Output voltage characteristic of heat pipe sink thermoelectric generator with exhaust heat utilization of motorcycles

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Abstract. Nowadays the great challenge to energy engineers is how to develop new and renewable energy sources to reduce the use of fossil fuels. In this direction, the research focuses on the recycle of wasted heat energy on a motorcycle exhaust gas into electrical energy using the concept of seed back. Recycle energy using this concept on a motorcycle is done because the bike has the energy efficiency of $\pm 35 - 40\%$ while the rest were dumped unceremoniously in the form of heat energy that is issued through the exhaust. This research aims to know the characteristics of the output voltage heat pipe sink thermoelectric generator utilizing waste heat of the motorcycle. This research has been done on the measurement of the output voltage is generated by the thermoelectric module series TECI-12706B type SP1848-27145 SA as a heat pipe sink thermoelectric generator to produce electrical energy. This research was conducted to know the output voltage from 4 thermoelectric modules arranged in series or parallel. Furthermore this thermoelectric generator will be the main energy source for SSUPER-BT devices. Stages of the research done by performing laboratory and road testing. In laboratory testing, simulation of thermoelectric generator made using aluminium rods contain Heater. two sides of the aluminium coupled to thermoelectric modules, heat pipe and CPU fan. in each experiment, the thermoelectric modules strung together in series or in parallel. The results showed on the TEGs with 4 thermoelectric modules in series were able to produce higher output voltage and current compared to TEGs with 2 thermoelectric modules with output voltage reaching 15.7 volts and 7.7 volts respectively. The TEGs circuit with 4 thermoelectric modules produces 72.6\% greater power than TEGs with 2 thermoelectric modules.

1. Introduction

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Development of renewable energy such as wind energy, geothermal, solar cell, ocean thermal energy conversation and others as power plants continue to seize the attention of energy engineers. The important consideration of research on the development of renewable energy is due to the desire to utilize renewable energy to replace the use of fossil energy as the main energy source.

The development of technology causes electricity be the one of the primary energy needs of the human being. Electricity is an energy that can be directly used in everyday life\cite{1,2}. Electricity service providers in Indonesia such as PLN are still using non-renewable fossil energy such as coal to generate electricity to supply the country's electricity needs. In the process of electricity generation only about 34% is actually converted into electrical energy while the remaining energy is lost or wasted in the form of heat energy commonly called heat energy waste.

Waste heat energy is generated by machines that process energy. Waste heat energy also occurs in the combustion process in motorcycle fuel engines. The small efficiency of motorcycles and the concept of thermodynamic law that has the system's need to reject heat as a by-product of its operation causes only about 40% of the energy that can be used to drive the motor. The remaining energy is lost and simply thrown into the environment through the exhaust in the form of waste heat energy. This waste heat has a higher entropy than the original energy source.

This is the background of research on the reuse of waste heat energy in motorcycle into electricity with the help of thermoelectric generator. By using thermoelectric generators, waste heat generated from the heat of the motor cycle exhaust can be recycled into electrical energy, which can then be reused to another activities\cite{3-5}.

Electricity on the thermoelectric generator due to different temperatures between the heated and cold sides of the thermoelectric module by rapidly transferring heat\cite{6-9}. The larger the temperature difference (\(\Delta T\)) between the hot and cold sides, the greater the power generated. Low curves so thermoelectric has a weakness in the efficiency side that is classified as low as 10%. Factors affecting the low efficiency of the thermoelectric module are the overall unconverted heat and cooling system on the cold side of the imperfect thermoelectric module\cite{10,11}. This study aims to find the Characterization Output Voltage Of Heatpipe Sink Thermoelectric Generator With Exhaust Heat Utilization Of Motorcycles

2. Methodology

2.1. Preparation and design of thermoelectric generator

Thermoelectric generators (TEGs) are designed using 4 thermoelectric modules TECI-12706B type SP1848-27145 SA dimensions 50 x 50 mm with 4 mm thickness in series in pairs between aluminium plate 120 x 120 mm, as shown in Figure 1. The TEGs system is used to capture the flow of heat flowing in the motorcycle exhaust channel, where the heat flowing in the drains is absorbed to the hot side of the thermoelectric through the heat absorber plate. The heat will be utilized to produce \(\Delta T\) on the thermoelectric module. The cold side of the thermoelectric module will be fitted with a heat pipe sink functioning to lower the temperature of the cool side of the thermoelectric to obtain a larger \(\Delta T\). The amount of \(\Delta T\) generated in the thermoelectric module is highly dependent on the heat of the exhaust and cooling by the heat pipe on the cold side of the thermoelectric module. Figure 2 is the design of the TEG system used to absorb heat in motorcycle exhaust channels.
2.2. Experimental set-up
The exhaust heat in the motorcycle exhaust channel is simulated using a heating plate using a catheter heater with heat reaching 240°C. Figure 3 is a schematic of TEGs output voltage characterization test. Voltage regulators are used to regulating heat loading in simulated exhaust heat. TEGs mounted on the simulator plate are loaded 15.57 Watt up to 28.18 Watt to achieve exhaust gas temperature 80°C up to 240°C. The exhaust gas temperature on the simulator plate is varied from 80°C, 100°C, 120°C, 140°C, 160°C, 180°C, 200°C, 220°C and 240°C. Several K type thermocouples are mounted on the simulator plate, the thermal side of the thermoelectric module, the cold side of the thermoelectric module and on the heat pipe sink section. The thermocouple is connected to the NI 9213 and c-DAQ 9174 acquisition data. The voltage and current generated for each load are measured using the Avometer and clamp meter.

Figure 1. Thermoelectric Module.

Figure 2. Design of TEGs system.

Figure 3. Schematic testing of output voltage characteristics of TEGs.
3. Result and Discussion

Tables 1 and 2 are voltage and current characteristics of TEGs that are coupled in series with 2 and 4 thermoelectric modules. From the table, it can be seen that in series circuit with two thermoelectric module, the highest voltage generated is 7.7 volts at a 77°C temperature different. In this circuit, the amount of maximum power that can be produced is 6.8 watts at a strong current of 884 mA. In the series circuit with four thermoelectric modules, the highest voltage is 15.7 volts which are achieved at a 126°C temperature different. In this circuit, the maximum power generated is 24.9 watts at a current of 1584 mA. The series with two thermoelectric modules produce 2 watts of power up to 6.8 watts in the temperature difference that range from 22°C to 77°C. The power of 2 watts to 24.9 watts in the 20°C to 126°C temperature different range is generated by series chains with 4 thermoelectric modules.

The temperature different that generated by series circuit with 2 and 4 thermoelectric module very influential to the magnitude of voltage and output current from TEGs, wherein circuit with 2 thermoelectric module, the temperature difference is not too big because in a certain time interval temperature hot side start propagating to the side cold so that the cold side of the temperature near the hot side temperature. This propagation is due to cooling on the cold side of the thermoelectric is less able to overcome the heat propagation from the hot side. Thermoelectric 2 circuits are also less able to manage exhaust gas temperatures so that thermoelectric efficiency is not able to overcome the exhaust gas temperature that affects the small delta temperature. The lower of temperatures different produces smaller voltages and stronger currents.

| Exhaust Gas Temperature (°C) | Thermoelectric module | Hot side Thermoelectric (°C) | Cool side Thermoelectric (°C) | Temperature Different ΔT (°C) | Voltage (Volt) | Current (mA) |
|------------------------------|------------------------|-----------------------------|-----------------------------|-----------------------------|---------------|-------------|
| 80                           | 2                      | 68                          | 46                          | 22                          | 3.6           | 558         |
| 100                          | 2                      | 88                          | 61                          | 27                          | 3.8           | 569         |
| 120                          | 2                      | 102                         | 74                          | 28                          | 4.1           | 602         |
| 140                          | 2                      | 122                         | 84                          | 38                          | 4.5           | 633         |
| 160                          | 2                      | 148                         | 93                          | 55                          | 5.3           | 679         |
| 180                          | 2                      | 163                         | 101                         | 62                          | 6.2           | 724         |
| 200                          | 2                      | 184                         | 112                         | 72                          | 6.8           | 783         |
| 220                          | 2                      | 201                         | 124                         | 77                          | 7.4           | 841         |
| 240                          | 2                      | 222                         | 145                         | 77                          | 7.7           | 884         |

| Exhaust Gas Temperature (°C) | Thermoelectric module | Hot side Thermoelectric (°C) | Cool side Thermoelectric (°C) | Temperature Different ΔT (°C) | Voltage (Volt) | Current (mA) |
|------------------------------|------------------------|-----------------------------|-----------------------------|-----------------------------|---------------|-------------|
| 80                           | 4                      | 58                          | 38                          | 20                          | 3.6           | 558         |
| 100                          | 4                      | 82                          | 40                          | 42                          | 4.8           | 669         |
| 120                          | 4                      | 105                         | 42                          | 63                          | 6.1           | 872         |
| 140                          | 4                      | 118                         | 44                          | 74                          | 7.5           | 993         |
| 160                          | 4                      | 138                         | 53                          | 85                          | 8.9           | 1109        |
| 180                          | 4                      | 158                         | 61                          | 97                          | 10.6          | 1224        |
| 200                          | 4                      | 178                         | 72                          | 106                         | 12.4          | 1343        |
| 220                          | 4                      | 198                         | 84                          | 114                         | 13.8          | 1461        |
| 240                          | 4                      | 218                         | 92                          | 126                         | 15.7          | 1584        |
Figure 4 was an output voltage and current distribution of TEGs with 2 thermoelectric modules assembled in series. The larger the temperature difference generated by the hot side with the cold side portion produces a higher voltage and current. Each of thermoelectric has the ability to produce temperature differently, but the temperature difference also depends on cold side cooling and efficiency of each thermoelectric module so that it will greatly affect the heat source temperatures. In a series 2 thermoelectric modules is only capable of producing a maximum temperature different of 77°C, which is smaller than the TGEs circuit composed of 4 thermoelectric modules. The maximum of temperature different at 126°C is capable of being generated by TEGs in circuits with 4 thermoelectric modules, as shown in figure 5. The larger of temperature different of TEGs with 2 thermoelectric modules result in greater output voltage and current TEGs also greater.

![Figure 4. Distribution of voltage and current with 2 thermoelectric module at exhaust gas temperature (a) and TEGs temperature different (b).](image)

![Figure 5. Distribution of voltage and current with 4 thermoelectric module at exhaust gas temperature (a) and TEGs temperature different (b).](image)
The magnitude of the output power generated by TEGs with 2 and 4 thermoelectric modules that are arranged in series are shown in figure 6. From the figure it appears that the temperature difference and the amount of power generated by each of TEGs are also different. In a series of TEGs with 4 thermoelectric modules have better thermal management capability so the result of temperature difference is greater than the circuit with 2 thermoelectric modules. This results in the maximum power capable of TEGs with 4 thermoelectric modules 72.6% greater than the power generated by TEGs with 2 thermoelectric modules, each producing maximum power of 24.9 watts and 6.8 watts.

4. Conclusion

From the research, it was found that TEGs with 4 thermoelectric modules in series were able to produce higher output voltage and current compared to TEGs with 2 thermoelectric modules with output voltage reaching 15.7 volts and 7.7 volts respectively. The TEGs circuit with 4 thermoelectric modules produces 72.6% greater power than TEGs with 2 thermoelectric modules.

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