac{h_1 - h_3}{600}\right)\right] \div 3 \quad (4)$$

The experiment was performed for 11 cases, including one in which the member was in a horizontal state. In each case, the inclination was raised around 0.04°. It means that

SEEK DIGITAL LIBRARY

the bolt is controlled quarter-turn. The test results are as follows.

TABLE I. TEST RESULTS

Case	*Test value (Deg.)*	*MEMS Inclinometer*	*LVDT*
0	0.000	0.000	0.000
1	0.040	0.040	0.042
2	0.080	0.080	0.086
3	0.120	0.117	0.130
4	0.160	0.147	0.170
5	0.200	0.183	0.211
6	0.240	0.223	0.254
7	0.280	0.264	0.297
8	0.320	0.305	0.338
9	0.360	0.344	0.382
10	0.400	0.382	0.424

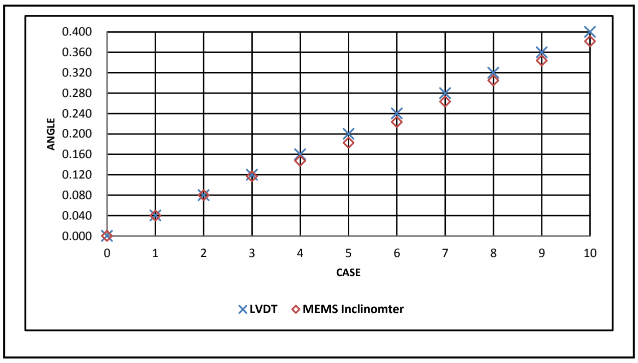


Figure 4. Result of Experiment

The Table 1. and the Figure 4. shown above present the same test results.

According to the test results, the LVDT and MEMS inclinometers produce a maximum error of 6.0% and 4.5% of the test value, respectively. In addition, there was a difference of at most 13.5% between the LVDT and the MEMS inclinometers.

This can be considered a very small difference, considering each sensor's resolution and ability and the degree of error obtained in the experimental circumstances.

In conclusion, the MEMS inclinometer that we designed and produced demonstrated sufficient accuracy and reliability.

IV. Conclusion

This paper began by discussing an inclinometer sensor that can accurately determine verticality and horizontality. It then reported on the design of a MEMS inclinometer based on MEMS technic, and proved the sensor's accuracy and reliability through simple experiments. As a result, we were able to draw the following conclusions

- The MEMS inclinometer is a sensor with a high degree of durability and produces relatively precise measurement values. We consider that it provides an alternative to the existing sensor.
- The installation of the sensor is easy because, since it is based on the MEMS technique, its volume and weight are extremely small.
- It has the merit of being a sensor that is not affected by electromagnetic interference between sensors, which can cause a problem in the measurement values that the sensor produces.
- In an experiment, it was demonstrated that the MEMS inclinometer proposed in this paper can output a stable value from different angles.

In conclusion, we have determined that in many ways, the proposed MEMS inclinometer sensor is advantageous in measuring inclination. Particularly in the field of civil engineering, verticality and horizontality are indicators that have a dominant bearing upon the overall completeness and safety of a structure while it is being constructed. Thus, an inclinometer is an indispensable sensor in the field of civil engineering. Therefore, the MEMS inclinometer proposed in the paper, with its various merits as described above, is considered to represent a new alternative. And the MEMS inclinometer is applicable in the field of civil engineering, effectively.

Acknowledgment

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government (MSIP) (No. 2011-0018360).

References

[1] VTI Technologies, Data sheet for the SCA 103T differential inclinometer series.

[2] Michelle Clifford, Leticia Gomez 2005 Measuring Tilt with Low-g Accelerometers, Freescale Semiconductor, application note

[3] Lijun Tang, Kairui Zhang, Shang Chen, Guojun Zhang, Guowen Liu 2009 MEMS inclinometer based a novel piezoresistor structure, Microelectronic Journal 40(2009) 78-82.

[4] Mohamed Saafi, Peter Romine 2004 Embedded MEMS for health monitoring and management of civil infrastructure, Proceeding of SPIE 5391, pp.331-343

[5] Simone Dalola, Vittorio Ferrari and Daniele Marioli, "Micromachined piezoresistive inclinometer with oscillator-based integrated interface circuit and temperature readout,"Meas. Sci. Technol. 23 (2012) 035107(11pp).

[6] Hrant Henri Djambazian, Chahe Nerguizian, Vahe Nerguizian and Maarouf Saad, "3D Inclinometer and MEMS Acceleration Sensors", in IEEE ISIE 2006, July 9-12, 2006

[7] Guo Qinglei and Liang Huawei, Miao Shifu and Huang Jian, "Design of a Plane Inclinometer Based on MEMS Accelerometer", in Proc. 2007 International Conference on Information Acquisition, July 9-11, 2007, Jeju city, Korea

SEEK DIGITAL LIBRARY

[8] LIN Da-wei, GUO Tao, "Design of Dual-axis Inclinometer Based On MEMS Accelerometer", 2011 Third International Conference on Measuring Technology and Mechatronics Automation.

About Author (s):

Dae Woong, Ha received the B.S. degree in architecture from Yonsei University, Seoul, Korea, in 2002, and the M.S. degree in structural engineering.
He is in dotor's course in the center for structural health care technology in Building, Yonsei University.

SEEK DIGITAL LIBRARY