

Energy harvester based on Terfenol-D for low power devices

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Abstract: *Rising requirements for a new constructions, force engineers to monitor them all day long. An attractive solution seems to be applications of wireless sensors. However, there is a barrier limiting their application, which is the need to supply them with an electrical power over extended period of time without using additional wiring or batteries. The potential solution of this problem seems to be an energy harvesting. This paper proposes a new energy harvesting device based on magnetostrictive material. In the course of the experiments with using Terfenol-D rods as actuators and sensors it has been shown, that the mechanical impact to the magnetic core based on Terfenol-D rod, NdFeB permanent magnets and coil set allowed to obtain an electric power signal enough to supply device of 100 Ohm load on their active state.*

Keywords: *: harvesting energy, low power microcontrollers, smart material*

1. Introduction

Problems with energy sources relate mainly to the large-scale applications which need a large amounts of electricity. However, it should be noted, that in the past few years there has been very rapid development of technology, which resulted in a significant reduction in the size of devices. In a world of universal miniaturization, it appears that the supply of electricity by wire is often not feasible and, increasingly, designers are faced with the problem of how to ensure and deliver that energy. In such cases, as a source of electrical current usually batteries are use. Unfortunately it turns out they are not sufficient as a good source of energy.

The primary disadvantage is that each battery has a specified number of hours it can work through. After this time, it must be replaced or recharged. In many cases it is impossible to achieve this because of the location of devices, which are often located inside the structure (construction), not allowing access to them from the outside without prejudice. An additional reason for seeking new energy sources is the fact that batteries have a large size compared to devices that uses them.

Currently conducting a series of studies aimed at finding new ways to provide electricity to the system. Among the new techniques of energy recovery - called energy harvesting (also known as power harvesting or energy scavenging) can be distinguished, such as use, heat, kinetic energy, or materials from the SMART Group. The first well-known group of active materials are piezoelectric materials (PZT). These materials are widely used in sensors, due to their characteristics, allowing them to transform the strain caused by a mechanical to an electrical signal. The second group of SMART materials, on which this work is concerned are magnetostrictive materials [1]. The researchers focus on this group, due to the fact, that in comparison with the piezoelectric materials, magnetostrictive materials have several advantages: high coefficient of magneto-mechanical coupling, high elasticity for magnetostrictive alloys, no ageing process, relatively high Curie temperature [2]. Using these materials, in a similar way, as is the case for piezoelectric materials, is possible by using Villari effect (also called reverse magnetostriction). That effect involves changing the intensity of the magnetic field (or magnetization) under the influence of mechanical forces applied to the material that introduce elastic strains. Change in magnetization in the material produces the electromotive force, which is converted by the coil into electricity. Different approaches to these materials can be seen among the previous work. The studies used both alloys that are made of magnetostrictive material in the form of flat strips [2] subjected to cyclic vibration, as well as composites consisting of piezoelectric material and magnetostrictive[3], as well as bulk magnetostrictive materials [4,5].

2. The aim of work

In the course of the work on the Smart Magnetics Materials (SMM), magnetomechanical properties of

Terfenol-D alloy ($Td_{0.3}Fe_{0.7}Dy_{1.9}$) was analyzed (magnetostriction, Villari effect). It was found, that these materials potentially might be used for so-called harvesting devices. Such devices are able to convert mechanical energy (with use of mechanical resonance) into electricity. The desired effect was obtained when the Terfenol-D rod was magnetically coupled with a strong permanent neodymium magnet NdFeB. One of the branches of the work has provided surprising results in terms of behavior Terfenol-D under the influence of a mechanical stroke. It turned out that a strong mechanical signal (hammer blow to the bar) and simple magnetic circuit (coil and magnet) has allowed the generation of current to supply a LED. This effect does not appear on such a scale in case of use rods made of other materials such as ferromagnetic low carbon steel. In comparison the resulting effect was 50 times smaller than the Terfenol-D rod. In the course of research and experiments the authors decided to create an alternative power source based on the observed phenomenon. The aim was to harvest energy from impact and generate electricity of about 1 mA at 3 V source generator. The search for methods to build Energy Harvesting Device (EHD) can be regarded as a key problem in search to power wireless measurement nodes. The main problem is that the work will have to meet the following criteria:

- current value of 1000 μA is needed to supply sensors, and embedded processor fitted with the converter to the sensor, as well as a communication unit,
- provide a level of voltage 3V during the activity,
- conversion and conditioning voltage/current from generator.

General diagram of circuit generation and signal conditioning is shown in Figure 1. It can be distinguished two parts: mechanical and physical in which, depending on the configuration is to produce an electric signal, and where the signal is processed further and possibly used.

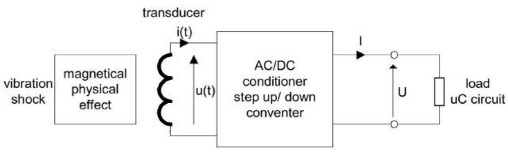


Fig. 1. Conception of energy harvesting node divided to three main modules: generation of energy, energy transmission, and energy supply

Novel pulsed-power supply contained a primary power source based on the fundamental physical effect of shockwave demagnetization of $Nd_2Fe_{14}B$ high-energy ferromagnet, which is magnetically coupled with other magnetic material, or mechanically coupled when the second material is nonmagnetic. This technology is new FMG (Ferro-Magnetic Generator) group based power supply, especially for harvesting [6,7,8].

3. Construction of Energy Harvesting Device (EHD)

The basic model of EHD, which the authors have used is the system of NdFeB permanent magnet, coil, core, and shock transferring component. Schema illustrated in Figure 2a. Because of the arrangement and configuration of the core and coils and permanent magnet the whole construction is called TCCM (Top Core Coil Magnet). The most important element of this system is the core that determines the amount of processing of the impact energy into electricity. One of parts of research concern on test the various types of materials used for cores, including the Terfenol-D or other ferromagnetic materials e.g. Terfenol-D powder, brass and steel. Figure 2b shows an example of the impulse response of force as it appears in the TCCM device. During the first phase, just before the strike, it is possible to observe a change in a voltage value, which is a result obtained from movement of ferromagnetic hammer in the magnetic field of neodymium magnets. Upon striking the resulting wave motion passing through the top pin and core to the neodymium magnet produces a strong change in magnetic flux system, which a induces voltage resulting from the resonance frequency of the mechanical harvester TCCM. The Resonant frequency depends only on selecting the material of the top pin and core.

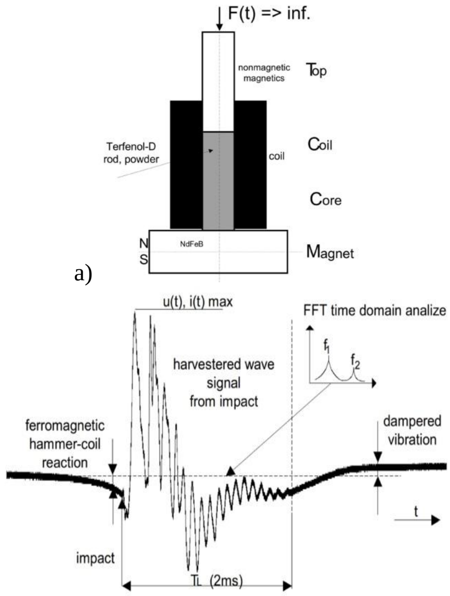


Fig. 2. a) scheme of harvester TCCM, b) examples of waveforms for Terfenol-D rod

In order to obtain qualitative and quantitative description of the phenomenon of generation of signal voltage and current in EHD type TCCM a special test stand was built. It has allowed comparison of the results obtained depending on the different types of cores. In Figure 3 the diagram shows the scheme of the test shock for TCCM harvesting device.

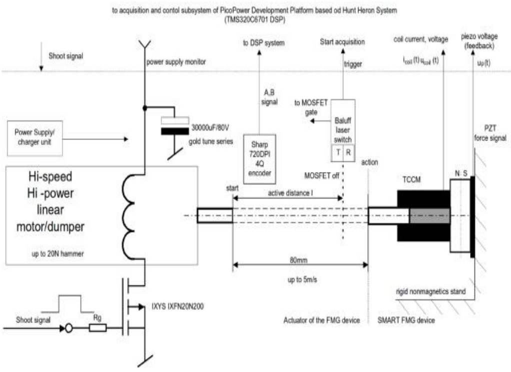
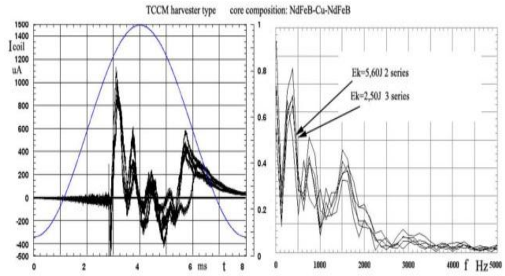


Fig. 3. Test stand for TCCM harvesting device

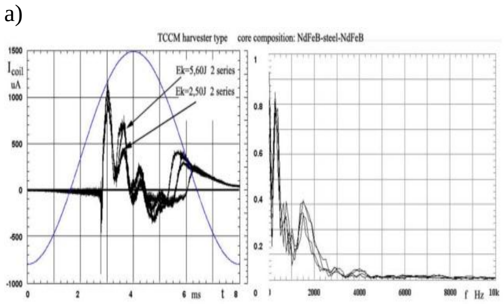
The harvesting device was attached in a horizontal orientation to the stiff surface. At this point it is worth to mention, that between this stiff surface and the TCCM device, the PZT force sensor was placed. The second important part of the test stand was an aluminum battering ram, which was placed in the main axis of the harvesting device. The starting position of the battering ram was 80mm away from the TCCM harvesting device.The ram was accelerated to the given speed with a use of linear motor (MOSFET) from IXYS company. Energy of the impact was controlled with a use of aluminum elements with different weights, which were fastened to the linear motor moving element. Taking into account a size of the harvester device it was decided to use battering ram with mass of 0.5kg. This allowed to obtain high reproducibility of battering ram speed, which consequently resulted in the stability of the impact energy E_k. The whole measurements were made on the basis of its own, dedicated measuring system.

4. Results

Selection of impact power was dictated by the strength of bulk Terfenol-D cores, above 6J energy for the core 5 mm in diameter and 10 mm in length meant that the core could crush during the tests. To be meaningful, all measurements were performed for two values of energy 2,5 J and 5,6 J. An alternative to solid Terfenol-D is its powder. In this form Terfenol-D is capable of withstanding impact of higher energy and less precise task, where the only limitation is the performance and durability of the body coil windings. The Study was successively completed for different types of cores and the results are showed respectively in the Figures. In the case of a core of brass (Figure 4a), there was no difference in amplitude of signals, even for different levels of hit energy of 2,5 J – 5,6 J. The steel core(Figure 4b) was more sensitive to the change of hit energy than the brass, however, it did not significant increase of the current signal. Rods based on Terfenol-D powder (Figure 4c) showed the greatest difference in the signal due to the applied energy. It is worth to mention that the core made of Terfenol-D was prepared by pressing powder between neodymium magnets inside a coil. The differences are even between hits with the same energy, therefore, presents the results only for one energy E_k = 5,6 J. Proved to be the most efficient Terfenol-D cores however, due to their fragility caused problems on the experimental.



a)



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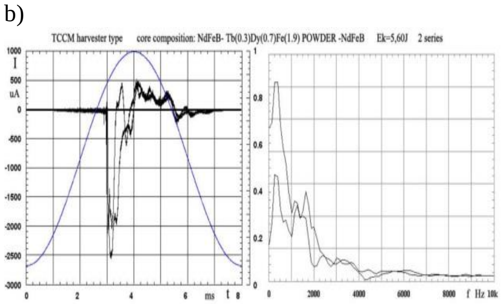

c)

Fig. 4. Current coil measurement for different rods: a)brass, b)low carbon stell, c)Terfenol-D powder

As a practical application the use of the harvester TCCM was chosen to supply based on the primary node ATMEL microcontroller. The system used ATMEGA48V [9] which could already be assigned to the voltage level of 1,8 V. This is the most common type of low power processors now used on an industrial scale. The microprocessor was powered by a DC to 1,8 V – 5,5 V, as a system transducer AC/DC on the rectifier used Schottky diodes. The signal acquisition and control of test parameters of harvesting device, the rectifier AC/DC, a microprocessor and a base station provides the dedicated system named PicoPower Platform, based on a system's Heron Hunt Engineering UK.

Figure 5 presents current consumption by the system capacitors-uC recorded as a reduction in voltage on measuring resistor R_{sense} = 4,7 Ohm.

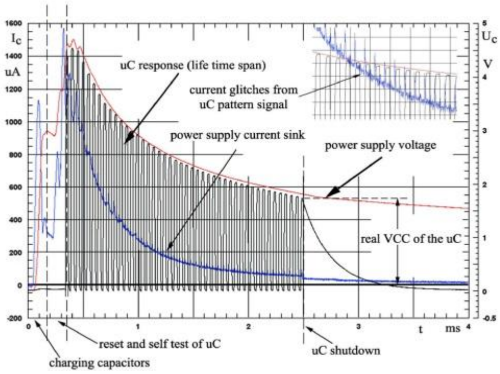

Fig. 5. Life span of microcontroller ATMEGA48V circuit powered from TCCM harvesting device induced at low impact energy 0,25J

In the first phase there is a very strong increase in current due to the initial charge on capacitors C1 and C2, which are very heavy loading on the signal generated by the harvesting device, followed by a decline in current consumption, given that it has not yet started uC. The voltage at this point is the value of U_c = 3 V and initializes a uC that performs a reset and proceeds to executes the code. Given that the peak of the pulse occurs from the harvesting device and recharges the capacitors to around 5 V. The algorithm code in uC is such that if there is a maximum voltage power cables to generate uC sequence of signals counted by the base station and then sent through the RS232 module HEGD3. The "life time" algorithm of the program from U_{max} = 5V to U_{min} = 1,8V microprocessor is able to send about 50 pulses, which translates into a value of about 3 ms life uC. By selecting the various sources of mechanical extortion obtained values up to 200 pulses, ie the life time of 8 ms uC. Therefore an EHD was developed, which is able to supply a popular microcontroller, which realizes its code throughout the life of 3 ms uC for small energy of impact E_k = 0,25 J with core made from Terfenol-D powder.

5. Conclusions

In the course of this work a prototype version of the device harvesting an impact energy was built. The system based on a commercially available magnetostrictive material which was Terfenol-D.

What is more, the importance of the type of material used to test was examined. The results shown that the high values of voltage and current that are possible to generate only by the Terfenol-D material.

Based on the proposed prototype EHD a special system to control microcontroller was made. At the time of supplying the EHD node has a possibility to control the action and send the correct signal to start.

It was shown that developed harvester, was able to supply a popular microcontroller, which realizes its code throughout the life of 3 ms for the small energy of impact E_k = 0,25 J from the core based on Terfnol-D.

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