# Comparison of Piezoelectric and Electromagnetic Technologies in Harnessing The Vibration or Sound of Trains as a Rail Contact Battery Charger

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**Abstract.** The development of sound energy as an alternative energy source has become increasingly important in addressing the limitations of fossil energy sources. This research focuses on the selection of piezoelectric and electromagnetic technologies to harness the vibration or sound of trains as a battery charger for rail contacts. The variables that were altered include the distance between the device and the train track, as well as the input sound frequency during laboratory testing. Although both piezoelectric and electromagnetic technologies have their respective advantages and disadvantages, this research provides conclusions based on field and laboratory tests. This research has significant implications for the development of renewable energy sources in the transportation sector, particularly in the use of sound energy in trains. One piezoelectric device produces 0.5 V at a 1 mm deflection. Field testing showed voltage results reaching 1.3 V, while electromagnetic technology produced 0.52 V. Laboratory testing showed piezoelectric voltage results of 0.72 V and electromagnetic voltage results of 0.43 V. By harnessing renewable energy from vibrations or sound, we can reduce our dependence on fossil energy sources and enhance the operational efficiency of trains. The results of this research can serve as a foundation for the development of more efficient and sustainable battery charging systems for rail contacts in the future

**Keywords:** charger, electromagnetic, frequency, piezoelectric, resonant, rail contact, sound

## 1 Introduction

The charging of batteries on rail contacts currently relies on electricity from the station to maintain the activation of the rail contacts. The function of these rail contacts is to allow the occurrence of direct current flow after the train passes a specific point or receives permission from another location [1]. The reliability of the power supply to generate alternative energy has become the focus of scientists in creating energy harvesting equipment, which is the process of capturing and converting sound, mechanical, and kinetic energy into electrical energy [2]. The demand for energy in Indonesia is increasing and evolving rapidly along with the rapid development in the fields of technology, industry, and information. Various forms of renewable energy are currently being developed, including energy from wind, steam, biomass, sound, and others. Sound energy is converted into electrical energy. Noise generated by trains in railway operation areas comes from sources such as locomotive engine noise, wheel-rail friction, rail joints, and sounds on bridges [3]. Interest in utilizing train

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noise as a source of renewable energy is increasing. Based on these events, the author wishes to harness renewable energy using the sound energy generated by the friction of train wheels using the concept of resonance.

The fundamental theory of piezoelectricity, often referred to as "Piezo," involves the generation of an electric field when subjected to pressure and the production of electrical voltage when compressed. It also functions in reverse, where mechanical pressure induces an electrical voltage [4]. Additionally, resonance, is denoted by the production of sound from a source triggering vibration in other instruments with the same frequency, resulting in amplification or enhanced response [5]. On the other hand, electromagnetic phenomena describe the combination of oscillating magnetic fields that propagate through space, carrying energy from one location to another. This occurs when a magnetic field is generated by winding wire around a conductor material like iron or steel. The operation of the transducer involves the conversion of vibrations or train sounds. These vibrations or sounds travel through a propagation medium and are then transmitted to the transducer for conversion. Inside the conversion transducer, these vibrations or sounds are harnessed to move a lever up and down, facilitating the conversion process.

The objectives of this research are threefold: firstly, to explore the process of converting the vibrations and noise generated by trains into electrical energy; secondly, to design the appropriate placement of transducers to investigate the resonance system of train vibrations and sound; and finally, to conduct tests aimed at determining the voltage produced by transducers, to utilize this electrical output as a power source for charging batteries on rail contacts by UPT Resor Sintel 3.6 Muaraenim.

## 2. Research Method

A graphical diagram that encompasses the steps and sequence of the mechanisms of piezoelectric and electromagnetic transducers is employed to aid in analysis, design, and problem-solving through decomposition into simpler components [6]. The testing method involves various transitions. The primary goal of this testing is to obtain voltage results originating from the resonance of train vibrations or sounds, the friction between train wheels and the rails, as well as the sounds produced by the train while passing at a speed of 15 km/h. To achieve this objective, a piezoelectric transducer assembled using the hammer method, a sound level meter for measuring sound, and an avometer placed on the outer side of the train track are utilized.

The descriptive analysis method is used to represent the test results of transducers regarding the characteristics of electrical energy conversion and sound damping. To obtain the results, the author utilizes the concept of calculating the mean, median, mode, and conducting data analysis.

The formulas for these calculations are as follows:

Mean Formula:
$\text{Mean} = (d1 + d2 + ... + d\_n) / n$

Median Formula for Odd Data:
$\text{Median} = \text{data}[k]$ where $k = (n + 1) / 2$

Median Formula for Even Data:
Median = (data[k] + data[k+1]) / 2 where k = (n + 1) / 2

Mode Formula:
Mode = (t_b + (d_1 * d_1)) / (d_1 + d_2 * K)

These formulas are used to calculate the mean, median, and mode for analyzing the test results of the transducers in terms of energy conversion and sound-damping characteristics.

## 3. Device Design and Modelling

### 3.1 Piezoelectric Device

The process of designing a tool involves the creation of its visual appearance and physical structure, considering functionality, aesthetics, and other technical factors. During this stage, designers merge technical knowledge and innovation to develop the initial concept into a more detailed design. In this case, the author employs 3D design software. The goal of designing a tool model is to produce a design that meets user needs, is effective in performing its tasks, and complies with established quality standards. A good design takes into account all relevant aspects and provides innovative, efficient, and practical solutions to the challenges at hand.

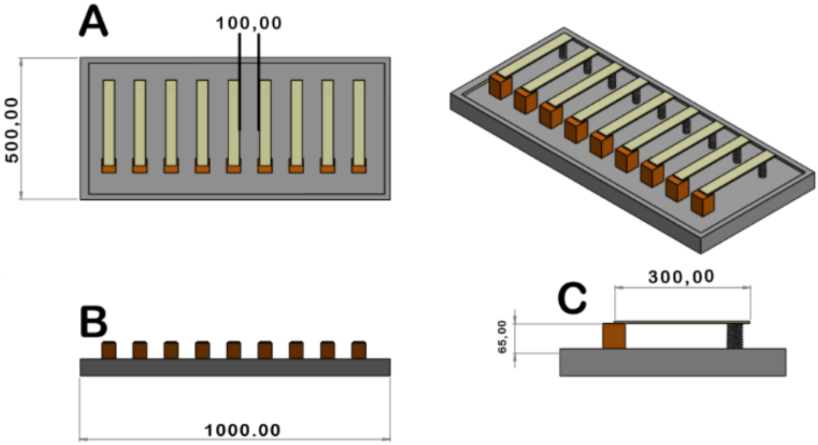

**Fig 1.** Piezoelectric devices with hammer methods

This transducer utilizes the piezoelectric properties of the material it's made from, where the material can generate electrical voltage when subjected to pressure or mechanical vibrations. When the vibrations or sounds of the train are received by the piezoelectric transducer, the piezoelectric material responds by producing electrical voltage. The labels A and B represent the display table, which measures 1 meter in length and 50 cm in width, providing sufficient space to position measurement devices and 9 piezoelectric transducers with a spacing of 10 cm between them. In label C, there is a display table with a 30 cm long bar supported by an H-beam. This bar has a height of 6.5 cm, held in place with rivet pins, and at its end, there is a spring with a 1 cm diameter. The bar and the piezoelectric components are attached at a 15° angle to optimize the hammer method for these piezoelectric components. The selection of a rigid spring aims to enable the bar to respond more effectively to the vibrations or sounds generated by the train.

### 3.2 Electromagnetic Induction Device

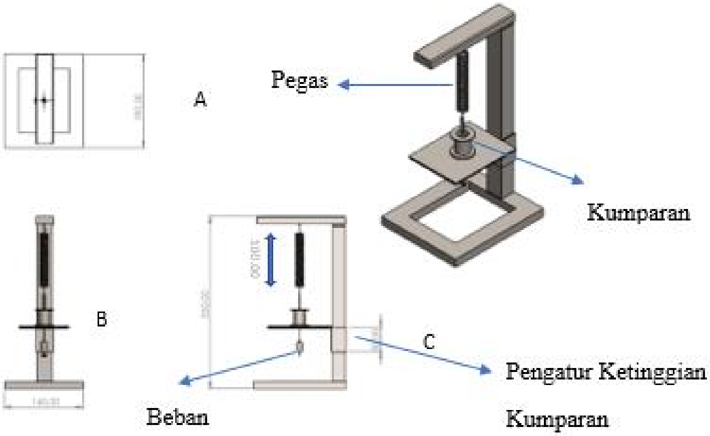

**Fig 2.** Principle of electromagnetic induction

This device harnesses the vibrations or sounds generated by the train, which cause the spring underneath it to vibrate. Within this spring, there is a magnet that, when vibrated, changes the magnetic field [7]. This alteration in the magnetic field subsequently induces an electric current within a conducting wire that passes through it.

### 3.3 Rail Contact Power Supply Diagram

rail contacts, serves as the "train entry" mechanism within a signal house and must be positioned in the "red" setting to prevent the button lock from being pressed before the train has truly entered and activated the rail contact. The entry signal handle must also be equipped with a mechanical button lock connected to a key located beneath the "train entry" mechanism, and the rail contact serves the dual purpose of locking the handle in the normal position[1].

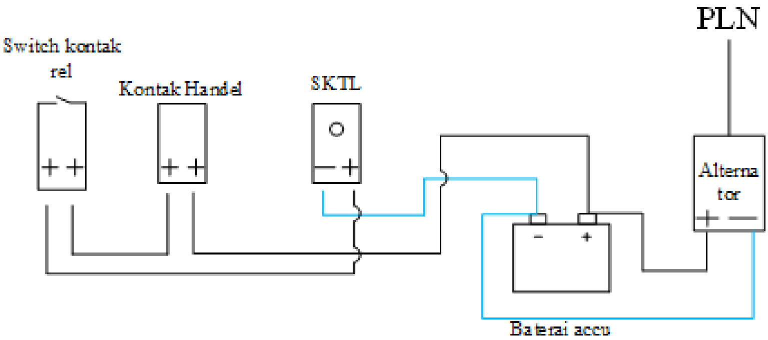

**Fig 3.** The existing wiring of rail contact power supply

In this diagram, the electrical cable from the PLN power source with a voltage of 220 VAC is connected to the voltage alternator input, responsible for reducing the voltage to approximately 12-13 VDC.

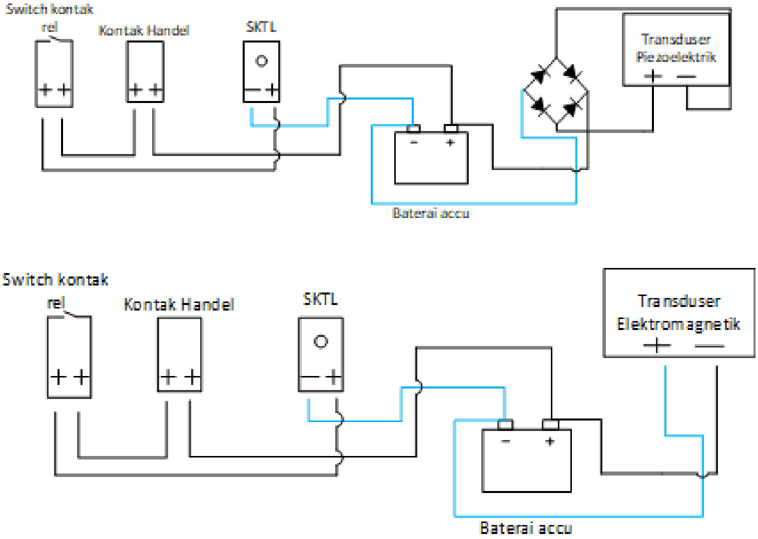

**Fig 4.** Proposed wiring of rail contact power supply

The purpose of this planned wiring is to provide an alternative power source in place of the PLN supply for battery charging at Banjarsari Station. The common issue faced is power outages, which could lead to the depletion of the SKTL power source and a halt in train services. Safety in the railway system is a critical aspect that must always be ensured to be reliable. This means that if there is a failure in the system, it should not endanger passenger safety during train journeys [8]. In such situations, this device can automatically take over to provide a temporary power supply and ensure the continuous operation of essential equipment[9].

## 4. Laboratory Testing

The frequency waveforms are designed to form a sawtooth pattern, which linearly increases from the minimum value to the maximum and then suddenly returns to the minimum value, resembling an inverted triangle wave. The testing is conducted in a closed, soundproof room, which leads to sound reverberation phenomena. The frequency signals are directed to the installed piezoelectric transducer, which responds with vibrations corresponding to the given frequency. Using a measuring instrument, an avometer, the voltage generated by the piezoelectric transducer is measured and recorded. The objective of this testing is to gain a deeper understanding of the response of piezoelectric materials to specific frequency signals and observe the voltage characteristics produced by the specified frequencies.

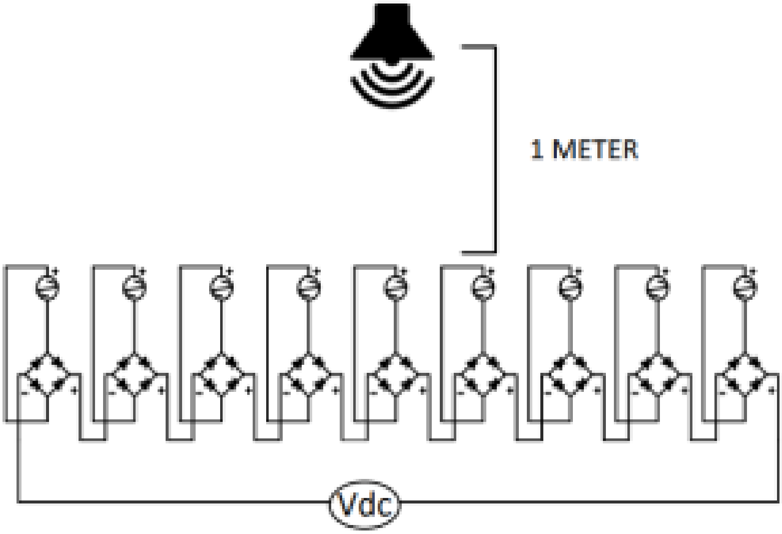

**Fig 5.** Laboratory testing scheme

**Table 1** Results of laboratory testing

| No | Frekuensi (Hz) | Jarak | Amplitude | Tegangan |
|---|---|---|---|---|
| 1 | 35 | 1 meter | 100 | 0.33 |
| 2 | 35 | 1 meter | 100 | 0.34 |
| 3 | 35 | 1 meter | 100 | 0.34 |
| 4 | 45 | 1 meter | 100 | 0.71 |
| 5 | 45 | 1 meter | 100 | 0.74 |

## 5. Field Testing

By placing the transducers near the rail, we can measure the intensity of the vibrations or sounds produced and analyze their impact on these components. The piezoelectric and electromagnetic transducers are positioned 1 meter from the outer side of the rail, forming a 30° angle with the train ballast surface. This is done to generate greater pressure on the piezoelectric transducer and vibrate the spring hanging on the electromagnetic transducer, thereby producing a magnetic flux.

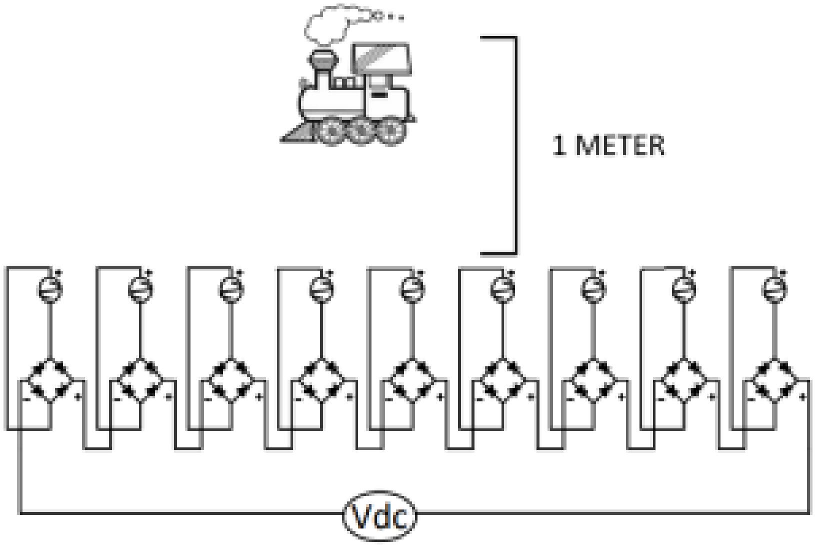

**Fig 6.** Field testing scheme

**Table 2** Results of field testing

| No | Jarak Dengan Kereta | Suara (Db) | Kecepatan | Tegangan (Vdc) |
|---|---|---|---|---|
| 1 | 1 Meter | 90 | 15 | 1.2 |
| 2 | 1 Meter | 90 | 15 | 1.4 |
| 3 | 1.5 Meter | 87 | 15 | 0,8 |
| 4 | 1.5 Meter | 87 | 15 | 0.7 |
| 5 | 2 Meter | 84 | 15 | 1.3 |

## 6. Experiment on 1 piezoelectric and 1 electromagnetic

The primary objective of this testing is to compare the response of a single piezoelectric component using the "hammer" method and a single electromagnetic component using the same method, i.e., inputting sound from the vibrations or sounds of the train.

**Table 3** Results of 1 piezoelectric and 1 electromagnetic testing

| No | Frekuensi | Jarak | Piezoelectric | Electromagnetic |
|---|---|---|---|---|
| 1 | 45 | 1 Meter | 0,5 | 0,4 |
| 2 | 45 | 1 Meter | 0,4 | 0,3 |
| 3 | 45 | 1 Meter | 0,5 | 0,4 |
| 4 | 45 | 1 Meter | 0,5 | 0,3 |
| 5 | 45 | 1 Meter | 0,4 | 0,3 |

## 7. Data Analytics

### 7.1 Analytics of field testing

**Table 4** Analytic of field-testing result

| Jarak (M) | Suara | Tegangan | | |
|---|---|---|---|---|
| | | rata-rata | median | modus |
| 1 | 90 | 1,35 | 1,3 | 1,3 |
| 1,5 | 87 | 0,68 | 0,65 | 0,6 |
| 2 | 84 | 0,035 | 0,035 | 0,02 |

In Table 4, calculations for the mean, median, and mode are provided. After applying these formulas, the following values were obtained for the respective distances between the transducer and the train: an average of (1.35, 0.68, and 0.035 VDC), a median of (1.3, 0.65, and 0.035 VDC), and a mode of (1.3, 0.6, 0.02 VDC) for distances of 1 meter, 1.5 meters, and 2 meters from the train, respectively.

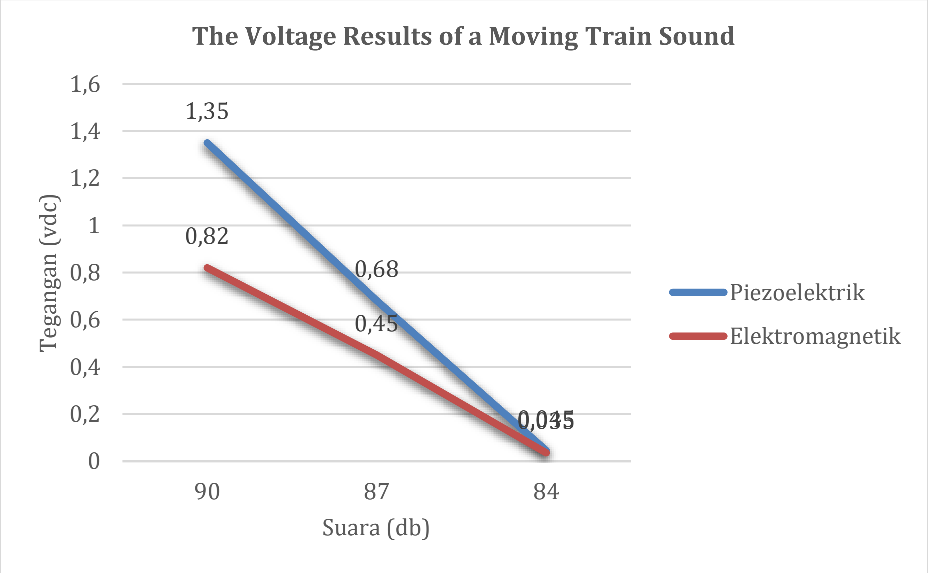

**Fig. 7.** The Voltage Results of a Moving Train Sound

### 7.2 Analytics of laboratory testing

**Table 5** Analytic of laboratory testing result

| Frekuensi (Hz) | Amplitude | Rata-rata | Median | Modus |
|---|---|---|---|---|
| 35 | 100 | 0.326 | 0.325 | 0.34 |
| 40 | 100 | 0.446 | 0.45 | 0.42 |
| 45 | 100 | 0.7275 | 0.725 | 0.71 |

After the calculations in the table using these formulas, the data for the settings of distance, frequency, and amplitude are at 1, 1.5, and 2 meters, respectively. Average values: 0.0326, 0.446, and 0.7275 VDC.Median values: 0.325, 0.45, and 0.725 VDC.Mode values: 0.34, 0.42, and 0.71. These values correspond to the respective distances from the source, illustrating variations in voltage measurements for the different settings.

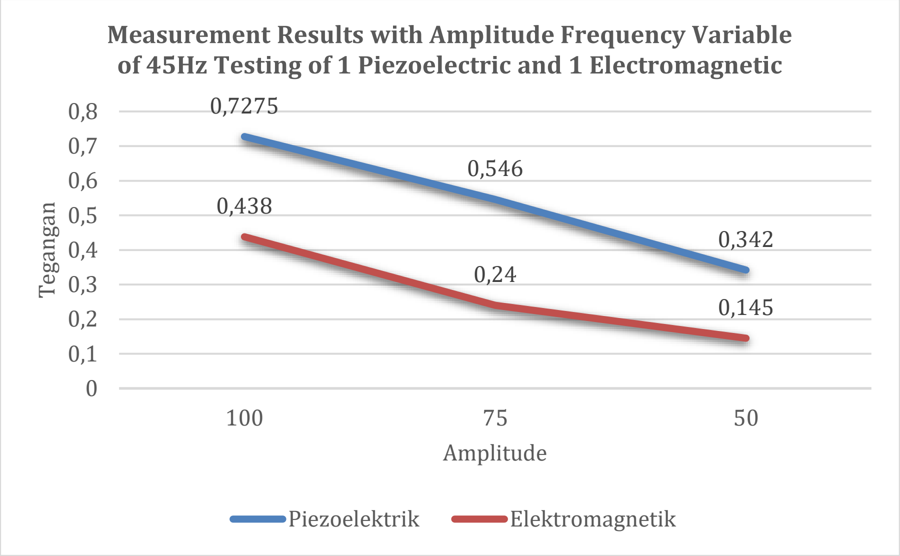

**Fig. 8.** Measurement Results with Amplitude Frequency Variable of 45Hz Testing of 1 Piezoelectric and 1 Electromagnetic

### 7.3 Analytics of 1 piezoelectric and 1 electromagnetic experiment

Hasil pengujian menunjukkan bahwa sensor piezoelektrik memberikan respons yang lebih cepat dalam merespons getaran yang diberikan oleh aplikasi frequency generator. Tabel yang disajikan dalam laporan laboratorium memberikan informasi rinci tentang karakteristik konversi energi dari masing-masing transduser, dengan jelas menunjukkan bahwa piezoelektrik memiliki keunggulan dalam mengubah getaran menjadi sinyal listrik dengan efisiensi yang lebih tinggi.

**Table 6** Analysis of result for 1 piezoelectric and 1 electromagnetic

| No | Frekuensi | Rata-Rata | Median | Modus |
|---|---|---|---|---|
| | | Piezoelectric | | |
| 1 | 45 | 0.45 | 0.45 | 0.5 |
| 2 | 45 | 0.44 | 0.4 | 0.4 |
| 3 | 40 | 0.35 | 0.35 | 0.3 |
| 4 | 40 | 0.39 | 0.4 | 0.4 |
| | | Electromagnetic | | |
| 1 | 45 | 0.34 | 0.3 | 0.3 |

| | | | | |
|---|---|---|---|---|
| 2 | 45 | 0.35 | 0.35 | 0.4 |
| 3 | 40 | 0.25 | 0.25 | 0.2 |
| 4 | 40 | 0.26 | 0.3 | 0.3 |

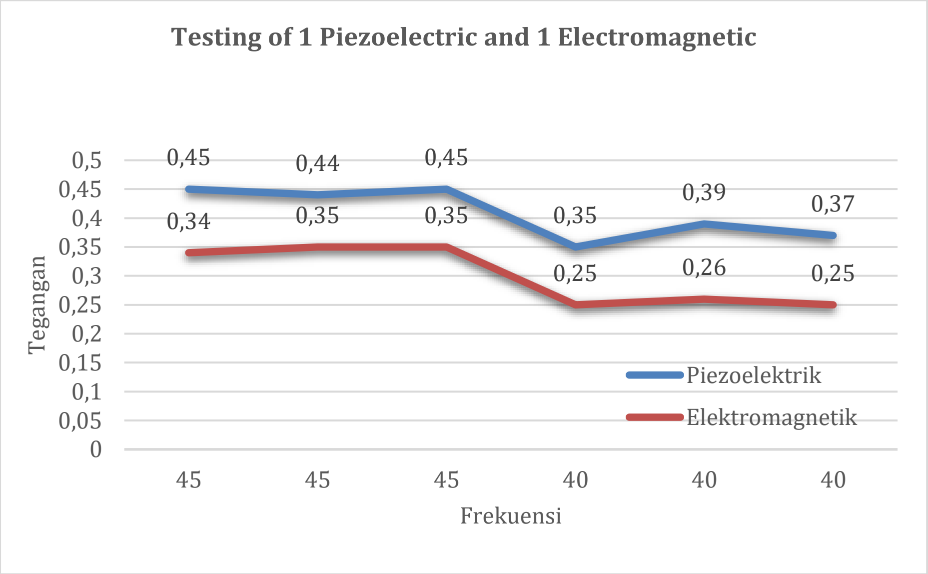

**Fig. 9.** Testing of 1 Piezoelectric and 1 Electromagnetic

The results of the testing of both transducers, namely the piezoelectric and electromagnetic transducers, indicate that they exhibit a fairly similar response to vibrations and sound. Data collected from these experiments has been presented in the form of graphs that illustrate the level of responsiveness of each transducer to the input of vibrations or sound.

## 8. Conclusion

Energy conversion to electricity through the vibration of a lever involves placing piezoelectric transducers in a way that generates a voltage according to the principles of piezoelectricity when exposed to mechanical force. Electromagnetic transducers transform vibrations and sound into changes in the magnetic field that induce electrical current in coils. The principles of resonance and matching sound frequency with the transducer's natural frequency enhance energy conversion efficiency. Transducers are positioned on the outer side of the train track during field testing. Testing is carried out at various distances: 1, 1.5, 2, 2.5, and 3 meters. At a distance of 1 meter from the outer side of the track, with a 30° angle of inclination, piezoelectric transducers are placed at a 15° angle. This is done to create increased pressure on the piezoelectric transducer spring and vibrate the electromagnetic transducer spring, resulting in an effect on the coil. Piezoelectric transducers are sensitive to sound and vibrations from the train engine, and findings suggest that the distance and angle of placement for piezoelectric and electromagnetic transducers affect the generated voltage. A single piezoelectric unit produces 0.5 V with a 1 mm lever deflection. Field testing reveals voltage results reaching 1.3 V, while electromagnetic transducers produce 0.52 V. Experimental results indicate that piezoelectric voltage is 0.72 V, and electromagnetic voltage is 0.43 V.

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