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# Innovation In Renewable Energy Systems: Utilization Of Piezoelectric Sensors On Railway Tracks To Harvest Vibration Energy

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***Abstract* — Green energy development focuses on the utilization of environmentally friendly energy sources, such as solar, wind, biomass, and geothermal, to address climate change and resource scarcity. In this context, the use of piezoelectric technology to harvest energy from vibrations and mechanical pressures generated by vehicles or trains shows significant potential as a sustainable energy solution. Piezoelectric technology offers a sustainable energy solution by harvesting energy from mechanical pressures and vibrations generated by vehicles. This system is effective in providing electricity for signaling and electronic equipment at level crossings, especially in locations far from the main power grid, by utilizing the pressure or vibrations generated by the weight of the vehicle to generate electrical voltage through changes in polarization in the piezoelectric material. This study uses a descriptive method with a quantitative approach based on experiments. In this study, a train configuration consisting of eight carriages and one locomotive is assumed, where each carriage weighs 35 tons, and the locomotive weighs 78 tons. Based on calculations, this train set is capable of producing 0.7695 Watts of electrical energy. If 16 train sets pass every day, the electrical energy generated reaches 12.31 Watts per day. This energy is used to support signaling systems, lighting, and other electronic equipment around level crossings. Its application not only increases sustainability by utilizing renewable energy sources but also reduces dependence on external electricity supplies. The use of piezoelectric technology offers a sustainable and environmentally friendly solution by utilizing renewable energy sources. This system is able to reduce dependence on external electricity while increasing operational efficiency and railway safety, especially at level crossings.**

***Keywords — Sustainable energy, railway vibrations, Piezoelectric sensors, level crossings***

## I. INTRODUCTION

Green Transportation is an approach to creating environmentally friendly modes of transportation by using environmentally friendly devices and reducing or even eliminating greenhouse gas emissions [1]. The transportation sector, which carries millions of tons of goods and passengers every day as the foundation of economic and industrial development, remains irreplaceable despite advances in the virtual world that are expected to reduce dependence on physical transportation; however, this sector continues to show rapid growth [2]. The application of the Green Transportation concept is essential to balance the growth of the transportation sector with efforts to reduce negative impacts on the environment. The ever-increasing energy needs of the transportation sector have the potential to put great pressure on the environment, because most of the energy used comes from fossil fuels.

Energy is a basic need that has a significant impact on human life, both renewable and non-renewable energy, but most of these types of energy are limited in quantity and will run out if not used sustainably [3]. The potential for renewable energy in Indonesia is quite large but has not been optimally utilized as a source of electricity, so appropriate policies are needed to strengthen national energy security for current and future generations. One of the promising renewable energy potentials is vibration energy, especially in the railway sector, where vibrations from train movements can be converted into electrical energy. [4]

Vibration energy is one of the promising energy sources for power harvesting in the railway sector because this energy is available directly when the train passes and has great energy potential, although the average level of vibration energy decreases from top to bottom of the track structure due to the energy stored and consumed in each section [4]. This energy is generated from the snake motion effect that occurs due to the movement of the train, with the vibration level increasing along with the increasing speed of the train and its operating frequency. In addition, ground vibrations caused by train loads can have an impact on the track structure through which the load passes. [5]This vibration energy has the potential to be used as one of the alternative energy sources in the railway sector, especially with the existence of energy harvesting technology that can convert vibration into electricity, thus supporting emission reduction and energy efficiency in train operations.

Railway crossings are generally guarded in locations with heavy vehicle traffic, using signal lights and barriers to inform motorists about passing trains [6]. At these level crossings there are electrical equipment that require electricity supply, so that the electricity generated from train vibrations can be used for these needs, thus becoming an efficient and sustainable alternative energy source. This approach not only improves energy efficiency but also supports the implementation of environmentally friendly transportation in the railway sector.

Based on this potential, this study will analyze the potential of vibration energy at the signaling point to be utilized as a power source based on piezoelectric sensors. This study is expected to provide innovative solutions for the provision of sustainable energy that supports efficient and environmentally friendly railway operations. The electrical energy produced will later be utilized for the signaling system, so that it can optimize the potential of existing renewable energy and contribute to national energy security efforts.

## II. LITERATURE REVIEW

### A. *Piezoelectric*

"Piezoelectric" comes from the Greek words *piezo* , meaning pressure, and *electric* , meaning electricity. Piezoelectric materials were first discovered in 1880 by Jacques and Pierre Curie. [7] Piezoelectric is a sensor device made of silicon or germanium that can produce electrical energy when it experiences deflection (direct piezoelectric effect). Conversely, when voltage is applied, it will deflect (reverse piezoelectric effect) [8]The advantage of piezoelectricity is that it does not require external power and can be used in small devices. However, its limitation lies in the leakage of charge in the material, which results in a limited voltage storage time after force [7]is applied.

### B. *Level Crossing*

In [9] according to (Wildan, 2013) , crossing a piece is point meeting Then cross vehicle motorized in one side and then cross train fire on the other side . According to Regulation Director General Transportation Land Number : SK.770/KA.401/DRJD/2005 concerning Guidelines Technical Crossing A Plane Between Road and Railway Tracks Fire , goal crossing a piece is :

- For increase safety transportation road with increase performance crossing a plot .
- For reduce accident incidents and victims transportation land at the crossing a plot .
- Functioning as guidelines and references in management and engineering at crossings a plot .

### C. *Battery*

Battery is device electrochemistry used For supply electricity to various system or device electricity that needs it [10]. Battery consists of from two or more cell electrochemical that changes energy stored chemicals become energy electricity . Every cell has a positive terminal ( cathode ) and a negative terminal (anode). The positive terminal show energy more potential tall than the negative terminal [11].

### D. *Energy*

Energy is a basic need for human life, both renewable and non-renewable energy which are limited in number and need to be utilized sustainably. Indonesia has great potential in renewable energy, but its utilization is not yet optimal. Appropriate policies are needed to strengthen national energy security. One promising renewable energy is vibration energy, such as that produced by the movement of trains which can be converted into electricity [4].

### E. *Vibration and Electricity*

Vibration is a back and forth movement through a point of equilibrium that is repeated regularly. Vibration is a back and forth movement through a point of equilibrium [12]. In the context of physics, vibrations are generally grouped into two main types, namely synchronous vibrations and non-synchronous vibrations. Meanwhile, electrical energy is one of the most important and vital needs of modern society [13]. The absence of electrical energy will have a major impact on the sustainability of human activities, especially in an increasingly global and technology-dependent world. Electrical energy also plays an important role in improving the quality of life and economic progress, because it supports various sectors of production and public services, such as health, education and communication.

## III. RESEARCH METHODOLOGY

This study uses a descriptive method with a literature study approach. The descriptive focus of this study is to design a tool to monitor the magnitude of vibrations produced by trains and calculate the conversion of these vibrations into electrical energy. The components used in this tool include piezoelectric sensors arranged in a parallel circuit, along with the addition of Arduino Uno. The following is a flow diagram and explanation of the operating system of the tool to be designed.

## A. Product Design

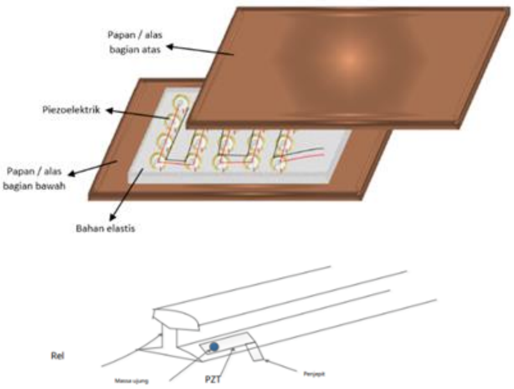


Fig 1. Product Design

## B. Device diagram

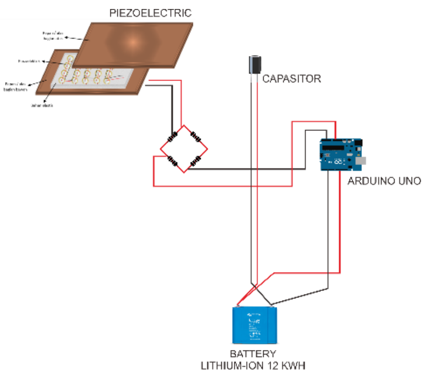


Fig 2. Device diagram

- **Piezoelectric** : Function as components that capture vibrations produced by interactions between police sleep and wheels vehicles passing by . Vibration This Then changed become energy electricity through the conversion process mechanical-electrical .
- **Arduino Uno** : Working as microcontroller in operation as device device soft board single source open used For translate vibration into numeric data .
- **Capacitor** : Functioning as device electronic For keep charge and energy electricity , as well as stabilize flow electricity .
- **Kwh Lithium-ion Battery** : Working as storage power generated from change vibration become electricity .

## C. Block diagram

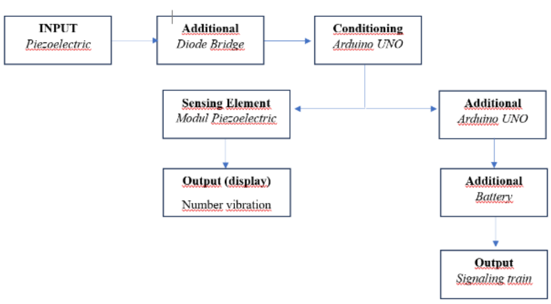


Fig 3. Block diagram

## D. Flow chart

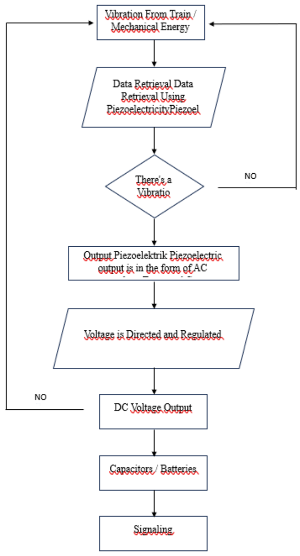


Fig 4. Flow chart

## E. Piezoelectric System Design Calculation

Based on literature , design system piezoelectric can determined as following :

1. Calculating the Force Produced by Vibrations

$$F = m \cdot a$$

- m = mass load (kg)
- a = acceleration produced by vibration

If frequency vibration ( $f$ ) known , acceleration maximum $a$ can counted as :

$$a = (2\pi f)^2 \cdot A$$

2. Count Load Electricity ($Q$) Generated Use Constants Piezoelectric

$$Q = D_{33} \cdot F$$

- Q = Charge Electricity
- $D_{33}$ = Constant Piezoelectric ( 2500 x $10^{-12}$ )
- F = Force

3. Calculation Generated Voltage ($V$), Voltage is also affected by the value capacitance ($C$):

$$V = \frac{Q}{C}$$

C = value capacitance element piezoelectric (120)

4. Count Energy Electricity ($V$) , Energy This generated per cycle vibration :

$$E = Q \cdot V = \frac{Q^2}{C}$$

5. Calculation Power Generated ($P$) , If vibration occurs at a frequency $f$ , so The average $P$power ( ) produced is:

$$P = E \cdot f = \frac{Q^2 \cdot f}{C}$$

Or , replace$Q = D_{33} \cdot F$ :

$$P = \frac{(D_{33} \cdot F)^2 \cdot f}{C}$$

- P = power electricity generated (W)
- f = frequency vibration (Hz)
- C = value capacitance element piezoelectric (120)

## IV. RESULTS AND DISCUSSION

Based on research data [14] and the Regulation of the Directorate General of Land Transportation Number SK. 770/KA.401/DRJD/2005, states:

Table 1. Daily Frequency, Average Load, and Average Speed of Various Vehicle Types

| Vehicle Type | Frequency per Day | Average Load (kg) | Average Speed (km/h) |
|---|---|---|---|
| Train (1 train set) | 16 | 358,000 | 90 |
| Motorcycle | 1969 | 140 | 40 |
| Car | 207 | 1,500 | 20 |
| Truck | 101 | 10,000 | 20 |
| Bus | 40 | 12,000 | 20 |

**Formula Consumption Power at the Crossroads Train Fire**

**At The Door Gate Crossing** Based on the data obtained , power ($V$)The voltage used at the crossing gate is 18V and the current used is is 18V.($I$) is 3A:

$$P = V \cdot I$$

So $P = 18 \times 3$= 54 watts

So power gained is 54 Watts. If One cycle in progress for 4 minutes , then can formulated as following :

$$E = P \times t$$

$$E = 54 \times 0{,}06 = 3{,}24\,Wh$$

**Voice Siren 16 Ohm + 15% (1KHz)** Based on the data obtained power generated is 30 watts, then :

$$E = P \times t$$

$$E = 30 \times 0{,}06 = 1{,}8\,Wh$$

**Light Signal** Based on the data obtained , the power it has is 20 watts, and the amount lights (n) is 4, then :

$$E = P \times t \times n$$

$$E = 20 \times 0{,}06 \times 4 = 5{,}3\,Wh$$

So , the total usage Power each cycle For door crossing + siren sound + light signal is 3.24 + 1.8 + 5.3 = 10.34 watts.

Based on data collected from journals, [15]data was obtained stating that in one day, the train crosses the level crossing 16 times per day, so the power required in one day is 165.44 Watts. In the previous literature study, the number of frequencies, average weight, speed, and vibration levels of various vehicles were mentioned. This data is then processed using a formula to convert vibrations into electrical energy. The calculation results are presented in the following table:

Table 2. Summary of Vehicle Frequency, Load, Speed, Vibration, and Generated Power

| Vehicle Type | Frequency per Day | Average Load (kg) | Average Speed at Level Crossings (km/h) | Vibration (Hz) | Power Generated (Watts) |
|---|---|---|---|---|---|
| Train (1 train set) | 16 | 358,000 | 90 | 1200 | 12.31 |
| Motorcycle | 1969 | 140 | 40 | 55.57 | 0.107 |
| Car | 207 | 1,500 | 20 | 33.34 | 0.078 |
| Truck | 101 | 10,000 | 20 | 55 | 2.78 |
| Bus | 40 | 12,000 | 20 | 40 | 2.91 |
| | | | | TOTAL | 18.185 |

The table above shows the energy output generated by a single device installed at a level crossing. Given that a level crossing requires a total energy consumption of 165.44 watts per day, approximately 10 piezoelectric devices would be required to meet the daily energy requirement. With the installation of these piezoelectric devices, the energy generated from the vibrations of passing vehicles can be efficiently utilized to power the level crossing, potentially contributing to energy savings and increased sustainability in transportation infrastructure.

## V. CONCLUSION

Based on the research results, the use of piezoelectric sensors on railway tracks shows significant potential for sustainable energy generation. By capturing and converting vibrations from passing trains and vehicles, the system can generate electrical energy to power signaling equipment and other electronic devices at level crossings. The study showed that a single piezoelectric device installed at a level crossing can generate about 18,185 Watts per day. Given that each level crossing requires 165.44 watts per day, about 10 piezoelectric devices are needed to meet this need

This technology not only provides an innovative solution for energy generation but also reduces dependence on external resources, increases energy efficiency and promotes environmentally friendly practices in railway infrastructure. Overall, this study highlights piezoelectric energy harvesting as a viable and sustainable method to support operational needs in the railway sector, contributing to renewable energy initiatives and reducing environmental impacts.

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REFERENCE

[1] Dwiputri, Saputra, Alimah and Hamdani, "Green Transportation Compatibility Study for Bogor City," *Journal of Architecture,* 2021.

[2] Salimifard, Hamid and Raeesi, "Green Transportation and the Role of Operation Research," 2012.

[3] Noviana, Wirawan, Sholihah and Nugroho, "Sustainable electrical energy: Potential and challenges of electrical energy provision in Indonesia," *Innovation Materials, Energy, and Sustainable Engineering,* 2024.

[4] YKMZ Guanson Shang, "Piezoelectric energy harvesting from rail track vibration using frequency up-conversion mechanism," *IFAC ONLINE PAPER,* 2022.

[5] Vina, "Vibration Analysis on Rail Bearings Due to Train Loads on Railroad Structures," 2020.

[6] Aswad, "Feasibility Study of Level Crossings between Railways and Highways," 2013.

[7] Edy, Budi, etc., "Testing of Sound Energy Conversion System into Electrical Energy using Piezoelectric," *Jurnal Ilmiah Elektronika,* 2018.

[8] Diana, Farisal, Ulum, "Power Generation Floor Using Piezoelectric with BuckConverter LM2596," *Jurnal Arus ElektroIndonesia (JAEI),* 2021.

[9] Sri, Dinda, "Study of Transportation Safety and Security at Level Crossings between Railroads and Public Roads," *Progress in Civil Engineering Journal,* 2020.

[10] Yolanda, "HOW THE BATTERY WORKS AND MAINTENSIONS ON THE KN. KUMBA," 2019.

[11] Faiz, Dimas, Soedibjo, "Design of Battery State of Charge Monitoring System on Electric Car Charging Station Based on Fuzzy Logic Considering Temperature," *ITS Engineering Journal,* 2016.

[12] Ginting, "Identification of Students' Misconceptions on Vibration and Wav Material by Using the Certainty of Response Index (CRI)," 2022.

[13] Sandoro and Rangkuti, "Independent Solar Power Plant Planning for Residential Homes," 2016.

[14] Hamdani and Anisarida, "Identification of the Capacity of the Letjen Ibrahim Adjie Sta. 3 + 100 Road Section at the Tasikmalaya City Railway Level Crossing," *Civil Engineering Journal,* 2020.

[15] Azhar Hamdani, Sigit Yuono, "HYBRID POWER SUPPLY SYSTEM USING 100 WP SOLAR PANEL AND 13 WATT HAND GENERATOR ON RAILWAY CROSSING GATE PROTOTYPE WITH 32 WATT LOAD," *e-Proceeding of Engineering,* 2020.