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Model of Street Light System Based on Piezoelectricity

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ABSTRACT:Indonesia has a high potential for motor vehicle ownership since there are 133 million motor vehicles in 2019. To overcome the limitations of fossil fuels whose availability is dwindling with increasing use or demand, renewable energy is designed as alternatives that are more environmental-friendly and can be used for the long term. The authors aims to utilize the pressure and vibration of vehicles on the road to generate electrical energy by utilizing piezoelectric. Piezoelectric is a reversible material, so when there is pressure and vibration, an electric field will occur and create mechanical deformation so that it can produce electrical energy. The tools used in this study were designed and investigated by considering the static motion of the vehicle. Researchers conducted experiments by looking at the current output and voltage so that the system output power was obtained. Experiments were carried out using a Vega motor, a Vario 125 motor, a CB150R motor, and a small car, as well as experiments with combinations and changes in vehicle load variables. As a result, the researcher found out the output value is directly proportional to the load obtained and the largest power results were obtained in the small motor experiment.

KEYWORDS: Energy, street light system, Motor vehicle, Piezoelectric.

I.INTRODUCTION

The need for electrical energy increases rapidly every year, along with the increase in activity and the number of people. The progress of the level of electricity in Indonesia is increasing rapidly but still relies on fossil fuels, especially coal. Coal is a non-renewable resource and one day it is feared that it will experience a crisis with high consumption and little availability. In addition, coal also has a high potential to damage the environment. To prevent environmental damage and the crisis of fuel availability, prevention is needed. One way to prevent it is to use renewable energy. Renewable energy can be supported by the potential of natural resources and other potentials, such as the very high number of motorized vehicles in Indonesia where in 2019 the number of vehicles reached 133 million vehicles (BPS; 2020).

Utilization of pressure and vibration from passing vehicles can use the Transducer system. The transducer is an energy that can be converted into other energy or can be interpreted as a device that converts a mechanical force or displacement into an electrical signal. The piezoelectric transducer is one type of active transducer that uses the working principle of generating electricity from piezo crystal material due to external forces. This type of transducer can receive input in the form of sound, vibration, and acceleration in the way it works (Krisdiyanto quoted in Almanda et al; 2016). Energy harvesting from vibration can use piezoelectric materials. Piezoelectric material is a material that can generate electricity when it is deflected (Mowaviq, M. I et al; 2019). In this study, researchers conducted an analysis and comparison of the output current, voltage, and power generated by the system from the designed tool.

The concept of this tool is to utilize the pressure of a motorized vehicle to apply pressure to the piezoelectric so that it will generate electricity. Based on the research results (Siregar, Matoga, 2021) it can be seen that the series circuit of the electric energy source will increase the voltage, while the parallel circuit of the electric energy source will increase the current so that the piezoelectric will be arranged in series-parallel.

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II.SYSTEM MODEL AND ASSUMPTIONS

2.1 System Design

Piezoelectrics are connected in series and parallel to increase and stabilize the piezoelectric output voltage supply. The advantage of a series circuit is that the resulting voltage value is the result of the sum of the output voltages on each piezoelectric so that the output voltage value will be greater along with the increasing number of piezoelectrics that are arranged in series (Diarnadi, d, et al; 2018). Meanwhile, the disadvantage of the piezoelectric series circuit is that if one of the piezoelectric components does not produce a voltage, there will be a voltage drop or the output voltage produced is much lower than when the circuit is in normal condition. It can be overcome by using a parallel circuit. Parallel circuits are series circuits that are arranged in a row. In a parallel circuit, the resulting voltage will remain stable even if a problem occurs in one component because it will be supplied by another series circuit. Piezoelectric parallel series circuits can be seen in Piezoelectric Series-Parallel Circuits.

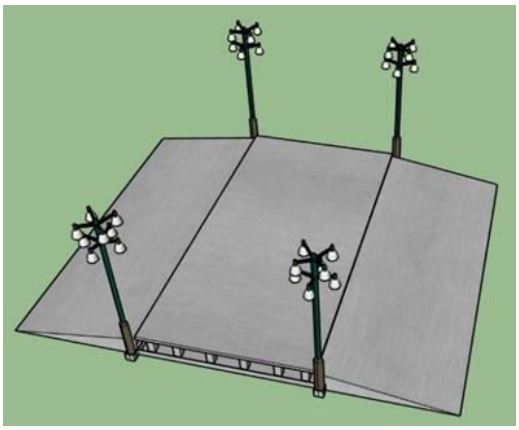

Fig. 1 The image of tool design

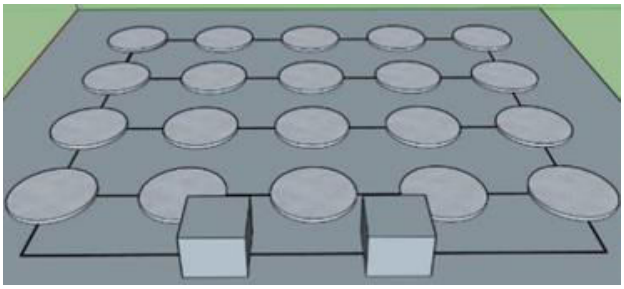

Fig. 2 The image of the system application

2.2 Working Principle

The Energy Storage system in the prototype uses a 12V battery. The 12V battery charger will use the output voltage of the piezoelectric series-parallel circuit. The piezoelectric series-parallel circuit depends on the vehicle passing through it, so the piezoelectric series-parallel circuit does not always produce electrical energy, so an energy storage system is used which aims to produce a stable and sustainable source of electrical energy. The voltage generated by the piezoelectric series-parallel circuit must be greater than the nominal voltage of the battery, which is 12V, then it is lowered and stabilized using a charge controller. It aims to prevent the battery from being damaged quickly due to an unstable charger voltage or exceeding the nominal voltage.

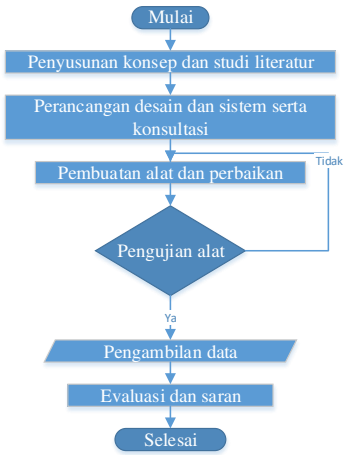

Fig. 3 Tool Technical Work Flowchart

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Fig. 3 describes the working system from design to tools that are suitable for use and produce the appropriate output. The design is carried out by consulting and researching the system based on literature studies, which aim to maximize execution and minimize losses. Execution and research were carried out at the Electrical Energy Conversion Laboratory, Faculty of Engineering, University of Jember.

2.3 Testing Techniques, Feasibility, and References

The test was carried out by experimenting with 4 types of vehicles, namely vega motorcycles, Vario 125 motorcycles, CBR motorcycles, and cars. The experiment was carried out in real-time by changing the amount of load for each data collection. Researchers take the current output, voltage output, power output by multiplying the current and voltage. In addition, the researchers also conducted a combination experiment on the type of motorcycle and the number of passengers.

III.PIEZOELECTRIC

Piezoelectric is a material that will produce an electric field when exposed to mechanical stress. Piezoelectric materials are also reversible where if an electric field is applied to the piezoelectric material, mechanical deformation occurs in the material (Angga, 2018). Because of the advantages of this material, piezoelectric materials are starting to be widely used as materials to make a system that can perform energy harvesting. This system can generate electrical energy by capturing pressure or vibrations that come from outside (Kurnia et al, 2017).

The voltage generated by each layer is equal to Vem, and because the use of piezoelectrics will be arranged in parallel, the addition of piezoelectrics does not affect the voltage, while the current generated from this arrangement is the sum of the currents generated by all piezoelectrics (Setiawan et all; 2020). Due to the piezoelectric generated voltage:
$Vem = Ve(1) = Vem(2) = \cdots = Vem(n)$
Then the resulting current: $Ipiezo = Ipiez(1) + Ipiezo(2) + \cdots + Ipiezo(n$
In contrast to the parallel piezoelectric, the series piezoelectric causes the generated voltage to be multiplied by the number of piezoelectrics used, the addition of a piezoelectric does not affect the current generated from the array (Setiawan et al; 2020).Due to the current generated by the piezoelectric:

$Ipiezo = Ipiez(1) = Ipiezo(2) = \cdots = Ipiezo(n)$

Then the resulting voltage: $Vem = Ve(1) + Vem(2) + \cdots + Vem(n)$

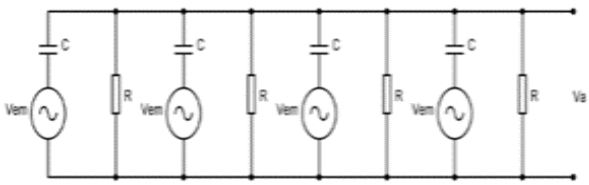

Fig. 4 Piezoelectric Parallel Circuit

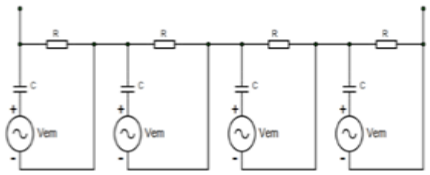

Figure 5. Piezoelectric Series Circuit

IV.MECHANICAL AND ELECTRIC PROPERTIES OF PIEZOELECTRIC

4.1 Mechanical Properties

Mechanical properties can descripted using Fig.6. If in this condition force balance, so the properties can shown as

Fa = Fk - Fe
Fa = k.x – k.d33.v

where : v = Q/C; Q = Fa.d33; C = ∈.A/tpiezo; k=Y.A/tpiezo

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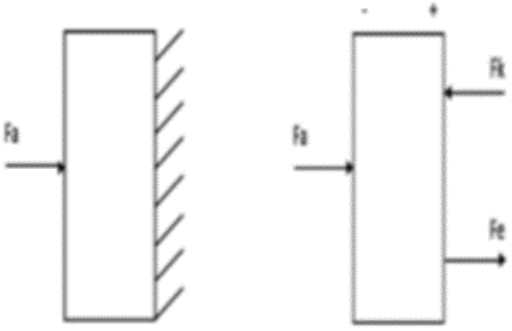

Fig. 6 Piezoelectric Mechanical Properties

Information:
Fa = Outer force of piezoelectric (N)
Fe = The electric force that occurs when the piezoelectric is applied to an external force (N)
F = The mechanical force that occurs when the piezoelectric is applied to an external force (N)
$d33$ = Piezoelectric charge constant (C/N)
k = Spring coefficient (N/m)
V = Electric potential (V)
Q = Electrical charge (C)
C = Capacitance (F)
$\in$ = Dielectric constant (F/m)
Y = Modulus young (N/m2)
A = Piezoelectric area (m2)
$tpiezo$ = Piezoelectric thickness (m)
x = Deflection of piezoelectric (m)

4.2 Electrical Properties

Based on Fig. 7, the following equation is obtained:

Va = Vem - Vc

So the relationship between the mechanical and electrical properties of single layer piezoelectric is:

Vem=(k.d33)/C.x ; I = (k.d33)/(C.Z).x

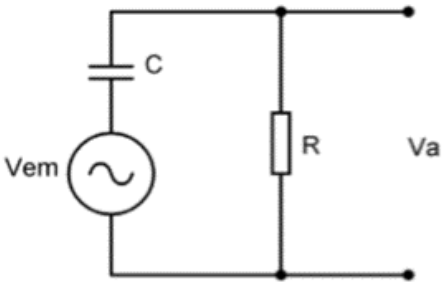

Fig. 7 Piezoelectric Electrical Properties

Where Z = Rpiezo + 1/ωC
Information:
= Piezoelectric voltage (V)
= Voltage across the resistor (V)
= Voltage across the capacitor (V)
Z = Impedance (Ohms)

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V. RESULT AND DISCUSSION

The working system of this tool uses several components such as piezoelectric, 12V power supply unit, boost converter, solar charge controller, 12V battery, 1000 watt pure sine wave inverter, 4A MCB, and a load of 100 watts PJU LED lamp.

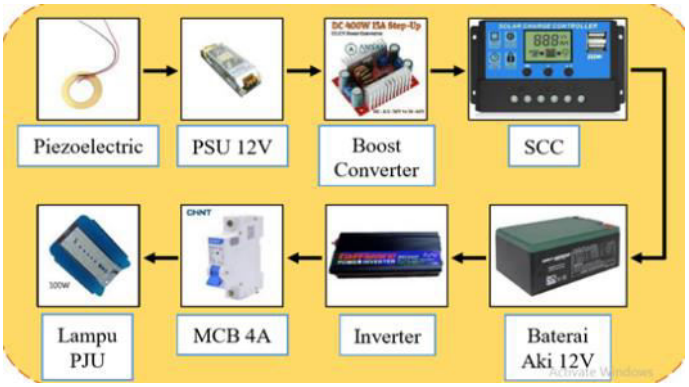

Fig. 8 Tool System Workflow

In Figure 5, the series-parallel circuit is used to combine parallel and series systems so that a constant and stable voltage is obtained, while the series circuit aims to maximize the current flowing. In addition, a series circuit can also be used to prevent the piezoelectric from reabsorbing the energy generated when the cross-section or surface of the tool is not fully stressed.

Table 1. Experiment Results

No	Test Type	Voltage (V)	Current (mA)	Power(mWatt)
1	Vega Motorcycle 1 person	3,96	0,13	0,5148
2	Vega Motorcycle 2 people	4,12	0,12	0,4944
3	Vario Motorcycle 125 1 person	3,55	0,12	0,426
4	Vario Motorcycle 125 2 people	4,95	0,14	0,693
5	CB150R Motorcycle 1 Person	4,99	0,11	0,5489
6	CB150R Motorcycle 2 People	5,13	0,13	0,6669
7	Vario Motorcycle 1 person + CB150R Motorcycle 1 person	7,54	0,13	0,9802
8	Vario 2 Motorcycle people + CB150R Motorcycle 2 people	6,83	0,18	1,2294
9	Vega Motorcycle + Vario Motorcycle	5,9	0,09	0,531
10	Small car	17,13	0,88	15,0744
11	Small car 4 people	15,45	1,284	19,8378

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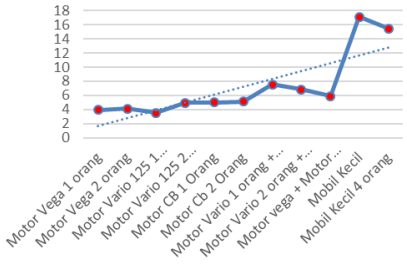

Fig. 9 Graph of Voltage Result

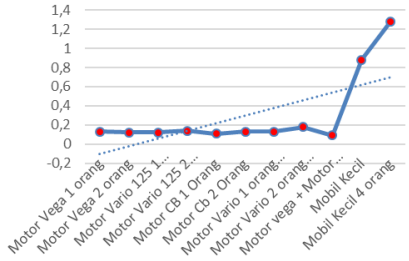

Figure 10. Graph of Flow Output

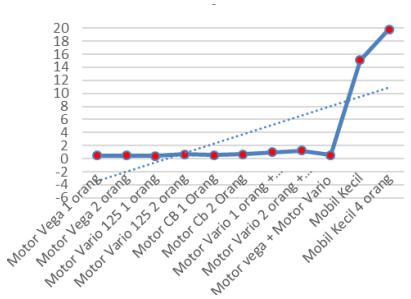

Figure 11. Graph of Power Output

Based on the test results, it can be seen that the highest output power is produced in the test using a small car with 4 passengers, the highest voltage is in a small car with 1 person, and the highest current is in a car with 4 people. This can be seen based on the resulting output power of 19.8378 Watt. In the test data, it can be seen that the greater the load that passes through the device, the greater the output power value will be. From the analysis, it was found that this tool is more suitable to be applied to toll roads because it can produce higher and more abundant power.

From several literature sources, there are data generated and output in a fixed state or the load is not moving, so that the load calculation can be carried out directly, but in making the tool it is necessary to pay attention to the system construction so that the tool does not disturb road users and a system that can harvest energy when the vehicle crosses the tool. The disadvantage of the tool is the use of Styrofoam material in energy harvesting when the vehicle is moving so that an energy harvesting system can be made to achieves the highest results on piezoelectric even though it does not reach the saturation point or does not get uniform pressure on the surface of the tool.

VI.CONCLUSION

From the discussion and review in the article, it can be concluded:
1. The Piezoelectric-Based Street Lighting System prototype works most optimally when testing using a small car with 4 passengers which produces an output power of 19.8378 mWatt.
2. Prototype Piezoelectric-Based Street Lighting System is more optimally used on toll roads because the vehicle intensity is quite high so that energy resources are always available.
3. The greater the load through the tool, the greater the output power will be.

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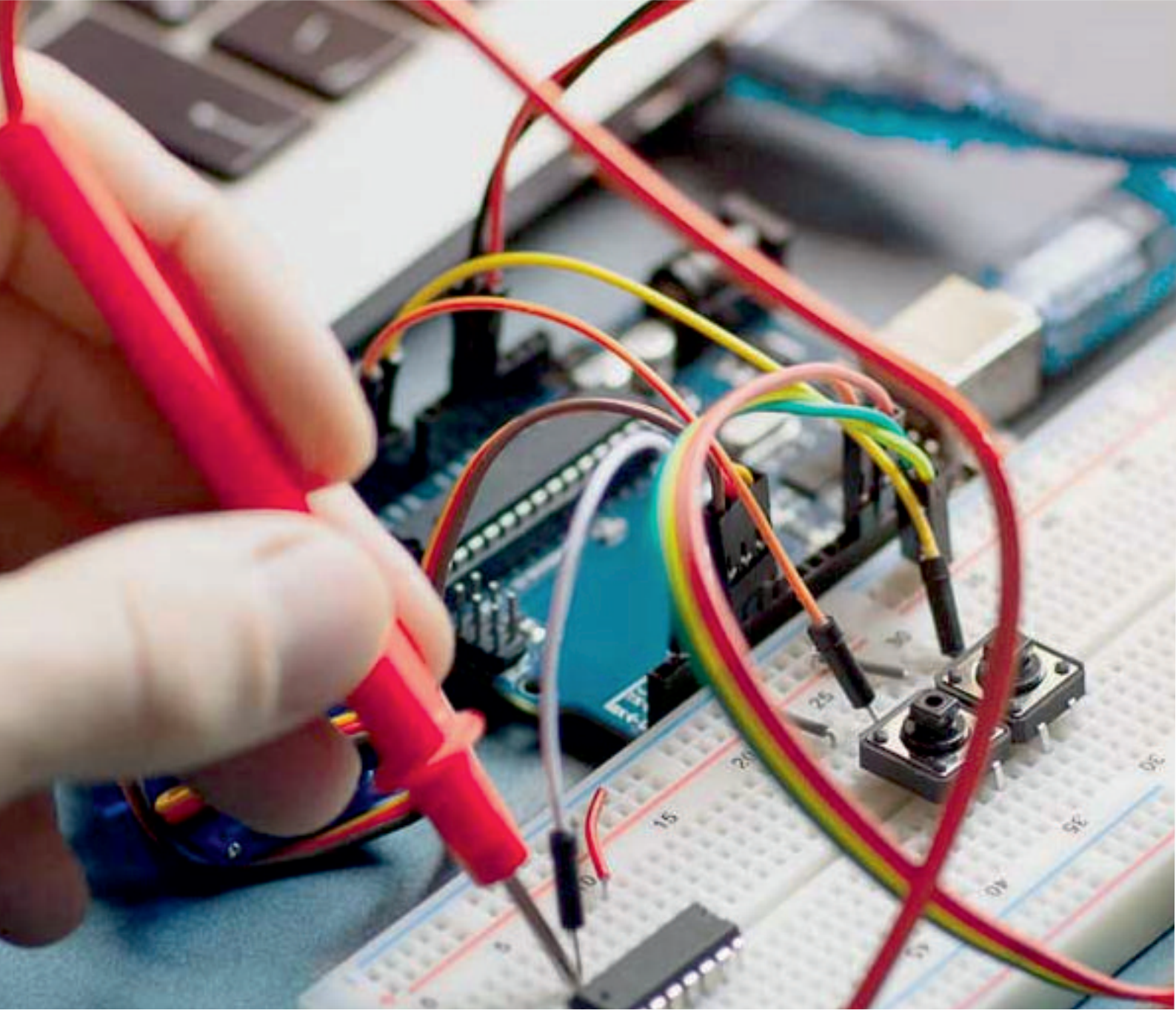

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