International Journal of GEOMATE, July, 2020, Vol.19, Issue 71, pp. 228 - 234
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2020.71.62346
Geotechnique, Construction Materials and Environment

ELECTRIC TURBO COMPOUNDING (ETC) AS EXHAUST ENERGY RECOVERY SYSTEM ON VEHICLE

Wagino[1], Erzeddin Alwi[1], Bahrul Amin[1] and *Wanda Afnison[1]

[1]Engineering Faculty, Universitas Negeri Padang, Indonesia

*Corresponding Author, Received: 13 Sept. 2019, Revised: 11 March 2020, Accepted: 23 March 2020

ABSTRACT: The utilization of exhaust gas flow with Electric Turbo Compounding (ETC) mechanism is applied on this research. On this mechanism, the exhaust gas flow is used to rotate the alternator. The ETC installation is designed to prevent the produce of a back pressure effect which disturbs the engine performance. This mechanism was chosen based on literature study that had been done previously to the exhaust gas flow utilization mechanism on several vehicles. As the result, the ETC mechanism is the most suitable to be developed on passenger vehicles with small capacities. The power transfer process on ETC uses a gear mechanism with 2:1 ratio to increase input rotation of the generator. From the test result, the charging current is 1.25-1.48 A at 850-2.000 rpm engine speed. It is such a quite low number when compared to the normal charging system, which is 6.23 – 8.1 A at 1.200 – 2.000 rpm engine speed.
Nevertheless, for the waste energy utilization, this number is much more promising to be developed in the future. From the result of this research, it is known that the installation of the ETC mechanism can be a solution for vehicle's wasted energy utilization on exhaust gas flow form even the amount of flow generated is small.

Keywords: Electric Turbo Compounding, Turbo Generator, Exhaust Energy Recovery System

1. INTRODUCTION

Since the development of modern mass transportations began, the Internal Combustion Engine (ICE) has shown its influence in supplying the needs of land, sea, and air transportation around the world. Apart from the increasing of environmental impact awareness and fossil fuels consumption which is increasingly worried according to industry experts. According to Dr. Thomas Weber of Mercedes-Benz, at least 90% of vehicles will be powered by advanced technology from the ICE engine in 2020. This condition is followed by an intensive research and development to improve the ICE engine efficiency so that the demands related to global pollution and energy crises can be fulfilled. Various latest technologies are offered to reduce energy consumption, such as alternative energy sources, energy-efficient combustion systems and even the utilization of wasted energy on vehicles.

The United States is one of many countries which aggressively aware of environmental issues and the energy crisis, has made concrete moves related to this matter. Most of engine and vehicle manufacturers are required to raise the standards of exhaust gas emissions and reduce the fuel consumption. The United States Department of Technology, through the Vehicle Technology Program (VTP) states that increasing the efficiency of internal combustion engines (ICE) is the most promising and cost-effective approach to improve vehicle fuel economy for over the next 30 years. They prioritize the targeted efficiency improvements of 30-45% for passenger vehicles and 25% for commercial vehicles in 2020[6].

Internal Combustion Engines (ICE) has a relatively low percentage of energy used efficiency [7][8]. This condition can be seen in the following figure:

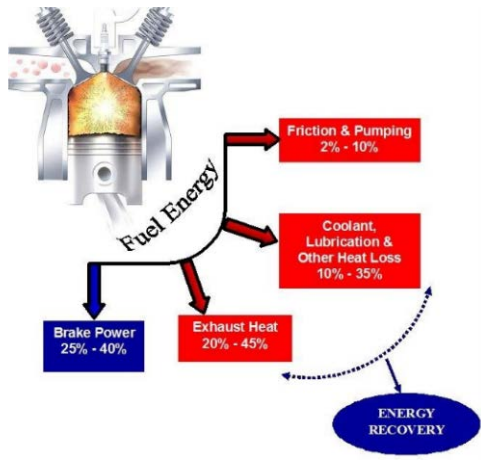

Fig.1 Energy distribution on Internal Combustion Engine (ICE)[1][2]

From the figure above we can see that only 25% - 40% energy is used to run a vehicle, which are 25% is for ICE (Gasoline Engine), 40% for ICE (Diesel Engine) and the rest are just wasted in the form of exhaust gas (20% - 40%), coolant, lubrication (10% -35%) and friction, pumping (2% - 10%). If this wasted energy can be recovered or converted into mechanical or electrical energy, this condition can certainly supply the energy needs of the vehicle and improve the overall system efficiency. A similar data is also released by the United States Department of Technology, which is only 15% of the total fuel energy used to run a vehicle [3]. The amount of energy losses on a vehicle can be seen in the following figure:

From the figure above we can see that only 25% -40% energy is used to run a vehicle, which are 25% is for ICE (Gasoline Engine), 40% for ICE (Diesel Engine) and the rest are just wasted in the form of exhaust gas (20% - 40%), coolant, lubrication (10% -35%) and friction, pumping (2% -10%). If this wasted energy can be recovered or converted into mechanical or electrical energy, this condition can certainly supply the energy needs of the vehicle and improve overall system efficiency. Almost the same data was also released by the United States Department of Technology, only 15% of the total fuel energy used to run a vehicle [3]. The amount of energy losses in a vehicle can be seen in the following picture:

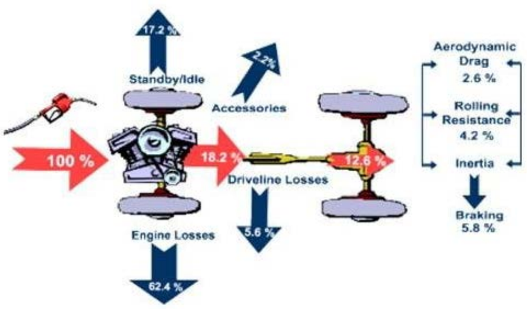

Fig.2 Fuel energy losses in a vehicle[9]

Based on figure 2, we can see that mechanical sector also has a potential to be utilized as new energy sources to increase vehicle energy efficiency. One of them is Electromagnetic Regenerative Shock Absorber (ERSA) [4] which restores vibration energy[3][4] on the vehicle's shock absorber into electrical energy, called KERS (Kinetic Energy Recovery System) which utilizes kinetic energy that appears during deceleration on the engine and then distributed as the motion energy. The amount of the energy lost when vehicle is idling is also optimized by the "idling stop " system, where the vehicle will automatically turn off if the it is detected for a short stop. Those are some solutions made by experts and automotive activists to improve vehicle efficiency.

Meanwhile, the Exhaust Energy Recovery System (EERS) [10] for the Internal Combustion Engine (ICE) has not been developed widely in the transportation sector. Unlike the utilization of exhaust gas energy[11][8] in large capacity diesel engines, ships and electric power plants which have high working hours and quite large potential for heat energy generated[12][9].

Based on this fact, the authors are interested in conducting a research related to the utilization of Exhaust Energy Recovery System (EERS) as a new energy source on vehicle. It is hoped that this research can improve vehicles' energy efficiency. This research is expected to be a solution to increase the vehicle energy efficiency

2. LITERATURE STUDY

The generated heat is the effect of the combustion system on the Internal Combustion Engine (ICE) engine. Normally, the generated heat is simply wasted through the cooling system, friction and exhaust gases. The distribution of the potential heat generated by the engine according to engine speed can be seen in the following figure:

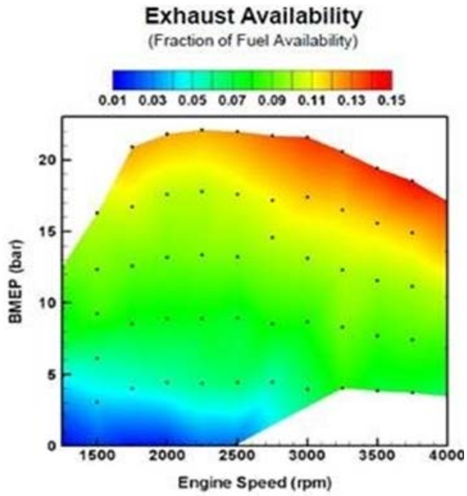

Fig.3 The distribution of heat according to engine speed

The National Oak Ridge Laboratory and the US Department of Energy collaborated to conduct energy recovery methods on vehicles. From the graph above, the potential exhaust gas energy that can be utilized is about 14%. It is known from the high value of Break Mean Effective Pressure (BEMP) according to engine speed.

Ricardo PLC [9] in his research described various ways to utilize the heat energy on the engine to be vehicle's new energy source.

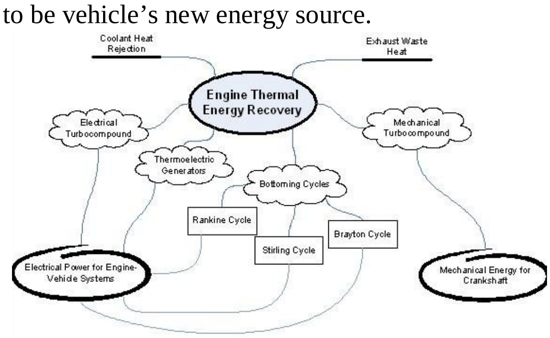

Fig.4 Harvesting Energy Engine Thermal mechanism [9]

This mechanism is intentionally used to improve engine performance and efficiency, where the wasted energy as its source.

In his research report, Ricardo tried to summarize various ways which can be done in the utilization of heat energy in vehicle. The mechanism is intentionally used to improve engine performance and efficiency, where the wasted energy as its source.

2.1 Mechanical Turbo Compounding

This system utilizes mechanical turbo movement driven by exhaust gases to produce new energy on the vehicle. The exhaust gas flow moves the turbine rotor and these rotations are used as an additional input to the crankshaft. This system is generally applied to the heavy duty diesel engine where this engine has a large piston displacement and a fast exhaust gas flow. The related research shows the increasing of energy efficiency is about 3-5%. The schematic diagram of Mechanical Turbo Compounding is shown in the following figure:

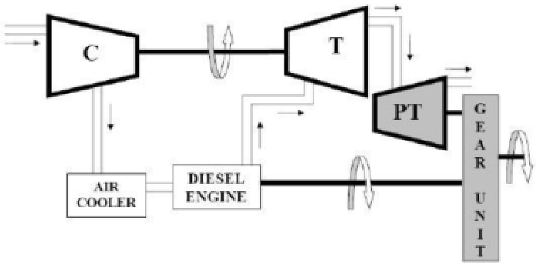

Fig.5 Schematic diagram of Mechanical Turbo Compounding.

The picture above produces the following FBD:
Mass continuity eq:

$$\frac{dm}{dt} = \Sigma\, Boundaries^{m} flux \quad (1)$$

Conservation momentum equation:

$$\frac{d(m_{flux})}{dt} = \frac{dpA+\Sigma\, Boundaries^{m} flux^{u})}{dx} - \frac{{}^{4c}f\frac{pu^2 dxA}{2D} - Cp\left(\frac{1}{2}pu^2\right)A}{dx} \quad (2)$$

Energy conservation equation:

$$\frac{d(Me)}{dt} = p\frac{dv}{dt} + \Sigma_{bound}\mathrm{m}_{flux}H - \mathrm{h}_g A(\mathrm{T}_{gass} - \mathrm{T}_{wall}) \quad (3)$$

Engine power:

$$P_{engine} = BMEP.\mathrm{V}_D.\eta_{cycle} \quad (4)$$

where n cycle is how many cycles in one second. For turbine simulations, the turbine performance characteristics are constant as long as the speed produced. Power is influenced by turbine mass, enthalpy differences across turbines as the (5) and (6) equation below:

$$\mathrm{P}_T = \dot{\mathrm{m}}_T.\eta_T.(\mathrm{h}_3 - \mathrm{h}_4) \quad (5)$$

$$\mathrm{h}_3 - \mathrm{h}_4 = \eta_{s.T}.\mathrm{C}_p.\mathrm{T}_3.[1 - (\frac{\mathrm{p}_4}{\mathrm{p}_3})^{k-1/k} \quad (6)$$

2.2 Electrical Turbo Compounding

According to its name, Electrical Turbo Compounding is almost the same as a mechanical system. The difference is the motion energy changes into electrical energy caused by high speed electric generators. It is called as electrical turbine when the position of the turbine generator separated from the turbocharger. But in some conditions, most of electric generators are put in the same place as the turbocharger. This condition is called a turbo generator.

Turbo generator is a component that is designed to be able to withstand the vehicle's wasted gas heat and produce the electrical energy. The generated electrical energy can be utilized to turn on and charge the electrical components, and also can be reused to move the vehicle. The use of turbo generators as an additional activator can increase vehicle energy efficiency by 3-10 % [10]. This mechanism is very suitable for small-sized vehicles, because the low-energy loss from this electric mechanism does not require a high exhaust gas rate as on the mechanical turbo compounding mechanism.

The power generated by the turbo mechanism is equal to the exhaust gas flow. The impact of Electric Turbo Compounding installation is analyzed by comparing the amount of generated energy to the Baseline Engine Brake Power. This Brake Engine Power is obtained from TorqueAs the name implies, Electrical Turbo Compounding is almost the same as a mechanical system. The difference is there is a change from motion energy into electrical energy caused by high speed electric generators. If the turbine generator position separated from the turbocharger it is called an electrical turbine. But in some conditions, most of electric generators are put in the same place as the turbocharger. This condition is called a turbo generator.

Turbo generator is a component that is designed to be able to resist to vehicle exhaust gas heat and be able to produce electrical energy. The generated electrical energy can be utilized to turn on the electrical components, charge the electrical components and also can be reused to move the vehicle. The use of turbo generators as additional drivers can increase vehicle energy efficiency by 3-10 % [10]. This mechanism is very suitable for small-sized vehicles because low-energy loss from the electric mechanism does not require a high exhaust gas rate as in the mechanical turbo compounding mechanism.

The power generated by the turbo mechanism is directly proportional to the exhaust gas flow. The impact of Electric Turbo Compounding installation is analyzed by comparing the amount of energy generated to the Baseline Engine Brake

Power. Brake Engine Power is obtained from Torque (T) and engine speed (n).

$$P_{br} = 2\pi nT \quad (7)$$

Where:

$$P_{br}T = P_{br} + P_{tc} \quad (8)$$

In general, specific fuel consumption is:

$$BSFC = mass\ fuel\ cunsumption/(P_{br.T}) \quad (9)$$

The basic principle of a power generator can be seen in the following figure:

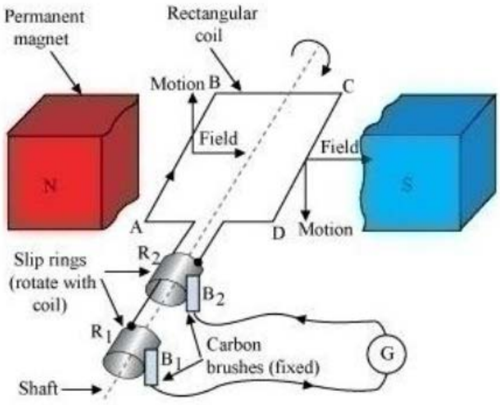

Fig.6 Generator basic principle

According to Faraday's Law, the equation can be formed from the figure above as below:

$$e = -Nd\emptyset/dt \quad (10)$$

Where:
e = Voltage/GGL
$\emptyset$ = Magnetic Flux
N = Number of coil
GGL is induced in a semi conductor of length and moves in a magnetic field with an average density of B and a relative velocity of "v", so:

$$e = Blv \quad (11)$$

Where:
l = length of wire conveyor (m)
B = Magnetic inductance (W/m^2 atau Tesla)
v = Velocity (m/s)
e = GGL (Volt)

3. RESEARCH PORPOSE AND TARGET

3.1 Research Purposes:

In general, the aims of this research are:

- To utilize the energy wasted in vehicles in the form of heat generated by the engine. From the literature study conducted there was 14% energy wasted in vehicles through vehicle exhaust gases [4].
- To obtain a new energy source that can be used for vehicle needs such as a source of charging current (alternator) and vehicle accessories.
- To reduce vehicle fossil fuel consumption by eliminating the alternator function that has been burdening the engine performance.
- To become an alternative energy source for a hybrid type vehicle.
- To increase vehicle energy efficiency.

In particularly, the aim of this research is to initiating the research relates to High efficiency vehicle which become one of UNP's flagship program in order to be an excellence college at the ASEAN level in 2020. Moreover, hopefully it will be an opportunity to do "Join research" between universities which have the same research domains.
.

3.2 Research Target

This research is expected to provide a new color in energy conservation research, especially on vehicles. Besides, it is also expected to open up other ideas related to energy conservation which has a big potential of energy wasted on vehicles. Thus, the UNP's target to become one of the leading universities in high efficiency vehicle term can be achieved.

4. RESEARCH METHODOLOGY

This research was conducted by the experimental method. Here, the muffler as a component to distribute exhaust gas with Electric Turbo Compounding (ETC) mechanism is installed. So the exhaust gas can be used as an input for the electric generator rotation.

We can see more detail in the following research diagram:

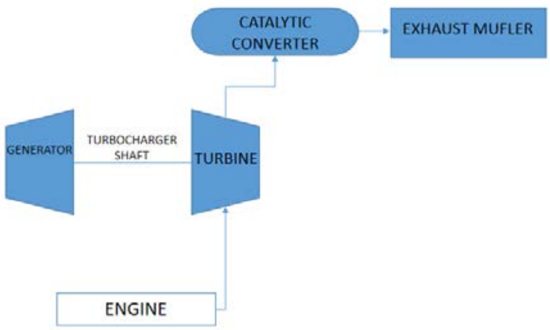

Fig.7 Schematic Research Diagram

5. RESULT AND DISCUSSION

5.1 Design

The initial stages of this research are the design and the planning of harvesting energy mechanism. The initial design is looking at the potential of exhaust gas flow on the vehicle. The writer simulated the potentially utilized exhaust gas flow by using the Solidworks design application. From the simulation result, it is known that the potential of exhaust gas flow which can be utilized as a new energy source for the ETC mechanism is 92,674 m/s with a flow velocity at the header is 35m/s. This number can be bigger depending on the amount of outflow on the muffler header and the engine capacity. Here are the results of the initial simulation of the exhaust gas flow on the vehicle:

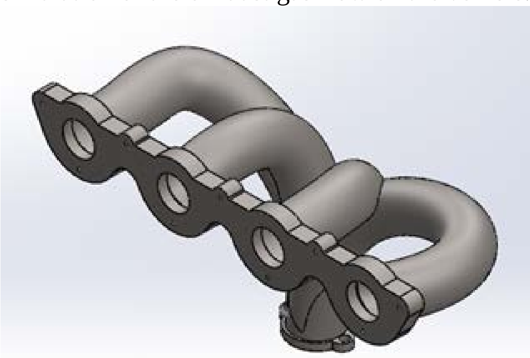

Fig.8 Exhaust header design

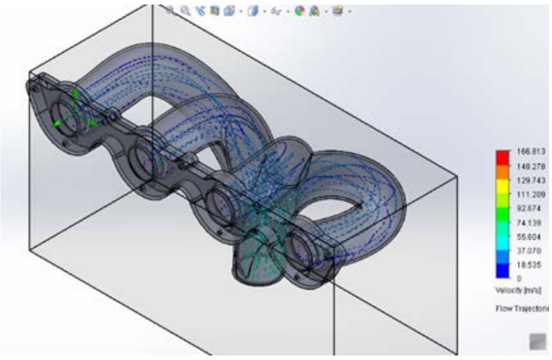

Fig.9 Flow simulation results

The next stage is the design of exhaust gas energy harvesting mechanisms. According to the ETC schematic diagram where the exhaust gas flow captured by the turbine and then routed to the alternator by using a gear mechanism. The alternator which is connected to the vehicle's charging system generates the charging current. The design of the ETC mechanism can be seen in the following schematic diagram:

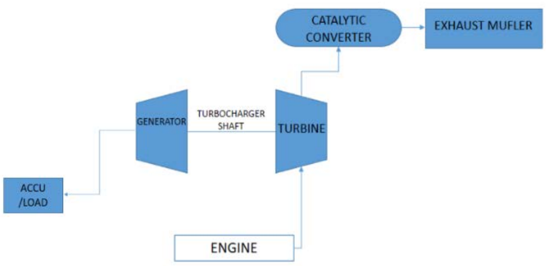

Fig.10 Designing the ETC mechanism on engine mechanism

5.2 Manufacturing Process

5.2.1 Changes in the basic mechanism of the turbocharger.

The first manufacturing process was changing the vehicle's Turbo mechanism which basically used the turbo to supply the air into the vehicle. In this research, the air intake mechanism was eliminated and replaced by a gear mechanism to move the generator. This manufacturing was conducted in the fabrication workshop Mechanical Engineering Department of UNP. The following figure is the documentation of reorganizing process on the turbocharger basic functions:

Fig.11 Changes in the intake function on the turbocharger

5.2.2 Gear manufacturing process

A gear mechanism was used to continue the rotation from the turbine to the generator. This mechanism is quite good in continuing the rotation of the turbine to the generator. The gear as the rotation transmission is design with 2:1 ratio.

The following figure is the gear mechanism which is used as rotation transmission on ETC:

Fig.12 Gear as an ETC rotation transmission

5.2.3 Assembly mechanism of ETC

Position setting was done on the ETC mechanism before the mounting process to the stand was carried out. It was to prevent any problems in the gear mechanism process.

The previous position setting will be used as a reference to make the ETC mechanism stand.

Fig.13 Setting the position of the ETC mechanism

After getting the right holder, the next step is to make a stand / ETC mechanism stand. This process was carried out in a basic technology workshop at the Automotive Engineering Department of UNP. The ETC stand mechanism has a very important role because it locks all ETC mechanisms position.

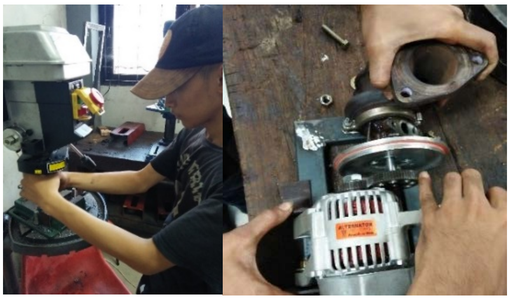

Fig.14 Making the ETC mechanism stand

The following figure is the ETC mechanism construction after it is attached to the stand.

Fig.15 ETC stand mechanism

5.2.4 Testing Process

This testing process is the final stage of the design and manufacturing process. Before conducting the test, the ETC mechanism is mounted on the engine stand where the charging system is installed. The details of the ETC test on the engine stand will be shown in the following layout:

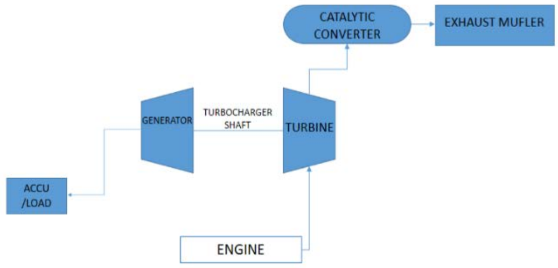

Fig.16 Layout Testing ETC

From the test result are obtained that with 1,200-3,000 rpm engine speed, it can produce 1.4-1.8 A charging current. The following table shows the results of charging current testing at each engine speed:

Table 1 Charging current Table according to Engine speed.

Attemp	Engine Speed (RPM)	Charging Current (A)
I	850	1.25
	1200	1.38
	1800	1.45
	2000	148
II	850	1.18
	1200	1.35
	1800	1.4
	2000	1.47
III	850	1.29
	1200	1.4
	1800	1.41
	2000	1.46

From the data and graphics above, it can be seen an increasing in the charging current as the engine speed increases. For safety and the test equipment conditions reasons, the testing process is limited to 1,200-3,000 rpm. As a comparison of ETC performance data, researchers tried to compare the ETC mechanism with the charging system used by vehicles in general. The testing on the vehicle was also in the range of 1,200-3,000 rpm to adjust with the ETC mechanism testing. From the test result, there is a significant difference from the amount of the current generated. Here is the comparison between the ETC's charging current mechanism and the amount of the charging current on the vehicle:

Table 2 Comparison of the ETC Charging Current VS car charging system.

Attemp	Engine Speed (RPM)	ETC Mekanism	Car
		Current (A)	Current (A)
I	850	1.25	6.23
	1200	1.38	7.54
	1800	1.45	7.6
	2000	1.48	8.04
II	850	1.18	6.3
	1200	1.35	7.5
	1800	1.4	7.7
	2000	1.47	8
III	850	1.29	6
	1200	1.4	7.3
	1800	1.41	7.8
	2000	1.46	8.1

6. DATA ANALYSIS

From the test results, the ETC mechanism was able to produce 1.4 - 1.8 A charging current at 850-2,000 rpm. There is a significant difference when it is compared to the charging current used on vehicle generally. It was produce 6.23 - 8.1 A charging current at 850 - 2,000 rpm. This condition is quite reasonable because the performance of the ETC mechanism depends on the combustion process on the engine. In addition, the ETC exhaust gas flow is different from the charging system on the car which uses engine power in moving the alternator.

7. CONCLUSION

- Several conclusions can be drawn from this research as followed:
- The installation of the ETC mechanism can be a solution to utilize the wasted energy on vehicles on the exhaust gas flow form.
- The ETC mechanism design has a lower charging current than the charging system mechanism on the vehicle in general. It is because the performance of the ETC mechanism depends on the supply and the amount of exhaust gas flow as the moving source.
- The maximum charging current that is produced by the ETC mechanism and vehicle with 2,000 rpm engine speed is 1.48 A for the ETC mechanism, and 8,1 A for the vehicle. It is because the limitation of the ETC mechanism in converting the exhaust gas into electric generator rotating power.
- Development of mechanism design and better material selection are needed to improve the ETC generator current voltage.
- The uses of low rpm electric generator can be an option considering to the low rotation which is produced by the exhaust gas.

8. REFERENCES

[1] Maksum H., Purwanto W., Afnison W., “Design Of Electromagnetic Regenerative Shock Absorber As A Tool Of Harvesting Vibration Energy On Vehicle,” Int. J. GEOMATE, vol. 15, no. 50, 2008, pp. 1–7.

[2] Afnison W., Alwi E., Maksum H., Setiawan M.Y., “Development of the Electromagnetic Regenerative Shock Absorber as an Energy Harvesting Tool for Vehicles,” Motiv. J. Mech. Electr. Ind. Eng., vol. Volume : 1, no. Number : 3, 2019, pp. 71–82.

[3] Afnison W., Guntur H.L., “Study of Double Cylinder Actuator Regenerative Shock Absorber With Oil Viscosity Variations,” Semin. Nas. Teknol. Itn Malang, vol. ISSN:2407-, no. ISSN:2407-7534, 2015, pp. 186–193.

[4] Afnison W., Amin B., “Distribution Of Viscous, Friction And Electric Dumping On Regenerative Shock Absorber (Rsa) Type Hydraulic Electro Mechanic Shock Absorber (Hemsa),” INVOTEK J. Inov. Vokasional dan Teknol., vol. 17, no. 2, 2017, pp. 45–51.

[5] Takigawa A., Mieda A., Peng Y., “Reaction Behavior of C 6 H 6 in the Three-Way Catalytic,” vol. 6, no. 12, 2014, pp. 2–6..

[6] Romagnoli A., Pesiridis A., Ricardo M.B., “Automotive exhaust power and waste heat recovery technologies,” Automot. Exhaust Emiss. Energy Recover., no. September, 2014, pp. 265–281.

[7] Pesyridis A., Automotive Exhaust Emissions And Energy Recovery, 2018.

[8] Zhuge W., He Y., Zhang Y., “Optimization of an electric turbo compounding system for gasoline engine exhaust energy recovery,” SAE 2011 World Congr. Exhib., 2011.

[9] Sorusbay C., “Exhaust Process And Emissions,” pp. 1–14.

[10] Mamat A.M.I.B., Botas M., Chiong M. C., Rajoo S., Petrovic S., Romagnoli A., “Exhaust Gas Energy Recovery Via Electric Turbocompounding,” Energy Procedia, vol. 75, 2015, pp. 1555–1559.

[11] Melda M., Hayati N., Dinata U.G.S., “Exhaust Gas Electric Energy Potential in Motorcycle,” J. Rekayasa Elektr., vol. 11, no. 5, 2015, pp. 163.

[12] Jye A.E.T.S., Pesiridis A., Rajoo D., “Effects of mechanical turbo compounding on a turbocharged diesel engine,” SAE Tech. Pap., vol. 1, 2013.