Shock Transducer with Hall Sensing Element

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Abstract - The aim of this paper is to show a determination method for mechanical shocks, using as sensing element an analogical Hall effect transducer. In the first part of the paper there will be enunciated the used physical principle, mentioning the conservation laws of mechanical energy and in following part we will describe the experimental setups and the behavior of the implemented captors. We will also analyze the factors that can generate errors or they can disturb the measurement process. There will be presented the sensors as well as a implementation method of the sensor in complex integrated parts which contain the signal processing circuits and the sensing element. We can consider this transducers not a replacement to the present methods (piezoresistive, tensometric, optical, etc), but a viable alternative which is easy to implement.

I. Theoretical Approach

The measurement of the aperiodical vibration or of the mechanical shocks is made in present technical applications with the help of the piezoresistive, tensometric, optical transducers.

The analogical Hall effect transducers, used in different mechanical configurations, can help us to distinguish a vast area of shocks and vibrations parameters.

It is very well know the fact that when a probe, which is in free fall condition, meets on it's trajectory an obstacle, for example a cantilever beam, an energetic transfer will be made between this two parts of the system.

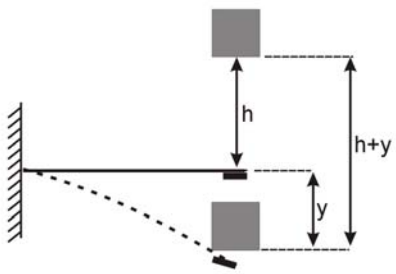

Figure 1. The transformation of the gravitational potential energy in elastic potential energy

Practicaly, the potential energy stored, during the time of the displacement, will be transferred to the beam according with following formula:

$$mg(h+y) = \frac{1}{2} \cdot k \cdot y^2 \qquad (1)$$

- where: - m – the probe's mass [Kg]
  - h – the throwing height [m]
  - y – the displacement of the beam [m]
  - k – the elastic constant [N/m]
  - g – the gravitational acceleration [m/s^2]

We have considered for the beam's potential energy calculation the behavior of a classic elastic spring due to the fact that the relative displacement is small and the load is end concentrated type.

According with the physical phenomena mentioned previously and considering that over the action of the weight G there aren't any effects or another exterior force, we can calculate the weight, respectively the mass of the probe with is in free fall condition, knowing the value of the elastic constant *k*, of the the throwing height *h* and of the the displacement of the beam *h* (which is measured with the aid of the Hall effect transducer).

$$G = \frac{k \cdot y^2}{2 \cdot (h+y)} \qquad (2) \qquad\qquad m = \frac{k \cdot y^2}{2 \cdot g \cdot (h+y)} \qquad (3)$$

II.Experimental Setup

Starting from the theoretical principle presented previously, were designed a few shock detectors which used the analogical Hall effect transducer.

In figure 2 and 3 are presented two detectores which are based on a sistem made from a cantilever beam with a permanent magnet and a analogical Hall effect transducer.

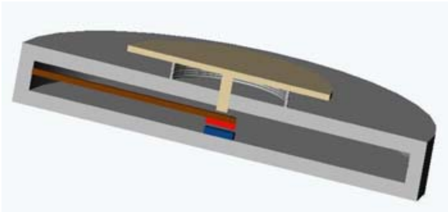

Figure 2. Shock detector using the principle of simple cantilevered beam

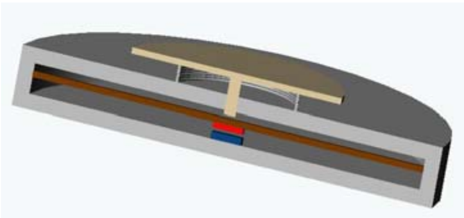

Figure 3. Shock detector using the principle of duble cantilevered beam

As shown in figures above, the devices consists of:

- detecting element
- spring
- elastic beam
- permanent magnet
- Hall effect transducer
- the detector's capsule.

Knowing the theoretical principle presented on the course of this paper, but considering the experimental resuts from the built sensors, we want to design a mechanical shock detector on a very small scale.

The experimental setup is shown in figure below:

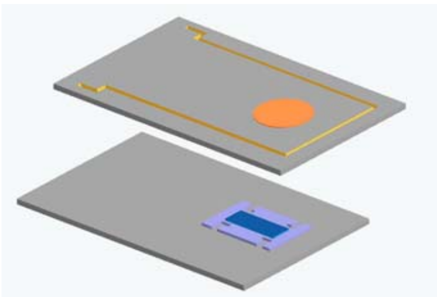

Figure 4. The main parts of the shock detector

As shown in figure 4, the detector had two distinct parts:

- mobile assembly,
- fix assembly.

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 to confer good measurement process repeatability.

The material used in the mobile assembly must be:

- *non-conducting* - to avoid the errors that can intervene because of the electric contacts between various components of the system,

- *non-magnetic* – to avoid the influence over the electric response of the transducer placed on the fixed assembly.

When implementing the mobile assembly, and taking into account the needed dimensions of the elements found in the sensing device, it is necessary to apply the imposed conditions used in the captors having elastic cantilever beams.

The most important part of the mobile assembly is the excitation coil, this having the role of generating the magnetic field required for the correct function of the sensing element, i.e. the Hall transducers.

The excitation coil characteristics are important because the different configurations can modify the response of the transducer to mechanical shocks generated by similar forces. For the present case, due to practical reasons, we have chosen a special coil, in a planar configuration, the coil being apart of the mobile element.

The design of this captor has preferred the coil solution to the similar one with permanent magnet. The reason of this choice was the inappropriate/unknown behavior of ultra thin permanent magnet. The constructive solution using a regular permanent magnet (the smallest we found being 2x2x2 mm) was disregarded because it still is too large for our configuration.

The fix assembly has to be made from the same materials as the mobile one, non-conducting and non-magnetic, but this time it is important that the transducer's support to include materials that can absorb the parasite external vibration.

The main part of the detector is the analogical Hall effect transducer. It can be made in different methods, either due the classical method of impurifying, if the transducer's support it is made from a semiconductor material, or in thin film technology, if the transducer will be attached after the building process. This approaching allows us to integrate, on the same chip or on the same film with the transducer, the signal processing circuits.

The transducer must be placed in such manner that the interaction with the magnetic field, given by the excitation coil, to generate a Hall voltage which must be: measurable, repetitive and with a characteristic easy to process.

In figure 5 we have a section view of the detector:

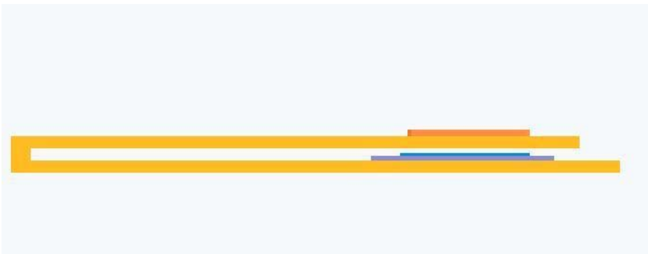

Figure 5. Section view of the detector

As shown in the figure above, the sensing element and the coil must be mechanically separated in order to insure an adequate distance needed for a proper operation. This distance is chosen as a function of the elasticity modulus of the mobile element and of the measuring range. The limit case which must be avoided at all costs is the situation when, due to a high impact force, the mobile element touches the sensing element causing irreversible modifications.

In order to determine the accuracy of the detector a series of measurements were performed using the experimental setup shown in figure 6. This experimental setup consists of :

1. the shock detector
2. graded beam
3. transducer support

The experimental procedure is : two probes of 4 and 6 g respectively are thrown from a well known height. Considering the elastic element constant as k=3920 N/m and the transducer function $y=f(U_{Hall})$, by the means of equation (3) we compute the mass of the each element for a series on 50 measurements for each element.

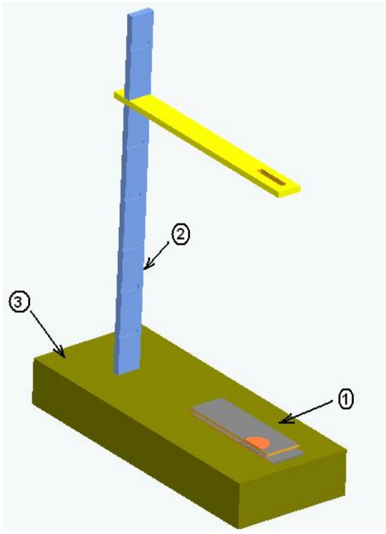

Figure 6. The experimental stand

The obtained values and the absolute error are presented in the following tables for each element respectively. The absolute error was computed using :

$$\varepsilon_i = x_i - x \quad (4)$$

Where $i=1...50$ is the measurement count.

i	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
x_i	4	4.2	4	4	3.9	4	3.95	4	4	4	3.8	4	4	4	4.2
ε_i	0	0.2	0	0	0.1	0	0.05	0	0	0	0.2	0	0	0	0.2
i	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
x_i	4	4	3.8	4	4	3.95	4	4	3.9	4	3.95	4	4.1	4	4
ε_i	0	0	0.2	0	0	0.05	0	0	0.1	0	0.05	0	0.1	0	0
i	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
x_i	3.7	4	4	3.9	4	4	4	3.95	4	4.1	4	4	4	4	4
ε_i	0.3	0	0	0.1	0	0	0	0.05	0	0.1	0	0	0	0	0
i	46	47	48	49	50										
x_i	4.2	4	4	3.9	3.95										
ε_i	0.2	0	0	0.1	0.05										

Table 1 : Values for the 4g element

i	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
x_i	6	6	6	5.8	6	6	6.2	6	5.95	6	6	6.1	6	6	5.9
ε_i	0	0	0	0.2	0	0	0.2	0	0.05	0	0	0.1	0	0	0.1
i	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
x_i	6	6.1	6	5.95	6	6	5.7	6	6	6	5.9	6	6.2	6	6
ε_i	0	0.1	0	0.05	0	0	0.3	0	0	0	0.1	0	0.2	0	0
i	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
x_i	5.9	6	6.1	6	6	6	6	5.8	5.95	6	6	6.2	6	6	6
ε_i	0.1	0	0.1	0	0	0	0	0.2	0.05	0	0	0.2	0	0	0
i	46	47	48	49	50										
x_i	5.95	6	6.2	5.95	6										
ε_i	0.05	0	0.2	0.05	0										

Table 2 : Values for the 6g element

The expected value *M[x]* is computed using equation (5), and the dispersion σ^2 with equation (6):

$$M[x] = \frac{1}{n}\sum_{i=1}^{n} x_i \qquad (5)$$

$$\sigma^2 = \frac{1}{n-1}[\sum_{i=1}^{n} x_i^2 - \frac{1}{n}(\sum_{i=1}^{n} x_i)^2] \qquad (6)$$

The r.m.s. deviation is given by:

$$\sigma = \sqrt{\sigma^2} \qquad (7)$$

X	4g element	6g element
M[x]	3.988	5.997
σ^2	$7.39 \cdot 10^{-3}$	$8.21 \cdot 10^{-3}$
σ	$8.53 \cdot 10^{-2}$	$9.05 \cdot 10^{-2}$

Table 3 *M[x]*, σ^2 and σ for both elements

In order to asses the repartition law of our results we have chosen to determine and plot the empiric repartition function. In order to do this we first determined the grouping interval d according to the *Sturges* law:

$$d = \frac{x_{\max} - x_{\min}}{1 + 3.322\lg(n)} \qquad (8)$$

The obtained values is d = 0.07143 for both elements for 7 grouping intervals.

The interval limits as well as the occurrence absolute frequencies (OAF) and the occurrence relative frequencies (ORF) for each element respectively are given in Table 4 and 5.

Grouping intervals			n_i - OAF	f_i - ORF	Σf_i
1	3.70000	3.77143	1	0.02	0.02
2	3.77143	3.84286	2	0.04	0.06
3	3.84286	3.91429	4	0.08	0.14
4	3.91429	3.98572	5	0.1	0.24
5	3.98572	4.05715	33	0.66	0.9
6	4.05715	4.12858	2	0.04	0.94
7	4.12858	4.20001	3	0.06	1

Table 4 : Values computed for the 4g element

Grouping intervals			n_i - OAF	f_i - ORF	Σf_i
1	5.70000	5.77143	1	0.02	0.02
2	5.77143	5.84286	2	0.04	0.06
3	5.84286	5.91429	3	0.06	0.12
4	5.91429	5.98572	5	0.1	0.22
5	5.98572	6.05715	32	0.64	0.86
6	6.05715	6.12858	3	0.06	0.92
7	6.12858	6.20001	4	0.08	1

Table 5 : Values computed for the 6g element

Using these data we can now plot, for both elements, the repartition empiric function (figures 7 and 8).

These functions allow us to anticipate a normal repartition law for our measurement data. Also the data as presented above offer a sufficient view of the accuracy of the measuring system allowing us to pass to the next stage of implementation.

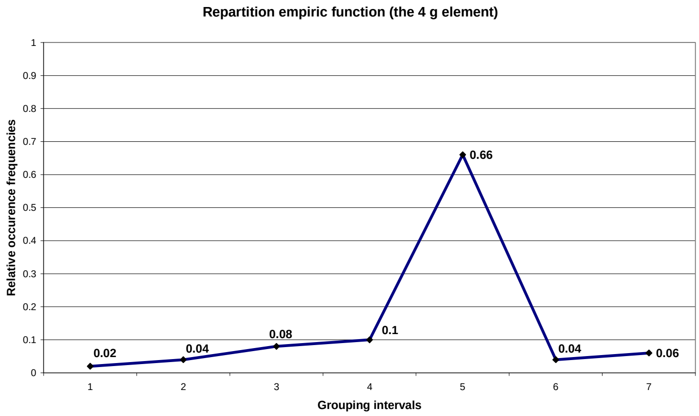

Figure 7 Repartition empiric function for the 4 g element measurements

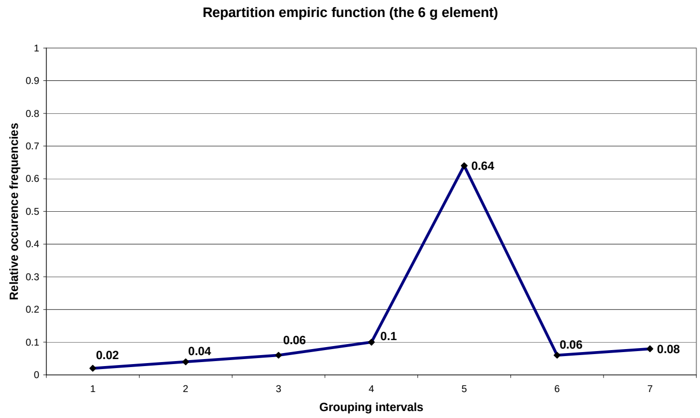

Figure 8 : Repartition empiric function for the 6 g element measurements

III. Conclusion

This approach is a first step toward the on chip implementation of this method. We can consider this transducers not as a replacement to the present methods (piezoresistive, tensometric, optical, etc), but a viable alternative which is easy to implement in MEMS technology.

However this is not the only structure witch can be used, the mechanical configuration can be changed in order to match specific requirements.

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