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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 prioritizes sustainable sources like solar, wind, biomass, and geothermal to combat climate change and resource depletion. In this context, piezoelectric technology offers a promising solution for energy harvesting from vibrations and mechanical stresses, such as those generated by vehicles or trains. This technology converts mechanical pressure into electrical energy via polarization changes within piezoelectric materials.

This system has proven effective in powering electronic devices and signaling systems at railway level crossings, especially in remote areas lacking grid access. This study employs a descriptive method with a quantitative approach, utilizing experimental data. Data acquired from experiments conducted with the device positioned at a railway level crossing, observing passing trains and various motor vehicles including cars, trucks, and buses, indicated a generated power of 18,185 watts. With the series installation of ten such devices, a total power output of 165.44 Watts per day can be achieved, which is sufficient to meet the energy demands of the signaling system.

The harvested energy powers signaling systems, lighting, and other electronic equipment at level crossings. Implementing this technology not only enhances sustainability through renewable energy use but also reduces reliance on external electricity supplies. Consequently, piezoelectric technology significantly improves operational efficiency and railway safety, particularly at level crossings.

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1. 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.

2. RESEARCH METHOD

This study uses an experimental method with a literature study approach. The experimental 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. With this method, the device is tested in a real situation, where the resulting data is analyzed to ascertain whether the device is functioning according to the predetermined objectives. This experimental approach is important to ensure the validity and accuracy of the research results, as well as to effectively evaluate and optimize the tool design.

A. *Product Design and Device Diagram*

In Figure 1, the device was designed based on a comprehensive literature review, which showed that arranging larger piezoelectric components in series can increase the electrical energy output more effectively than a parallel circuit configuration. Therefore, the dimensions of the device were set at 6 cm x 6 cm to fit the width of the rail [4]. Therefore, the device dimensions are set at 6 cm x 6 cm to fit the width of the rail. with 1 device having 6 - 7 piezoelectrics arranged in parallel.

This device is strategically positioned in the middle of the railway tracks. Given that the typical length of a railway track section at a level crossing ranges from 15 to 20 meters, and considering the device's length of 6 cm, it is feasible to install 10 such units. This arrangement is anticipated to significantly enhance the effectiveness of electrical energy harvesting.

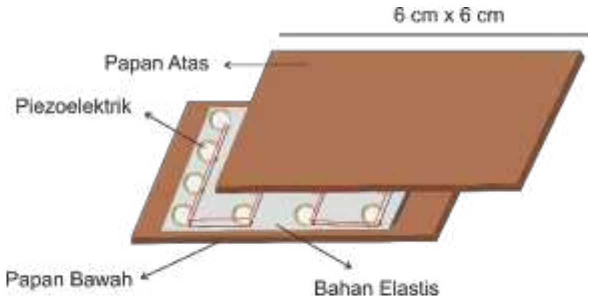

Figure 1. Product Design

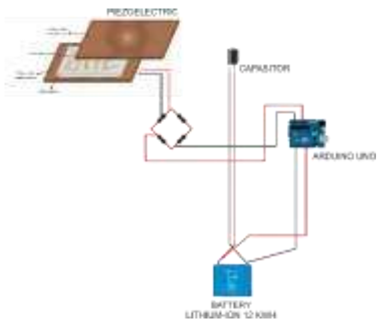

Figure 2. Device Diagram

- **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.

B. *Flow chart*

Figure 3 will explain how the tool works. When the tool is turned on, the Arduino will initialize all previously configured sensors. Then the vibration sensor will read the conditions around when there is vibration or there is vibration that passes through the vibration will be converted into electricity which then the Arduino records the electricity produced and after that is distributed to the lithium battery which functions as a storage of electrical energy and distributes it to the signaling system.

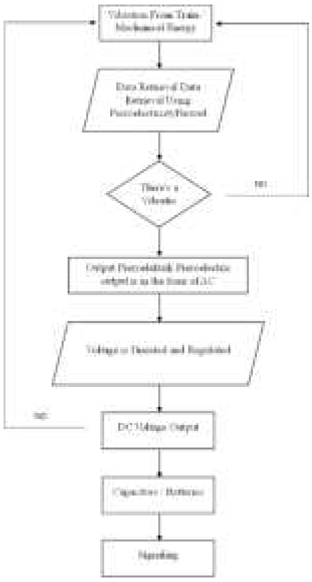

Figure 3. Flow Chart System

C. *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 (2500×10^{-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 mPower Generated (P),
If vibration occurs at a frequency f, so the average (Ppower) 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)

3. RESULTS AND DISCUSSION

Based on data obtained from field observations on level crossings, it can be seen that there is a frequency, speed and vibration for each vehicle:

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

3.1. Formula Consumption Power at the Crossroads Train Fire

1. **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:

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

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

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

3. **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.

3.2. Frequency in train crosses

based on observations made in the field, obtaining data on frequency, speed, vibration, and total weight on each train, motorbike, car, bus, and truck. This data is then processed using a formula to convert vibrations into electrical energy. The calculation results are presented in the following table:

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.

4. CONCLUSION

Research findings indicate that the application of piezoelectric sensors on railway tracks holds considerable promise for sustainable energy generation. By harnessing and converting vibrations produced by passing trains and vehicles, these systems are capable of generating electrical energy to support the operation of signaling systems and other electronic equipment at level crossings. The study demonstrated that a single piezoelectric unit installed at a level crossing can produce approximately 18,185 watts per day. Considering that the energy requirement for each level crossing is around 165.44 watts per day, it is estimated that about 10 piezoelectric units would be necessary to fully meet this demand.

This technological approach not only offers an innovative solution for energy generation but also decreases reliance on external energy sources, enhances energy efficiency, and promotes environmentally sustainable practices within railway infrastructure. Overall, the research underscores the potential of piezoelectric energy harvesting as a practical and sustainable strategy to fulfill operational energy needs in the railway sector, supporting renewable energy initiatives and contributing to the reduction of environmental impacts.

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