Dariusz JASIULEK
KOMAG Institute of Mining Technology,
Pszczynska 37, 44-180 Gliwice
djasiulek@komag.eu

THE USE OF LOST ENERGY FOR SUPPLYING THE DISPERSED NETWORKS OF SENSORS

Key words

Coal mining, energy harvesting, piezoelectric energy harvester, self-powered sensor.

Abstract

The possible use of self-supplying sensors, which use energy, lost during physical phenomena, for monitoring the selected parameters of mining machines operating in areas threatened by methane and/or coal dust explosion hazard, is presented. Self-supplying sensors are more and more often used in intelligent control systems. They use in their supply systems phenomena such as heat flow, the energy of vibrations, or light. The analysis showed that this technology could be used in automatics and diagnostics systems of mining machines and equipment.

Introduction

The results of projects associated with development of wireless, self-supplying sensor networks for operation in areas threatened by methane and/or coal dust explosion hazard are given. Analysis of possible sources of energy to be used in building the networks of sensors, as well as the methods for energy conversion and tests on a piezoelectric energy harvester are presented in the article.

The use of the systems for monitoring the operational parameters of the machines in areas threatened by methane and/or coal dust explosion hazard is regulated by the 94/9/EC (ATEX) Directive, which puts limitations on the designer. Directive 94/4/EC (ATEX) is a obligatory legal act for the entire European Union. General requirements concerning the design of electric devices used in areas threatened by explosion hazard are included in the PN EN 60079 0:2009 Standard harmonized with the ATEX Directive. Requirements of the regulations limit the possibilities of the modification of existing control and monitoring systems.

This especially concerns the following cases:

- Extensive technical systems in mine roadways – e.g. belt conveyors of length up to a few kilometres for transportation of run-of-mine;
- Changes in the equipment configuration of the machines and devices in mining areas, resulting from the advance of the mining front;
- The accumulation of heavy machines in a small area and the necessity of removing heat; and,
- The automation of technological processes in mining the minerals to limit the number of people working in threatened areas.

Bearing in mind the needs of the mining market [1, 11], work aiming at the development of wireless networks of self-supplying sensors in the machines operating in areas threatened by methane and/or coal dust explosion hazard was undertaken. There are on the market systems of dispersed pressure sensors, which organize communication with use of wireless networks, supplied from batteries [11], which generates a problem associated with the duration of sensor operation and the frequency of measuring data transfer.

When building the self-organizing network of wireless sensors [4], it is necessary to determine an alternative method to supply its components, based on lost energy during physical phenomena in the surrounding environment, e.g. energy of mechanical vibrations [12, 13, 14], thermal energy [3], energy of rotary movement or energy of electromagnetic radiation [18].

1. Methods for conversion of energy

There are the following popular methods for energy conversion, which can be applied undergrounds in mining operations:

The electromagnetic method, which uses Faraday's law saying that electromotive force, is induced in a conductor placed in an alternating magnetic field. The alternating magnetic field is most often generated by moving magnets, and systems of coils play the role of conductor. [9, 17, 18].

The piezoelectric method uses the phenomenon consisting in generation of electric charges on the surface of piezoelectric material under mechanical stresses. A piezoelectric component is placed in a device in a way ensuring maximal use of energy of mechanical phenomena, which occur in the device [6, 7, 8, 16, 18].

The electrostatic method includes conversion of kinetic energy of vibrations into electric energy with use of variable capacitor, which is polarized by operation of electrets (a dielectric material that has a quasi-permanent electric charge or dipole polarisation). Electret generates an external electric field and is the electrostatic equivalent of a permanent magnet [9, 18].

The magnetostriction method is based on the phenomenon of ferromagnetic materials deformations in magnetic fields. The Villari effect is the inverse effect. The change of dimensions under a magnetic field can have a linear or volumetric character [9].

The thermoelectric method is based on recuperation of thermal energy [3, 5]. To convert, e.g., thermal energy to electricity, thermogenerators are used. These devices produce electricity as a result of temperature difference and the stream of thermal energy. There are two main types of thermogenerators; those based on the Seebeck effect (Peltier Cells) and those using the phenomenon occurring in Stirling engines. Peltier Cells are based on Seebeck thermoelectric phenomenon (Seebeck effect), which consists in the generation of electromotor force (also called *thermoelectric force*) in a circuit consisting of two different materials, contacts of which have different temperatures [3]. It is the result of the relationship between the contact potential difference between materials and the temperature. Contact potential is generated as a result of diffusion through the contact surface of electrons from one material to another [3, 18].

2. Sources of energy available in underground

Considering the specific character of the processes realized in hard coal mines, the sources of energy, which can be used to supply components of self-supplying, wireless network of sensors, were identified. Sources of energy available underground in mining operations are as follows [2, 14]:

Sources of mechanical energy:

- The vibrations of machines,
- Rotary movement,
- Braking energy, and,
- Human motion,

The sources of thermal energy:

- The heat from machines and equipment (lost energy),
- The heat from the human body, and
- The heat from rock mass.

The sources of energy coming from electromagnetic radiation:
- Electric motors, transformers, and
- Power cables.

The sources of energy coming from the air flow:
- The flow of air in vetube fans, and
- The flow of air ventilating the mine workings.

3. Energy of mechanical vibrations – Piezoelectric Energy Harvester

Machines operating in underground workings generate vibrations from rotating components, toothed gears of electric motors, etc., as a result of mining processes and transportation of run-of-mine.

It is possible to use the energy of vibrations to supply the sensors measuring the following parameters:
- The temperature at any place and the change of sensor's position during the machine exploitation,
- The pressure of medium in a hydraulic system,
- Vibrations (vibrodiagnostics),
- The tension of flight-bar conveyor's chain, and
- The illuminance of mine railways (suspended monorails and floor-mounted railways).

Piezoelectric components (piezoelectric transducers, Piezoelectric Energy Harvester) and electromagnetic generators are most often used components, which convert the energy of mechanical vibrations into electricity. These components have to be tuned to the machine's vibrations, or automatic tuning has to be applied.

Available piezoelectric components most often are adapted to operation within the range 40–250 Hz. The amplitude of vibrations also affects the generated power. After the initial laboratory test [2], the Piezoelectric Energy Harvester MIDE V-21BL-ND (Fig 1) was selected for further tests associated with use of piezoelectric components in the process of supplying the sensors [10].

V21BL-ND transducer has a narrow range of resonance frequency, and it is tuned by adding a weight at its end. Voltage generated by the transducer changes, depending on operational frequency and transducer articulation. The relationship between power and voltage at an operational frequency 40 Hz is presented in Fig. 1. The weights that should be used to load the transducer as well as amplitude of articulation, at which a specified output voltage can be reached, are defined in the catalogue card of the transducer.

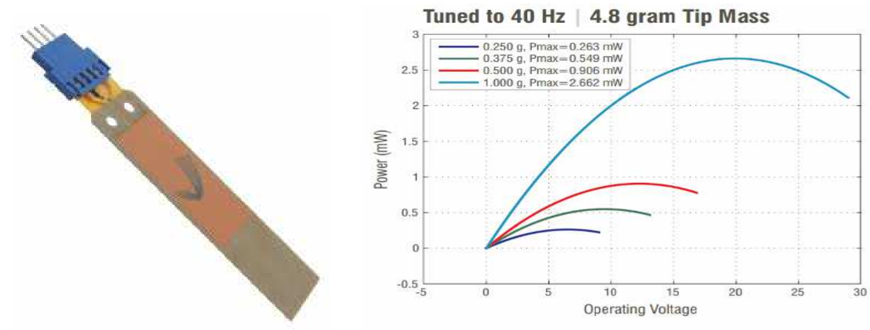

Fig. 1. V21BL-ND piezoelectric transducer and its operational characteristics at 40Hz [10]

Piezoelectric Energy Harvester MIDE V-21BL-ND tests were carried out using a diesel engine (Volvo Penta D5AT, which is the engine used in mining machines). The engine was installed on the test bench in order to set torque. During tests, the voltage generated by the Piezoelectric Energy Harvester MIDE V-21BL-ND, the operating parameters of the inverter (input UIN and output UOUT voltage), and vibration measurements were recorded. Figure 2 shows an electronic system of the test rig. A LTC3588 converter was used as the basic element of the electronic system. The following parameters recorded by the oscilloscope are indicated in the following diagram:

- U_{IN} – input voltage, generated by the Piezoelectric Energy Harvester MIDE V-21BL-ND,
- U_{OUT} – output voltage, to supply the sensor (simulated load),
- U_{PGOOD} – system status, the high value of this parameter indicates that the "unit" (the sensor) is supplied by energy of vibrations. The theoretical considerations assume that, for the proper operation of the sensor, the power-on time must be at least 100 ms, which is the time necessary to take measurement and to send a signal by radio.

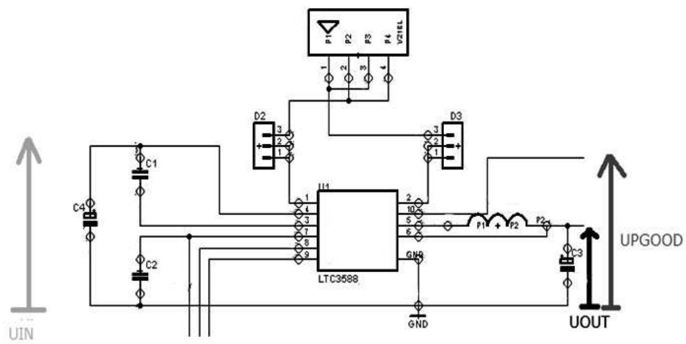

Fig. 2. Diagram of the measurement system [12]

Verification of the results of laboratory tests in real conditions was the work objective. These tests allowed us to determine how the electronic system works under changing operational conditions. It was decided to use the additional mass of the 2 g installed at the end of the Piezoelectric Energy Harvester. According to the data sheet, the oscillation frequency is tuned to 60 Hz. In the study, nine series of measurements were taken at various engine speeds (in the range of 820 to 1796 r.p.m.). In the test, the elements are installed in a horizontal position (Fig. 3) with a magnetic holder.

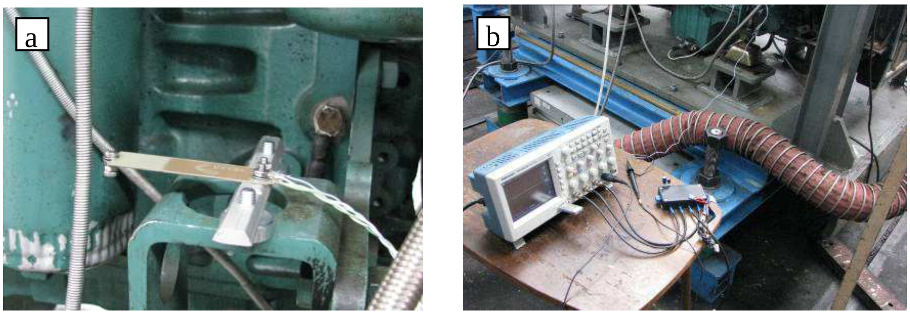

Fig. 3. a) Piezoelectric Energy Harvester MIDE V-21BL-ND installed on Volvo Penta D5AT, b) test rig [12]

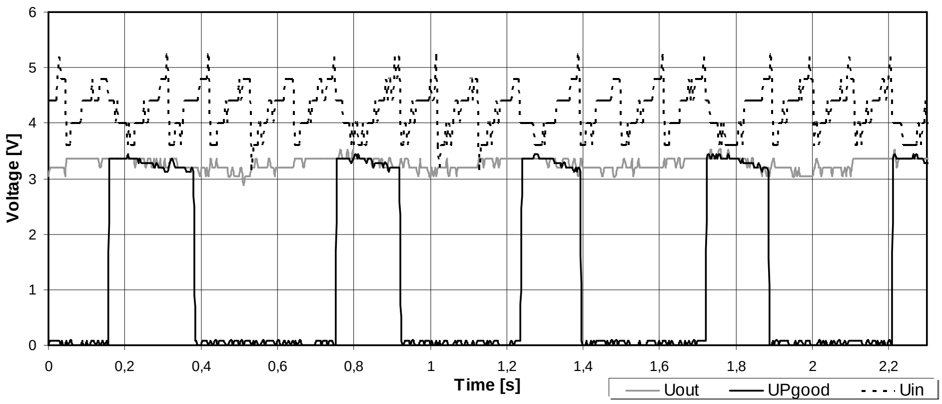

Fig. 4. An example of the time process of voltage signals recorded during the test [12]

Then the analysis of signals recorded during tests was made to verify how the electronic system responsible for the management of generated energy works under the simulated load (Fig. 2).

The demand for energy of the temperature sensor was calculated. It was found that the sensor has to operate minimum for 100 ms (UPGOOD signal) to take the correct measurement and to send the information by radio signals. The sensor was simulated by adding the load resistance R = 10 kΩ to the electronic system. The voltage of simulated receiver is equal to 3.3 V and the current is 0.33 mA.

The sample time process of the signals recorded during the measurements are given in Fig. 4. The UPGOOD signal was at high level for 152 ms in intervals of about 320 ms.

Summary

More and more solutions appear on the "energy harvesting" devices market, which is a sign that this relatively new branch is under development. This is possible mainly due to the commercialization of low-energy electronic systems. In the case of underground mining in the areas threatened by methane and/or coal dust explosion hazard, it is impossible to use common solutions.

The possibility of using the energy lost in physical phenomena to supply the components of network self-supplying sensors is presented. It was proven that the utilization of the energy of mechanical vibrations and energy of rotary movement is possible.

The laboratory tests of the piezoelectric energy harvester were made with a diesel engine used to drive mining machinery. The results of the study allowed selecting the Piezoelectric Energy Harvester MIDE V-21BL-ND to conduct further research work on self-powered sensor networks. The results showed that it is possible to supply the electronic system with a microcontroller and a radio system by the piezoelectric energy harvester.

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Wykorzystanie energii odpadowej do zasilania rozproszonych sieci czujników

Słowa kluczowe

Górnictwo, energy harvesting, przetwornik piezoelektryczny, czujniki samozasilające.

Streszczenie

W artykule zaprezentowano możliwości wykorzystania czujników samozasilających, które wykorzystują energię traconą w trakcie zjawisk fizycznych, do monitorowania wybranych parametrów maszyn górniczych działających w obszarach zagrożonych wybuchem metanu i/lub pyłu węglowego. Czujniki samozasilające są coraz częściej stosowane w inteligentnych systemach sterowania, wykorzystują do zasilania takie zjawiska jak przepływ ciepła, energię drgań lub światło. Przeprowadzona analiza wykazała, że taka technologia może być stosowana w układach automatyki i diagnostyki maszyn i urządzeń górniczych.