Some Aspects Concerning Designing and Manufacturing of Shock Detectors with Analogical Hall Sensors

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The analogical Hall effect sensors are met in multiple applications which impose the measurement of some small displacements. The aim of this paper is to deal with a few aspects concerning the usage of these sensors in the design and manufacturing of shock and mechanical vibrations detectors.

In general, shock and vibration detectors have both fix and mobile elements. The energy of a certain external impulse is transmitted to the elastic elements, which react through a movement from an initial position of equilibrium. Considering that these movements are very small, the analogical Hall element can be a viable alternative in determining the produced movement.

The mechanical shock detectors which are based on Hall effect sensors can be classified in two categories:

a) transducers in which the shock is directly transmitted to the elastic element, and
b) transducers in which the shock is transmitted to the elastic element through the carcass.

Figure 1 presents a simplified type of shocks detector which uses Hall effect sensors. The detector has two distinct parts: *the mobile assembly* (1) and *the fix assembly* (2).

The mobile assembly is made from materials with good elastic properties, which can allow a relative constant deformation under the influences of external forces and confer good measurement process repeatability. The main part of the mobile assembly is the excitation coil, having the role of generating the magnetic field required for the correct function of the sensing element. The excitation coil can be replaced by a permanent magnet, if the properties of the mechanic system allow it.

The fix assembly is made from the same materials as the mobile one, but this time it is important for the transducer's support to include materials that can absorb the external parasite vibration. The main part of the fix assembly is the analogical Hall effect transducer. It can be made either through the classical impurifying method or in thin film technology.

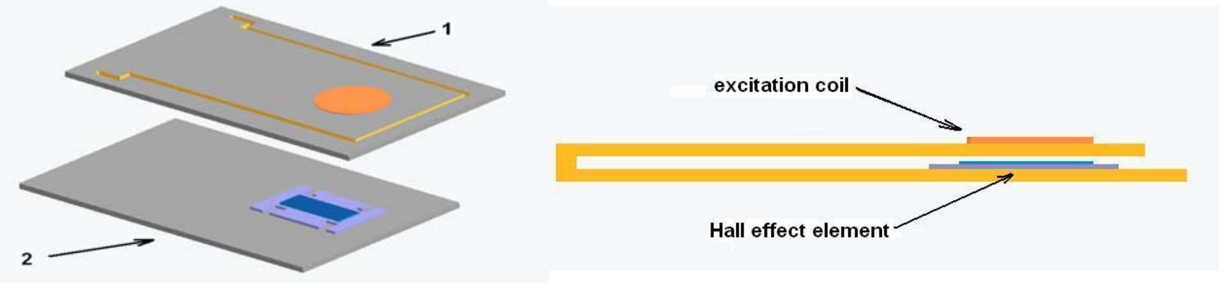

Fig. 1. Shock detector using Hall effect elements.

The transducer must be placed in such manner that the interaction with the magnetic field generates an output voltage which must be measurable, repetitive and easy to process.

During our tests using such detectors we have noticed often deviations of the transducer's behavior from the expected values. This fact is due to multiple factors which can influence the measurement process, the problems being caused either by the nature of the material used, or by the misbehavior of the detector's components.

1. The influence of the material composition and of the position

During the measurements using the transducers in which the shock is directly transmitted to the elastic element we have noticed that the system reacts in a different manner to ferromagnetic and nonmagnetic probes. This is due to the interaction between the permanent magnet of the sensing element and the free falling probe, the magnetic forces accelerating the fall.

Another important factor is the position in which the contact between the probe and the elastic element takes place or the α angle under which the contact occurs, sometimes this angle being different than 90°.

Figure 2 presents different cases in which the measured values are different, although the mass of the probe m = 4 g and the height h = 60 mm remain unchanged:

a) $\alpha = 90°$, non-ferromagnetic probe
b) $\alpha = 90°$, ferromagnetic probe
c) $\alpha \neq 90°$, non-ferromagnetic probe
d) $\alpha \neq 90°$, ferromagnetic probe.

Although apparently these factors presented above don't seem to influence the result excessively, it has to be said that choosing an inappropriate probe or treating superficially the excitation system of the lamellas may cause relative errors up to 70-80%.

In the examples from figure 2 the relative errors are:

- e_r[%]=86,7%, when the probe is ferromagnetic and the contact angle with the captor is 90°;

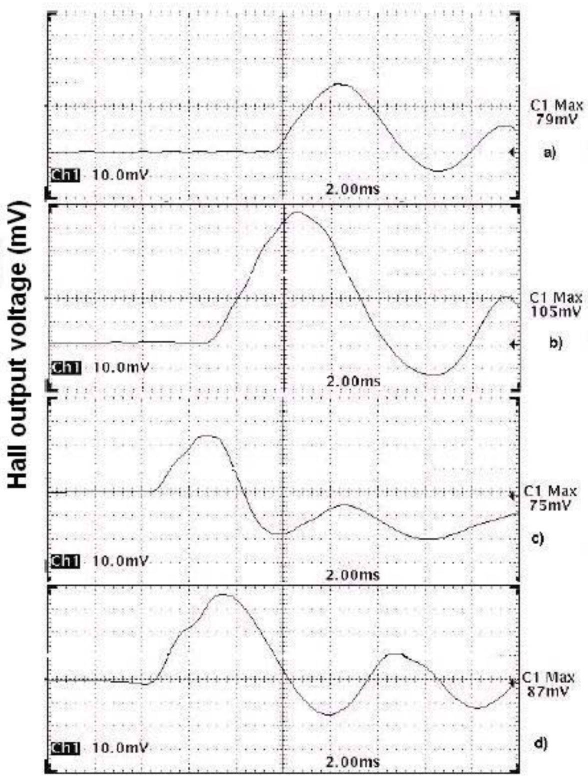

Fig. 2. The influence of the probe's material composition and of the position of the impact on the measurement's result.

- e_r[%]=13,3%, when the probe is non-ferromagnetic and the contact angle with the captor differs from 90°;
- e_r[%]=26,7%, when the probe is ferromagnetic and the contact angle with the captor differs from 90°.

2. The distance between the elastic assembly and the transducer

The analogical Hall effect transducer and the excitation element, whether it is the coil or the permanent magnet, are mechanically separated in order to ensure an adequate distance for the mobile's element movement. This distance depends on the elastic properties of the mobile assembly and on the measurement domain.

The limit case which must be avoided at all costs is the situation when the mobile assembly touches the sensing element. This is due to a high impact force, causing irreversible modifications in the system.

The physical changes of the system are not the only problems that can occur in this case. Even if the mobile elements of the detectors are strong enough to resist to proper mechanical impact, the measurement becomes impossible to be realized because the mobile assembly doesn't perform a free oscillating movement.

As shown in figure 3, on the acquired wave there are irregularities exactly in the area of maximum voltage, which is around the values necessary to determine the properties of mechanical system and oscillating movement.

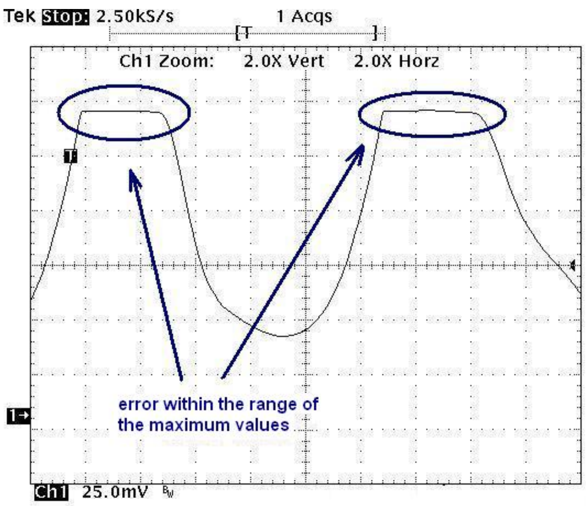

Fig. 3. Error due to the distance between the elastic element and the sensor.

3. The change of field lines orientation

Another often occurred problem, especially in the case of shock transducers using as mobile element components with a high elasticity, is that of the transducer's torsion. Therefore, the magnet's movement is incorrect, causing the change of angle under which it oscillated in the sensible area of Hall element.

Due to this fact, the field lines needed to excite the sensor change their orientation, generating negative output tensions and leading to significant errors in appreciating the movement.

For example, the detector from figure 4 uses two Hall sensors disposed symmetrically to the magnet incorporated in the lamella. The signal from the two transducers will be measured using the oscilloscope, the voltage on the first channel being positive and

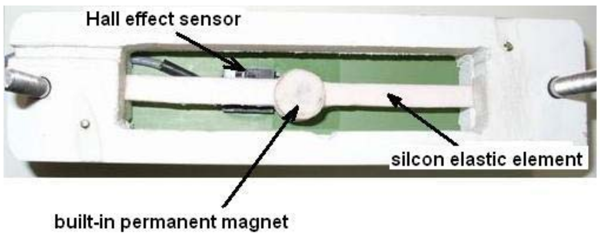

Fig. 4. Shock detector with silicon elastic element double embedded

ascendant while the magnet approaches the first transducer, respectively negative and descendent in the case of the second transducer.

In figure 5 we notice that the value of output voltage decreases suddenly and changes its sign. A simple way of avoiding these problems, also applicable in the case of a too high elasticity of lamella, is either to reduce the mobility of the elastic element or to choose a higher hardness of the used silicon.

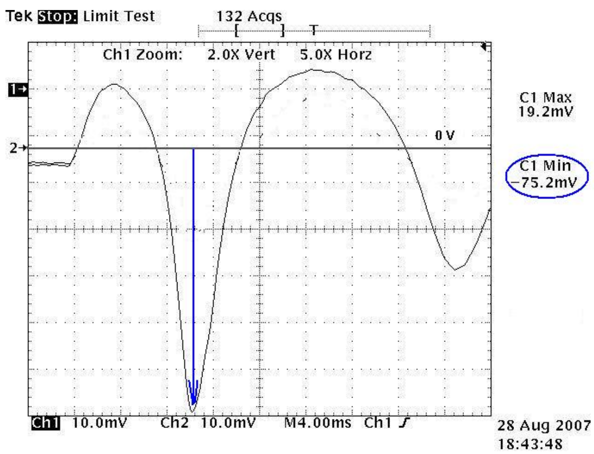

Fig. 5. Error due to the change of field lines orientation.

4. Fixing the constitutive elements or sticking the detector to the support

Many errors that appear at the vibration and shock detectors are due to the physical faults of the components or to their incorrect placement in the measurement systems. The wrong sticking of transducers to the body, subject to the mechanic shock, can also influence the output signal of the transducer.

The configuration in figure 6 presents a type of wave formed after measuring a shock applied to a transducer whose elastic element

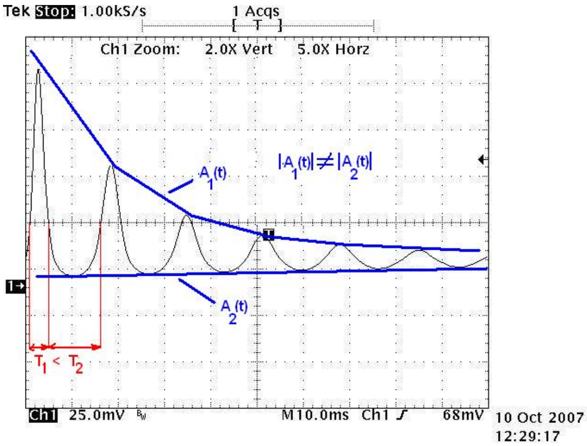

Fig. 6. Error due to unsimmetrical embedding of the elastic lamella.

with an embedded lamella is not symmetrically closed at its ends. Therefore, the holding system is not symmetrical to the lamella's axis, the movement is incomplete in both directions, and the answer on a certain period is out of proportion.

In the above configuration we can easily notice that the answer on the first half-period is different than the one on the second, regarding time as well as amplitude.

Another problem is the incorrect joining of the system's components. This can cause a major distortion of the measured signal, which is a composition between the initial shock and the parasite vibrations that proceed from the unwanted interaction between the system's elements.

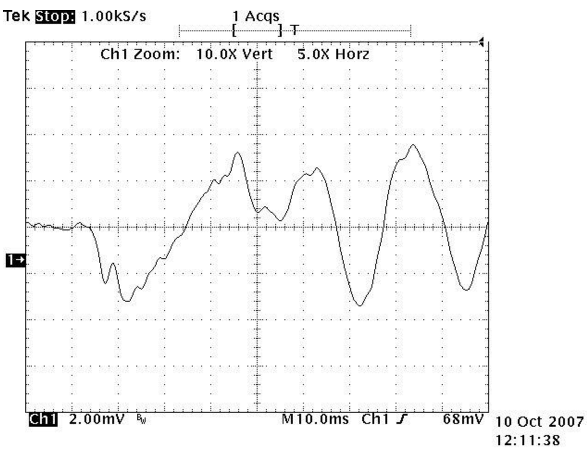

Fig. 7. Error due to the incorrect joining of the system's elements.

The problems mentioned above make the signal generated by the transducer impossible to be processed, next to a fastening, respectively to a poor sticking of the detector to the body liable to the excitation forces.

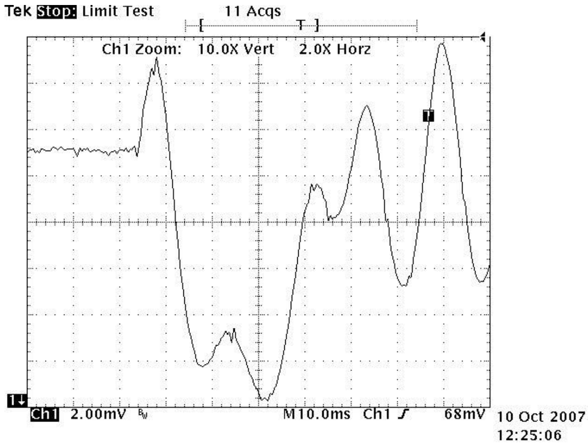

Fig. 8. Error due to incorrect joining and poor fastening of the transducer's elements.

5. The elasticity of the mobile element

The answer of the shock detector is strictly dependent to the elastic properties of mobile elements. A too high rigidity makes their move imperceptible by the Hall element. A too high elasticity can cause an insignificant damping of the vibration, making impossible the measurement of the differences between two successive maximums or leading to a random behavior of mobile element.

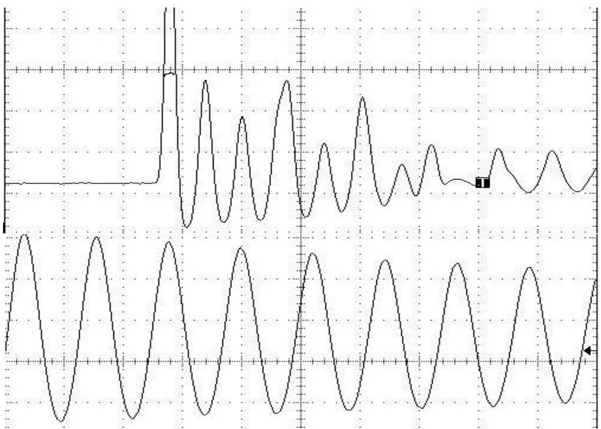

Fig. 9. Error due to the elasticity of the mobile element.

As a result of our researches regarding the use of galvanomagnetic transducers in measuring magnetic shocks, we can assert that the Hall effect can be easily used in measuring mechanic shocks.

In some cases problems can occur in the evaluation of measured signal due to some factors depending to the projection and placement of transducers. Even so, a careful approach of each constructive aspect leads to results with a good repeatability, having admissible errors in the limits imposed by the utilizable range, and moreover to a high detectors reliability.

References

1. Binu, S. - *Fibre optic displacement sensor for the measurement of amplitude and frequency of vibration*, Optics&Laser Technology, vol. 39, November 2007, pp. 1537-1543.
2. Broch, J.T. – *Mechanical Vibration and Shock Measurements.* Bruel&Kjaer, 1980.
3. Crescini, D. – *Piezoresistive thick-film sensors for force and vibration measurements.* Proceedings of the XIII IMEKO World Congress, Torino, Italy, 1994, pp. 271-276.
4. Fan, K., Wang, Y. - Silicon Micromachined High-shock Accelerometer with a Bonded Hinge. Structure Journal of Micromechanics and Microengineering, vol. 17, nr. 6, June, 2007, pp. 1206-1210.
5. Fieldhouse K.N., - *Tehniques for identifying sources of noise and vibration*, Sound and Vibration, 4/1970, pp. 14-18.
6. Ferrari, V. - Silicon resonant accelerometer with electronic compensation of input-output cross-talk. Sensors and Actuators A (Physical), vol. 123-124, 2005, pp. 258-266.
7. Hongwei, Q. - A single-crystal silicon 3-axis CMOS-MEMS accelerometer. Proceedings of the IEEE Sensors 2004 (IEEE Cat. No.04CH37603), 2004, vol. 2, pp. 661-664.
8. Târnovan, I.G., Ţebrean, B., Crişan, T.E. – *Hall Effect Transducers Used in the Parameter Extraction of Captors Having Elastic Cantilever Beams* - Proceedings of the 2007 IEEE Sensors Applications Symposium, San-Diego, USA, February 2007.
9. Târnovan, I.G., Ţebrean, B., Crişan, T.E. – *Shock Transducer with Hall Sensing Element* – 15th IMEKO TC4 Symposium on Novelties in Electrical Measurement and Instrumentation, Iaşi, Romania, September 2007.
10. Târnovan, I.G. – *Metrologie electrică şi instrumentaţie* – Editura Mediamira, Cluj-Napoca 2003.
11. Ţebrean, B. – Consideraţii privind măsurarea şocurilor cu traductoare Hall – lucrare de disertaţie, Cluj-Napoca 2006.
12. Ţebrean, B. – Cercetări experimentale privind utilizarea traductoarelor Hall în măsurarea şocurilor mecanice – raport de cercetare, Cluj-Napoca 2007.
13. Zemansky, M.W. – *Fizică.* Editura Didactică şi Pedagogică Bucureşti, 1983.

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