Assessment of the suitability of piezoelectric generators in copper ore mines

Zbigniew Maksymczyk

KGHM CUPRUM sp. z o.o. – Centrum Badawczo-Rozwojowe, Wrocław,
e-mail: zmaksymczyk@cuprum.wroc.pl

Abstract
This paper discusses the benefits and disadvantages of using piezoelectric generators in copper ore mines. Two piezoelectric generator models were tested at a measuring station specially designed for this purpose. The advantages of such generators are discussed, mainly: benefits arising from the capability of generator operation without the need to install an electrical system (energy source at any location in a mine where equipment generating mechanical vibrations is installed) and ecological benefits arising from application of renewable energy sources (RES). However, a flaw of piezoelectric generators is that they can generate only a small amount of energy, which only makes it possible to supply power to certain signs, conveyors, lamps or other (low-power) equipment.

Keywords: piezoelectric generators, RES, tests

Ocena przydatności generatorów piezoelektrycznych w kopalniach rud miedzi

Streszczenie
W artykule omówiono korzyści i niedogodności wynikające z zastosowania generatorów piezoelektrycznych w kopalniach rud miedzi. Przebadano dwa modele generatorów piezoelektrycznych na specjalnie zaprojektowanym do tego celu stanowisku pomiarowym. Omówiono zalety generatorów, do których należą: korzyści wynikające z możliwości pracy generatorów bez konieczności montowania instalacji elektrycznej (źródło energii w każdym miejscu kopalni, w którym są zamontowane urządzenia generujące drgania mechaniczne) oraz korzyści ekologiczne wynikające z zastosowania odnawialnych źródeł energii (OZE). Natomiast wadą generatorów piezoelektrycznych jest to, że mogą one wyprodukować niewielką ilość energii, co daje możliwość zasilania tylko niektórych, wybranych transparentów, przenośników, czy lamp, bądź też innych niskomocowych urządzeń.

Słowa kluczowe: generatory piezoelektryczne, OZE, badania
Introduction

Significant emphasis has been placed on development of Renewable Energy Source (RES) in Poland and around the world in recent years. Piezoelectric micro-generators are a modern way to obtain green energy by taking advantage of dynamic interactions (e.g. dynamic, time-variable pressure) of autonomous mining machinery, vibrations generated by belt conveyors or vibrations generated by the drives of mine fans and hoisting machines to generate electricity [1]. Micro-generators of this type could power lighting of signs, belt conveyors, or lamps at locations where it is difficult to supply power over cables.

1. Design of the station and methodology of measurements

Tests were conducted on a specially designed laboratory station. The laboratory station was equipped with an Agilent 55521A sine signal generator (1), connected to an amplifier of a Data Physics PA-30E shaker (2). An amplifier was connected to a Data Physics V20 shaker (3), on which a piezoelectric generator (4) and Piezotronice M352C65 PCB acceleration sensor (5) were mounted. Outputs of the acceleration sensor and piezoelectric generator were connected to two channels of a METEX oscilloscope (6).

![Fig. 1. Construction of the test for testing piezoelectric generators](image)

During tests, two systems consisting of V20W and V25W (MIDE company) piezoelectric boards connected to EHE004 stabilizing and processing systems were analyzed [3]. Table 1 presents basic parameters of applied piezoelectric boards.

<table>
<thead>
<tr>
<th>Model</th>
<th>Dimensions</th>
<th>Temperature of work</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Width [mm]</td>
<td>Length [mm]</td>
<td>Thickness [mm]</td>
</tr>
<tr>
<td>V20W</td>
<td>38</td>
<td>81</td>
<td>1.5</td>
</tr>
<tr>
<td>V25W</td>
<td>38</td>
<td>81</td>
<td>1.5</td>
</tr>
</tbody>
</table>
Each of the studied board models consist of two parallel, connected piezoelectric elements. Both elements have separate signal outputs, which is why the following were tested:

- each element separately,
- elements connected in series (double voltage and current at the same level are obtained)
- elements connected in parallel (double current and voltage at the same level are obtained)

The listed connection types are presented in fig. 2.

Fig. 2. Type of connection piezoelectric elements a) serial, b) parallel

In the initial phase, a piezoelectric board was connected to the measuring station without a stabilizing system. It was decided to apply such a solution in order to determine the resonance frequency of a given board model. The frequency characteristic of piezoelectric elements is presented below.

Fig. 3. Characteristic of $U=f(f)$ for piezoelectric panel V20W and V25W
On the characteristic, it can be observed that resonance frequencies for the V20W board are at the levels of approx. 58 Hz and approx. 695 Hz, and for the V25W board, they oscillate around the values of approx. 61 Hz and approx. 539 Hz. Resonance frequencies obtained from piezoelectric systems yield the highest voltage and thus the greatest power. Boards were also examined from the perspective of efficiency at different acceleration values: a=0.25g to 1.75g$^1$. The results of these tests are presented in table 2.

Table 2. Efficiency of piezoelectric boards depending on acceleration

<table>
<thead>
<tr>
<th>Board model</th>
<th>V20W</th>
<th>V25W</th>
</tr>
</thead>
<tbody>
<tr>
<td>f</td>
<td>a</td>
<td>U$_{ind.}$</td>
</tr>
<tr>
<td>[Hz]</td>
<td>[m/s$^2$]</td>
<td>[V]</td>
</tr>
<tr>
<td>2.45</td>
<td>1.20</td>
<td>1.60</td>
</tr>
<tr>
<td>4.90</td>
<td>3.50</td>
<td>3.10</td>
</tr>
<tr>
<td>7.35</td>
<td>5.40</td>
<td>6.80</td>
</tr>
<tr>
<td>9.80</td>
<td>6.60</td>
<td>14.20</td>
</tr>
<tr>
<td>12.25</td>
<td>7.60</td>
<td>15.60</td>
</tr>
<tr>
<td>14.70</td>
<td>8.40</td>
<td>16.80</td>
</tr>
<tr>
<td>17.15</td>
<td>9.00</td>
<td>18.00</td>
</tr>
</tbody>
</table>

On the characteristic in figure 4, it can be observed that the system connected in series generates voltage approximately double that of the parallel system or individual board, and that the increase in voltage is not linear. However, it should also be noted that, if the system generates double voltage, the value of current will be halved. The parallel connection of the board is optimal, and lower voltage was obtained for this connection while current was doubled.

$^1$ g – gravitational acceleration equal to 9.80665 m/s$^2$
Boards were initially tested without the EHE004 stabilizing system. Thanks to this, the capabilities and most important parameters of the board itself were tested. To check the output of the entire system, it was connected and fastened to a shaker, as before. The system inter-operated with a V20W board.

The EHE004 system is a stabilizing and processing system. It is tasked with stabilizing the input signal. The final effect is acquisition of a useful signal on the system's output for powering a light source.

This system can be configured in several ways [3]:

- Switch 1
- Switch 2
- Switch 3

Fig. 4. Characteristic of U=f(a) for piezoelectric panel V20W and V25W

(poje. – one element, szer. – elements connected serial, równ. – elements connected parallel)

Fig. 5. Electronics for voltage stabilization
Switch 1:
It has 2 switches and serves for changing output voltage:
Switch 1 – in 0 – 1 configuration
Switch 2 – in 0 – 1 configuration
00 – 1.8V
10 – 3.3V
01 – 2.5V
11 – 3.6V

Switch 2:
Serves for configuration of the EHE 004 system’s operation:
1 – Normal mode (operates throughout the entire period of the signal – recommended for obtaining max. power),
2 – Superseries mode (operates for half of the period of the signal).

Switch 3:
Serves for changing the piezoelectric connection system
1 – Series (Normal)
2 – Parallel

The most optimal connection during testing was the setting of Switch 2 – in position 1 and Switch 3 – in position 2, as well as regulated voltage depending on the level required for lighting up the LED: 2.5V, 3.3V and 3.6V. The voltage of U = 1.8V is too low to achieve LED activation.

A LED was used for testing (with blue color – for this color, glow (activation) current is the lowest and equal to approx. 10-12mA; for comparison, this current is equal to approx. 18-20mA for a red diode – the resistance of a blue diode is approx. R ≈ 300 Ω). Thanks to the diode, it is possible to verify how the piezoelectric system behaves when inter-operating with a light source. The current flowing in the circuit can be learned from the resistance and drop in voltage on the LED, and then the power that the piezoelectric system is capable of providing can be calculated.

The EHE004 system was configured to supply voltage of U= 2.5V on the output. The voltage drop on the diode is equal to U = 2.6V, as illustrated in figure 6. By substituting values into the formula of Ohm’s Law, we obtain:

\[ I = \frac{U}{R} = \frac{2.6V}{300\Omega} \approx 8.6 mA \]  \hspace{1cm} (1)

where:
U - voltage drop on diode [V]
R - resistance [Ω]

In order to calculate power on the resistor, we use the formula:

\[ P = U \cdot I = 2.6V \cdot 8.6 mA = 22.4 mW \]  \hspace{1cm} (2)
Fig. 6. Characteristic $U=f(t)$ for piezoelectric panel V20W
(meter range 4s/div, $U=2.5\text{V}$), $f_{\text{rozonans}}=58\text{[Hz]}$

Fig. 7. Characteristic $U=f(t)$ for piezoelectric panel V20W
(meter range 1s/div, $U=3.6\text{V}$), $f_{\text{rozonans}}=58\text{[Hz]}$
Figures 6 and 7 present registered LED operation characteristics for voltages of $U = 2.5V$ and $U = 3.6V$, respectively. Both trials were conducted at the same amplitude of vibrations – acceleration of approx. $9.8 \text{ m/s}^2$. Thanks to this, one can observe that the frequency of activation is greater when the diode is supplied with lower voltage. When voltage is higher, frequency is lower.

At a higher voltage, the LED consumes more power. This can be observed based on the brightness with which the diode glows. At a higher voltage, the diode glows more brightly, however the system is not capable of generating enough power to ensure continuity of such operation. The diode glows for a short time, but intensely. At a lower voltage, the LED glows less brightly. Depending on needs, by controlling voltage, the system can be used to light places where there is an absence of any light or as a warning element where a broken signal (diode flashing) is required.

The LED glow time for voltage $U = 2.5V$ is equal to $t \approx 12s$, and for voltage $U = 3.6V$, this time is very short, approx. $t \approx 7ms$.

### 2. Capability of applying piezoelectric generators as power sources in electrical equipment in mines

Lit signs intended for displaying warnings or information with the purpose of improving safety of the crew and improving work organization, are used in underground areas of mines. Conveyor dumping stations and passages for humans above conveyor belt lines are locations particularly advised for such signs. These signs are currently mostly equipped with 40W bulbs or 22W LEDs powered by 230V voltage, operating temperature range -5°C to +40°C; housing protection rating IP 54. The use of piezoelectric generators as autonomous sources of electricity would require the construction of a set with power of approx. 20W. The set would have to be equipped with an ion-lithium battery guaranteeing support of LED power supply during periods when mechanical vibrations are not generated. Conducted studies have shown that piezoelectric boards do not allow for the construction of an autonomous source of electricity guaranteeing continuity of power supply to illuminated warning and information signs, due to low available electrical power amounting to approx. 40mW. Costs arising from introduction of piezoelectric systems into copper ore mines are very high. Considering the issue from an economic perspective, it is difficult to see positive aspects. Another problem is that one piezoelectric system is insufficient for supplying power to an illuminated sign or warning signs. The application of several dozen such systems will proportionally increase the cost of the entire system to an unaffordable value.

### Summary

A great advantage of piezoelectric systems is that they can be installed without additional cabling. This is very helpful in situations where installation of such cabling is difficult or impossible. Installing such a system in a facility/room where alarm signaling devices are required would certainly improve work safety of personnel. In recent years, sensors with a piezoelectric system have entered into use. This is based on accumulation of energy (over a given period of time by the piezoelectric system), followed by excitation of the sensor and wireless data transmission to the control room. The entire process lasts from several to a dozen or so milliseconds.
and the piezoelectric system is capable of providing enough power to enable data reading and transmission. Such elements are universal, since they can inter-operate with any sensor (temperature, pressure, water level, level of air or other gases). It should be noted that a system generating vibrations does not maintain the same resonance frequency over the course of its operation – which results e.g. from wearing of the parts of a given machine or from maintenance and repair performed on a machine. Every piezoelectric system is designed for a given resonance frequency, and even a small change of this frequency may reduce the performance of such a system to a great extent. It is known from available information that systems that would self-adapt to resonance frequency are not currently manufactured (which is a current problem). Considering the above, the state of the art and of technology around the world in the field of piezoelectric generators should be monitored. Advances in nanotechnology allow one to surmise that solutions effective enough to find practical applications in mines will appear in the years to come.

References


