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Simulating Utilization of Waste Heat of Motor Vehicles-Based On Thermoelectric Generator

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ABSTRACT

The main power source of motor vehicle is combustion engines which use fossil fuels (diesel, gasoline, pertamax etc.) as fuel. The total heat supplied to the engine in the form of fuel, 30-40% of fuel is converted into mechanical work, heat remaining is released through the exhaust pipe and the engine cooling system. The unused heat source in motor vehicles could potentially be used to generate electricity as a supplier of electricity needs in a vehicle. The technology used to convert the heat energy into electrical energy known as the thermoelectric generator, which uses the Seebeck theory as the basis of the principle works. This study uses a cylinder with a heating element inside (heater) as a heat source such as the exhaust pipes designed in a motor vehicle. Cylinder temperature is simulated as the temperature of the exhaust pipes of motor vehicles by varying the input voltage supplied to the heater (150V, 175V, 200V and 225V). This study also uses sub-sonic wind tunnel as a source of wind to vary the speed of exhaled air to test equipment to simulate the vehicle speed (20 km/h, 30 km/h, 40 km/h, 50 km/h and 60 km/h). By using 8 thermoelectric modules arranged in series electrical, power (P) generated a maximum of 0.88 Watt with voltage difference (ΔV) 11:13V and a maximum temperature difference (ΔT) 47.61°C. This condition is obtained on the input voltage at 225V heater with air velocity 20 km/h.

Keywords: Thermoelectric generator, heater, sub-sonic, wind tunnel.

1. INTRODUCTION

Along with the rapid technological developments, and information industry, electrical energy into one of the basic needs that are very important in human life today, where almost all human activities related to electrical energy. Most of the primary energy use for generating electrical energy derived from fossil fuels, while availability is limited and continue to diminish. The internal combustion engine is one of the major consumer of fossil fuels worldwide. Of the total heat supplied to the engine in the form of a 30-40% fuel is converted into mechanical work [1]. The remaining heat lost to the environment via the exhaust (muffler) and the engine cooling system which causes thermal pollution see figure 1. Therefore, it takes the reuse of heat energy to be used as a more useful energy. The technology use to convert the heat energy into electrical energy known as the thermoelectric generator.

Thermoelectric generator (TEG) is a power plant based on the Seebeck effect, which was first discovered in 1821 by Thomas Johann Seebeck [2-5]. Seebeck concept illustrates that if the two pieces of metal material (usually semi-conductor) connected and maintained at different temperatures, then the material will flow electric current [6].

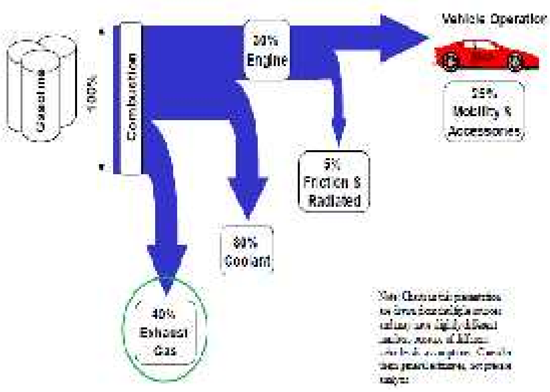


Figure 1. Visualization of energy use on the machine [7]

This technology has been widely researched in the present century like, in the report Nandy et al, he simulate a heat source using a heater (heater) varied the voltage, is 110V and 220V.

The test results showed that with twelve peltier elements arranged in series with the heater voltage 220V, can produce a maximum output power 8,11 W with an average temperature difference of 42.82 ° C [6]. Idrus and Muhammad Amrullah in the thesis utilization of waste heat of the exhaust stack muffler (ESM) Mobilio Honda 1500cc with a thermoelectric generator. Results showed a single module achievement TEG (TEG modules 8 with connectivity modules in series electrical TEG) produces a maximum temperature difference is 15:28 ° C, 7.1071 V, 0.2589 W at 3000 rpm rotation [8]. This condition obtained with vary the engine speed at a car with zero vehicle speed or stationary. Therefore, we need to do research the use of waste heat of vehicles by providing different speeds.

The purpose of this study is as follows: 1) Knowing the influence of the input voltage on the voltage regulator that given to the heater against the cylinder wall temperature changes; 2) Knowing the influence of air speed on the ability of cylinder wall maintaining the temperature maximum; 3) Knowing achievement thermoelectric modules (P) of simulated thermoelectric generator with variations in airspeed.

2. Basic Theory

Thermoelectric is a device that can convert heat energy directly into electrical energy or vice versa, to convert electrical energy into the heat pump/cooling. Based system works temoelektrik divided into two temoelektrik cooling (thermoelectric cooler) and thermoelectric plants (thermoelectric generator) **[3]**. In the thermoelectric generator using the Seebeck effect as its working principle, where the thermal energy is converted into electrical energy, while the thermoelectric cooling using the Peltier effect as a working principle which is the inverse of the Seebeck effect which converts electrical energy to the temperature difference **[3]**.

The simple design of the thermoelectric module consists of a p-type semiconductor (lack of electrons) and n-type semiconductor (excess of electrons) are connected electrically in series and thermally in parallel. The structure of the thermoelectric module can be seen in Figure 2. consisting of ceramic substrack, thermoelectric legs, metal interconnects and the external electrical connections.

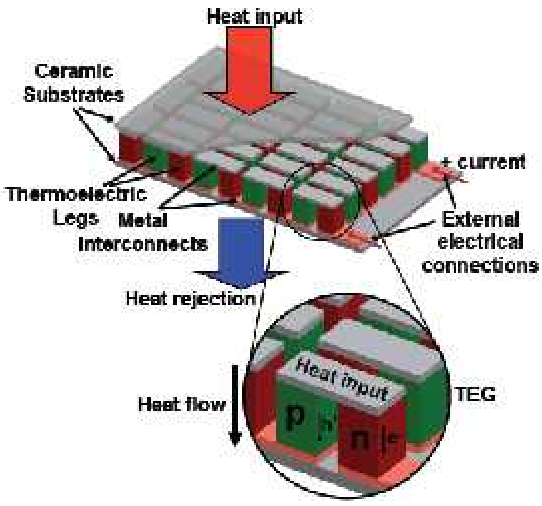


Figure 2. Structure of the thermoelectric module [9]

The ability of thermoelectric material to produce a high energy conversion efficiency is determined from the material used. To determine the ability of a material known by the thermoelectric module figure of merit (FOM). FOM can be determined by the following equation 1 **[10]**:

$$Z \quad = \frac{S^2\sigma}{\lambda} T \qquad (1)$$

Where σ is the electrical conductivity of the material, λ is the thermal conductivity and S is the Seebeck coefficient. Conventional unit of the Seebeck coefficient FOM namely [μV / K]. FOM also commonly symbolized by *ZT* where *T* is the average temperature between the hot side to the cold side $(T_h + T_c)/2$ of the thermoelectric modules. The higher the niali ZT (ZT = 1) of a material the higher the efficiency of thermoelectric modules. The maximum efficiency of a heat engine such as thermoelectric module is determined by the Carnot efficiency (η_{carnot}) **[10]**:

$$\eta_C \quad = \frac{T_h - T_c}{T_h} = 1 - \frac{T_c}{T_h} \qquad (2)$$

Where, T_h is the temperature of the hot side and the cool side T_c is the temperature of the module.

Carnot efficiency can be directly connected to the thermoelectric *ZT* so that maximum efficiency can be calculated using equation 3 **[10]**:

$$\eta_m \quad = \frac{T_h - T_c}{T_h} \frac{\sqrt{1+Z} - 1}{\sqrt{1+Z} + \frac{T_c}{T_h}} \qquad (3)$$

In Figure 3 is an illustration of the cycle thermoelectric generator using the material A and B, the second junction temperature is maintained by heat T_h and cold temperatures T_c $(T_h > T_c)$ and at terminal 1 and 2 are connected to external loads (R_L). Thermoelectric efficiency (η) can be calculated by equation 4 **[9]**:

$$\eta = \frac{P}{q_h} \qquad (4)$$

Where, P (Watt) is the power to the external load R_L (Ω) and q_h (Watt) is the heat energy that is fed to the hot side of the junction. Heat energy in the heat input to maintain the temperature of **[9]**:

$$q_h = K.\Delta T + S.T_h.I - 1/2.I^2R \qquad (5)$$

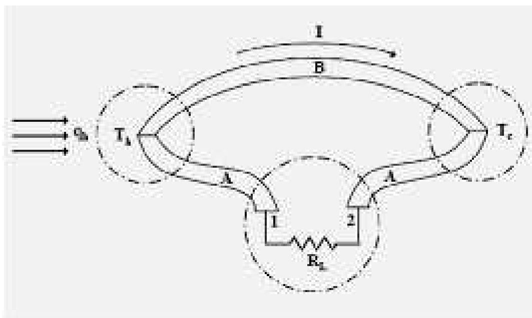


Figure 3. Illustration of the cycle thermoelectric generator [9]

Where, K is the thermal conductivity TEG modules. Rated power (P) obtained by equation 6 :

$$P = I^2 R_L \qquad (6)$$

Where, *I* (A) is the current flow in the cycle and is defined as the ratio between the Seebeck coefficient (*S*) between the material A and B, the temperature difference (*ΔT*) with a total cycle custody **[9]**:

$$I = \frac{S.\Delta T}{R + R_L} \qquad (7)$$

Where:

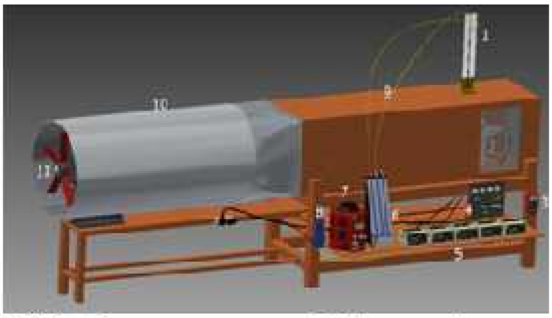
K: TEG modules Thermal conductivity [W/m °C]

R: The electrical resistance of the TEG modules [Ω]

ΔT: temperature difference between the hot side to the cold side [°C]

3. RESEARCH METHODS

In this study, using a cylinder with aluminum material dimension of 190 x 46 mm, placed in the middle third heating element (heater) respectively 130 W. These cylinders are designed like the exhaust pipe (exhaust) on the Honda Mobilio 2014 E type 1500cc MT by giving the input voltage to the heater to simulate the exhaust temperature. Outside the walls of the cylinder block is placed aluminum (body) to be attached to the thermoelectric module. Each side of the body is placed second thermoelectric modules are arranged evenly which serves to generate a voltage difference of the temperature difference on its side. To increase the temperature difference, use fins (heatsink) which laid the cold side of the module temoelektrik to increase the area of heat transfer to the thermoelectric module. Before the installation of thermoelectric modules to the body and heatsink thermal pasthe first applied on each side of the module to reduce the trapped air (air gap) in the contact area. The temperature of each side of the thermoelectric module and the end of the heatsink and the cylinder wall are measured using the type termoekopel K. Thermoelectric Modules connected in electrical series connected with LED lights to indicate that power is generated. Measurement of voltage difference on the module is done on a wired connection connectivity module and LED lights. Installing the study can be seen in Figure 4. Thermoelectric generator that has been assembled is placed inside the wind channel by providing air velocity variations are regarded as vehicle speed, assuming the velocities at the same test equipment to vehicle speed.



1. Pitot tube
2. Test equipment
3. Multimeter
4. LED
5. Diplay and thermocouple
6 Manometer
7. Voltage regulator
8. Tube manometer
9. Wind tunnel
10. Directional air
11. Motor and impeller

Figure 4. Installation Research

4. RESULTS AND DISCUSSION

Testing tools thermoelectric plants is done by doing a variation on the voltage regulator voltage supplied to the heater, this variation to model temperature variation on Honda Mobilio 2014 E-type rotary engine 1500 cc MT 1500 rpm to 3000 rpm. The input voltage of the voltage regulator is given on the heater of 150 V, 175 V, 200 V and 225 V. Then compare the maximum output voltage variation exhaled fluid velocity at the tool thermoelectric plants (thermoelectric generator). Varisai airspeed done of 20 km/h, 30 km/h, 40 km/h, 50 km/h and 60 km/h, the speed is considered to be the average speed of motorists in urban areas and areas with the assumption that air speed of the tool thermoelectric plants the same as the speed of the vehicle.

Data is collected until the data generated stable and did not increase or decrease the temperature and voltage difference. The temperature on the heater will reach a maximum point which depends on the voltage applied via the voltage regulator, when the maximum temperature on the heater is reached, then the temperature in the cylinder wall will be constant.

From figure 5. shown in the relationship between the temperature of the cylinder wall and the muffler (T) with time (t) of the input voltage variation is given on the heater and rev the engine. In these graphs can be seen that the temperature of the heater began to stabilize around 40 minutes and continued data acquisition of up to 60 minutes.

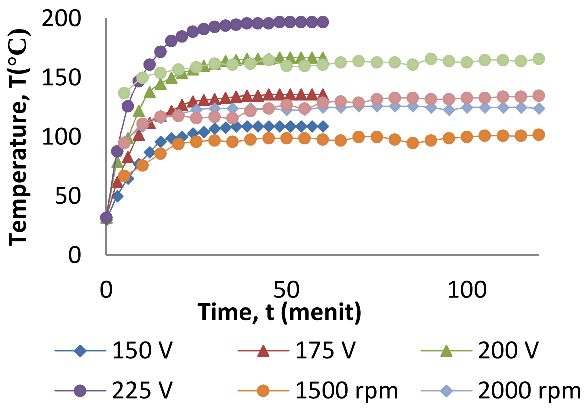


Figure 5. Changes in the temperature of the cylinder wall and the muffler (T) versus time (t) with input voltage variation on the voltage regulator and the spin machine.

These data show that the temperature at a voltage of 150 V input voltage regulator closer to the temperature at the engine speed 1500 rpm, 175 V approaching the engine rev 2000 rpm and 2500 rpm, and the temperature at 200 V input voltage approaches the temperature at the engine speed of 3000 rpm. The maximum temperature that can be absorbed from the cylinder wall heater at 197 °C with voltage input supplied to the regulator voltage of 225 V. This condition is obtained on the air speed of 20 km/h.

In the figure 6 looks the relationship between the cylinder wall temperature (T) with time (t) on the variation of airspeed. The cylinder wall temperature obtained an average yield of differences in input voltage regulator. This graph shows the effect of air velocity to change the cylinder wall temperature, increasing air velocity affects the ability of the cylinder wall to maintain the maximum temperature by providing the same voltage on the heater. Where at the speed of 20 km / h average temperature maximum stable at 152.25 °C and with increasing air velocity average temperatures sequentially decreased to 116.75 °C with an air velocity of 60 km/h. This is due to the increased coefficient of convection air around the test equipment.

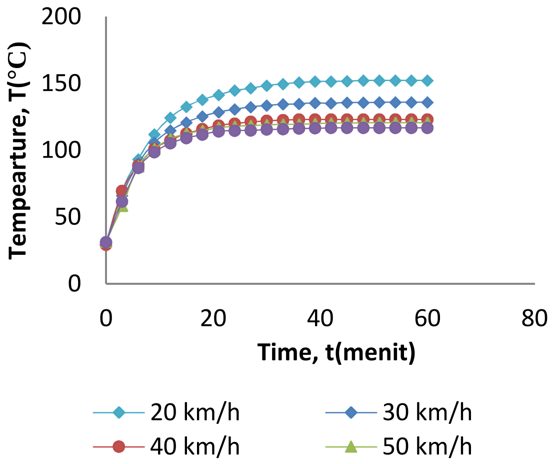


Figure 6. Changes wall temperature cylinder (T) versus time (t) with a variation of airspeed

From the figure 7, shows the relationship changes the voltage difference (ΔV) to the temperature difference (ΔT) with variations in airspeed. A voltage difference is the result of measurements resulting from the testing of thermoelectric plants with a series of modules arranged in series.

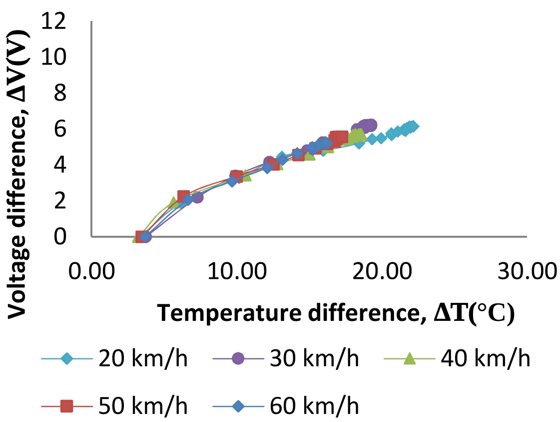


Figure 7. Changes in voltage difference (ΔV) to the temperature difference (ΔT), with a 150 V voltage regulator

The figure 7, shows that the temperature difference is directly proportional to the voltage difference is greater the temperature difference the greater the voltage difference is generated. Based on the graph input voltage of 150V in voltage regulator generates a maximum voltage difference 6.17V and 22.15°C temperature difference, the condition is obtained when the air speed of 20 km/h and with increasing air velocity consecutive decline.

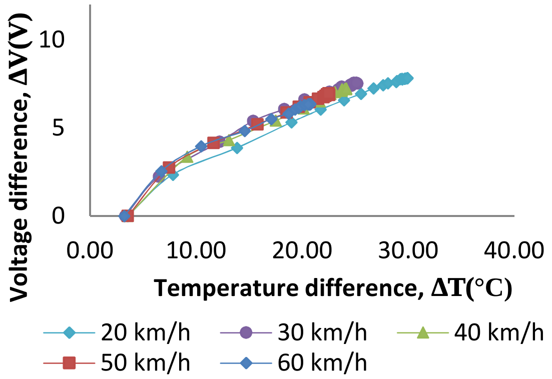


Figure 8. Changes in voltage difference (ΔV) to the temperature difference (ΔT), with a 175 V voltage regulator

In the figure 8 is the relationship changes the voltage difference (ΔV) to the temperature difference (ΔT) with input voltage of 175V. Same as figure 7 with 5 variations of speed, maximum voltage generated by the difference of maximum temperature of 29.90°C are 7.84V.

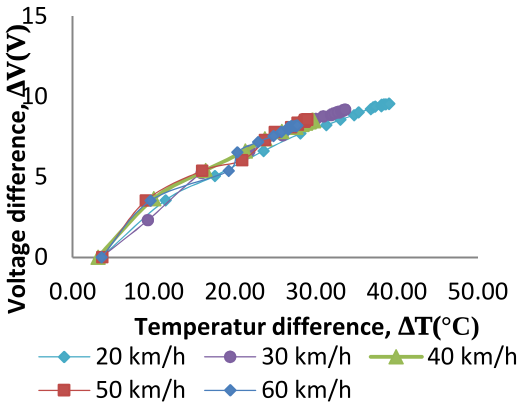


Figure 9. Changes in voltage difference (ΔV) to the temperature difference (ΔT), with a 200 V voltage regulator

In the figure 9, shows the change in the voltage difference (ΔV) to the temperature difference (ΔT) with the input voltage regulator is given on the heater to 200 V. The shape of the graph is equal to the previous Figure, yet different voltage and the resulting maximum temperature difference increased to 9.54V and 39.01°C.

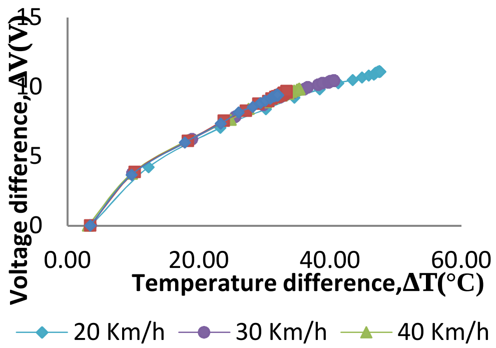


Figure 10. Changes voltage difference (ΔV) to the temperature difference (ΔT), with a 225 V voltage regulator

From the figure 10, shows the change in voltage (ΔV) to the temperature difference (ΔT) with a maximum input voltage at 225V voltage regulator. In this graph shows voltage difference and the maximum temperature difference generated in this study, where the speed of 20km/h produces a voltage difference (ΔV) to a maximum of 11.13V with a maximum temperature difference (ΔT) 47.61°C. With this voltage difference is capable of powering 4 pieces LED red and blue 2 pieces that are arranged in parallel.

The figure 11, showing the relationship of power (P) of the temperature difference (ΔT) in thermoelectric plants. Rated power (P) is obtained based on the calculation of the electrical circuit with a load of 32.866 Ω resistor. With a maximum temperature difference in the thermoelectric modules ranging from 47.61°C can generate power of about 0.88W. This power is obtained by the voltage regulator input voltage 225V and air speed 20km/h which is exhaled in test equipment. From graph can be seen that, along with increasing air speed generated power decreases. This is due to a decrease in temperature difference (ΔT) thermoelectric module so that the voltage difference is generated to be low.

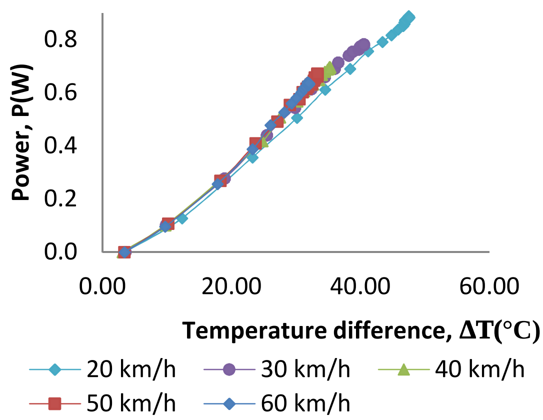


Figure 11. Relations temperature difference (ΔT) to the power (P)

The amount of power produced is also influenced by electrical resistivity and thermal characteristics of the force of the thermoelectric generator (TEG) **[11]**. In the internal system, TEG has different obstacles affecting the voltage generated. In each module being used has a different detainee so that the generated power becomes low. Another factor affecting the power generation is the amount received by the temperature of the module with the potential difference between the two layers of semi-conductors and caused the flow of electrons known as thermal force. The electron flow would be great if the value of thermal great force. To get the maximum force required thermal heat transfer and heat dissipation on both sides of the module optimally, because if uneven heat transfer electron transfer will be stalled due to the absence of electrons is slowing **[11]**. Heat transfer from a block of aluminum on the test equipment to the hot side of the thermoelectric module is mediated by thermocouples as the measurement of temperature, causing the temperature uneven.

To determine the value of the maximum efficiency of thermoelectric plants in this test can be seen in figure 12. The maximum efficiency obtained are 4.89% to 47.61 °C temperature difference, the condition is obtained on the air speed 20 km/h with an input voltage regulator is given to heater 225 V. The efficiency value obtained from the calculation by comparing the external load equal to the internal load module, in this case equal to the power generated great heat energy is absorbed.

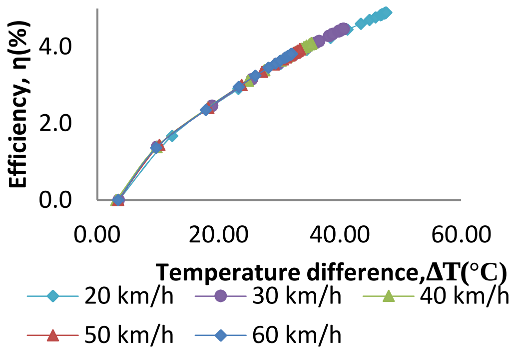


Figure 12. Relationships efficiency (η) with a temperature difference (ΔT)

5. Conslusion

Based on the test results and data processing and analysis conducted on the use of simulation study on vehicle exhaust gas can be deduced as follows:

1. The greater the input voltage to the voltage regulator to the larger heater temperature generated on the cylinder wall and be stable when the maximum temperature of the heater has been reached. The maximum temperature of the cylinder wall in a stable state for each of the input voltage variation is 96.84°C (150V), 116.80°C (175V), 141.00°C (200 V) and 164.00°C (225V).
2. The maximum temperature of the cylinder wall decreases with increasing air velocity by providing input voltage to the heater of the same. With five variations of airspeed obtained maximum temperature average cylinder wall respectively 152.25°C (20 km/h), 136.00°C (30km/h), 123.00°C (40 km/h), 120.75°C (50km/h) and 116.75 (60 km/h).
3. The use of 8 thermoelectric module with serial connectivity electricity and 32 Ω

resistor as a load, increase in power (P) decreases with increasing air velocity is given. The maximum power generated is 0.88W with the air speed 20 km/h at 225V input voltage heater and lowest power obtained when the air speed of 60km/h are 0.63W with the same input voltage.

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