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Abstract—**The utilization of exhaust waste heat is now well known and the basic of many combined cooling, heating, and power installations. Heat recovery from automotive engines has been predominantly for turbo-charging or others such as cabin heating, thermoelectric, and air conditioning. The exhaust gases from such installations represent a significant amount of thermal energy that traditionally has been used for combined heat and power applications. This paper explores the theoretical performance and simulation of natural aspirated spark ignition engine model of 1.6 L, which is occupied with waste heat recovery mechanism (WHRM). Mathematical model and simulation test results suggest that the concept is thermodynamically feasible and could significantly enhance system performance depending on the load applied on the engine. However, the experimental test should be conducted to validate the simulation results as for scalability and reliability that require further investigation.**

Keywords—**Waste heat recovery; Natural aspirated engine; Turbo-system.**

I. INTRODUCTION

The number of motor vehicles on the globally roads and the number of miles driven by those vehicles continue to grow, resulting in increased air pollution, increased petroleum consumption, and increased reliance on the sources of petroleum. To overcome these trends, new vehicle technologies must be introduced to achieve better fuel economy without increasing harmful emissions. For internal combustion engine (ICE) in most typical gasoline fuelled vehicles, it is well known that only approximately 25% of the fuel energy is utilized for vehicle in rotating the wheels and accessories [11]. As shown in Fig. 1 and Fig. 2, the remainder of the fuel energy is lost in the form of waste heat in the exhaust and coolant, as well as friction and parasitic losses [11].

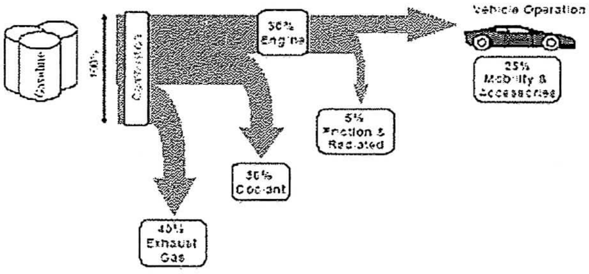

Figure 1. Typical energy path in gasoline fuelled Internal Combustion Engine Vehicle [11]

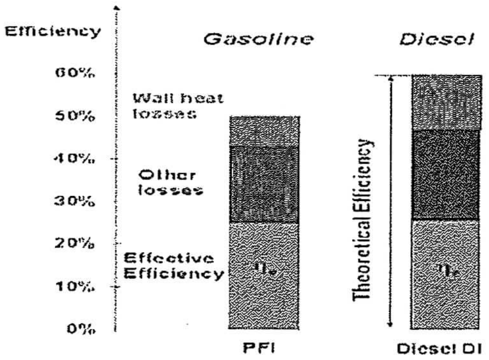

Figure 2: Efficiency of Gasoline and Diesel Engines [7]

Since the electric loads in a vehicle is increasing due to improvements of comfort, driving performance and power transmission, it is interesting to utilize the wasted energy by developing a heat recovery mechanism of exhaust gas from internal combustion engine. It has been identified by [4] that the temperature of exhaust gas varies depending on the engine load and engine speed as shown in Fig. 3. From the figure, it can be seen that significant amounts of energy that would normally be lost via engine exhausts can be recovered into electrical energy. Theoretically, the engine exhaust gas can be harnessed to supply an extra power source for vehicles and result in lower fuel consumption, greater efficiency and an overall reduction in greenhouse gases.

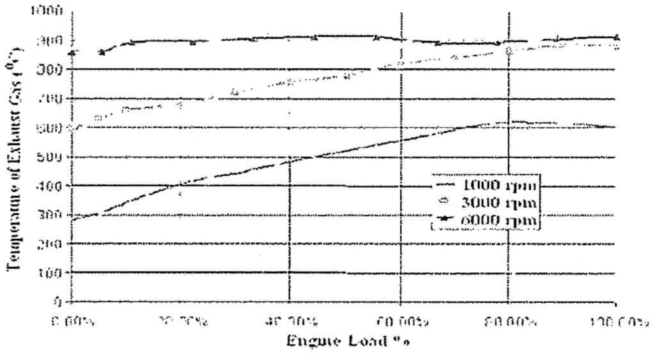

Figure 3. Temperature of Exhaust Gas [4]

The aim of this research is to create waste heat recovery mechanism that can produce power generation system that can be used for electrical purposes such as air conditioning, power steering, or other electrical/electronic device in automotive vehicle.

A. Current study on waste heat recovery

The main points of this section can be highlighted as follows:

1. Most of the proposed works for waste heat recovery is using diesel engine since the gas exhaust is in the high temperature, the compression ratio is high, the higher mass flow rate of air, and higher load compared to spark ignition engine [6, 8].
2. Most of the current methods of recovery of waste heat are reported in literatures using turbocharger, thermoelectric, turbocompound, absorption air conditioning system [2, 9, 10].
3. Only few proposed work using spark ignition engine for this purpose. It might be the problems as mentioned above are difficult to recover the waste heat, and also can generate knocking and reduce the engine performance [1, 3].

These motivate us to investigate a heat recovery mechanism from exhaust gas using natural aspirated spark ignition engine for additional power in automotive vehicle.

II. METHODOLOGY

In this work, a novel waste heat recovery mechanism for auxiliary power unit in automotive vehicle is proposed. By using a model of spark ignition engine equipped with waste heat recovery mechanism (WHRM), the power produced of WHRM can be determined.

The methodology research of this work is based on the modeling and simulation, then validated by the experimental works and continued with the data learning method to propose the optimum validation of the results.

The simulation is done in simulink Matlab. All the conditions of simulation work and experimental work are in the free load condition with neutral position of transmission engine.

In this simulation, all the sub systems in the engine model are simulated in each sub system model and integrated every sub system to another to achieve the desirable results. These simulation results are obtained from the mathematics model of spark ignition engine equipped with WHRM and validated with discrete analogue data from the experimental work. The whole sub system model is shown in Fig. 4.

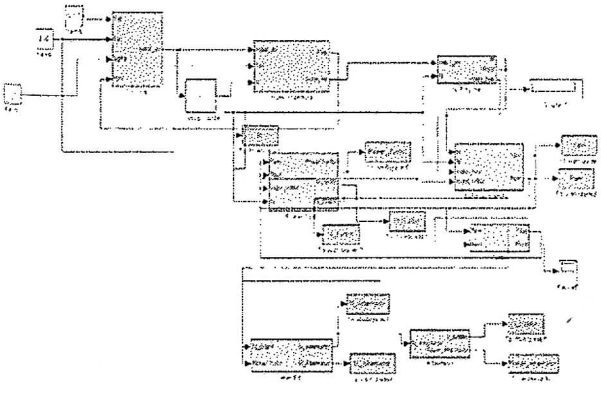

Figure 4. Simulation of Engine model and WHRM

III. RESULTS AND DISCUSSION

Below, the result of simulation is obtained. The pressure and temperature exhaust with increasing engine speed are shown in Fig. 5 and Fig. 6. These simulation results are obtained from the engine model and validated with discrete analogue data from the experimental work.

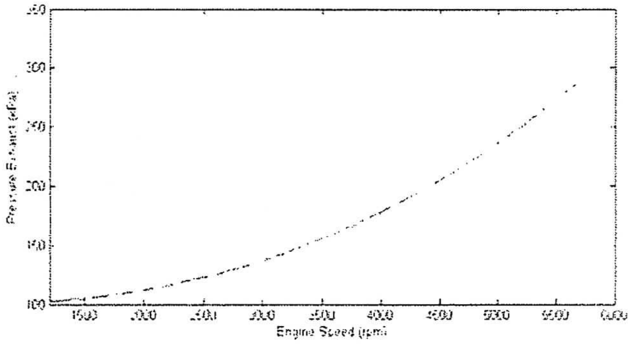

Figure 5. Pressure Exhaust vs Engine Speed

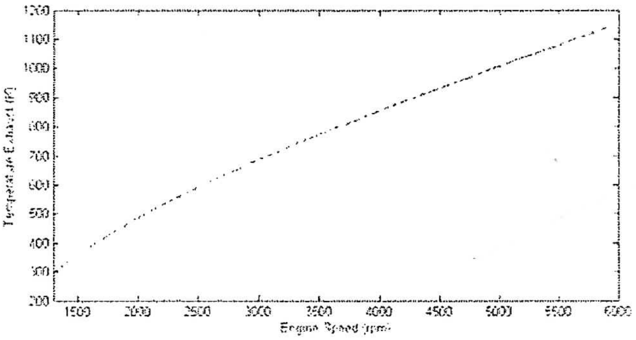

Figure 6. Temperature Exhaust vs Engine Speed

It is clearly shown in Fig. 5 that pressure from exhaust manifold is increasing with increasing engine speed. Since the engine is a natural aspirated spark-ignition (SI) engine, the pressure exhaust is lower than SI turbocharger engine [7] and diesel engine [5]. The reasons are the SI turbocharger engine has higher pressure boost in intake manifold resulting a higher pressure exhaust, and for diesel engine, the pressure ratio is more higher than a natural aspirated SI engine.

Fig. 6 shows the temperature from exhaust manifold with increasing engine speed. The temperature exhaust will increase when the engine speed is increasing. However, these temperatures are slightly lower compared to diesel engine [4]. At the 0% engine load of diesel engine, the temperature of exhaust is higher than the simulation results, nevertheless at 6000 rpm of engine speed, both of the temperatures of exhaust are almost same.

Based on the simulation results of temperature from exhaust manifold and exit temperature from WHRM, the power produced and torque by waste heat recovery mechanism (WHRM) can be determined by the model of modified turbocharger model. The exit temperature from WHRM is validated with discrete analogue data from the experimental work.

As shown in Fig. 7, the power will raise when the engine speed is increasing. When applying the normal driving, the engine speed is around 1500 up to 3500 rpm, WHRM can produce the power from 1 up to 4 kW. This kind of energy is significant enough to be recovered for an auxiliary power in automotive vehicle.

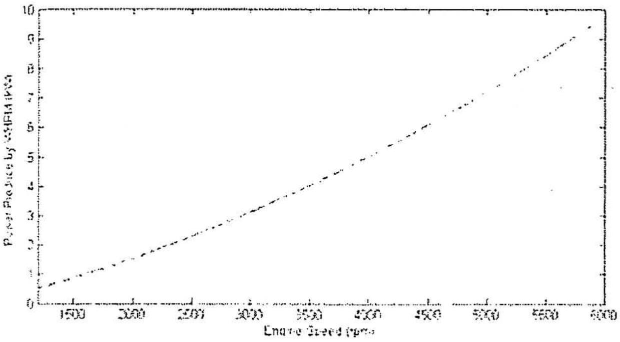

Figure 7. Power Produced by WHRM vs Engine Speed

The torque generated by WHRM can be observed in Fig. 8 with increasing engine speed. The simulation results of torque can be obtained based on power produced by WHRM and WHRM shaft speed. The speed of shaft WHRM, which is shown in Fig. 8, is validated with discrete analogue data from the experimental work.

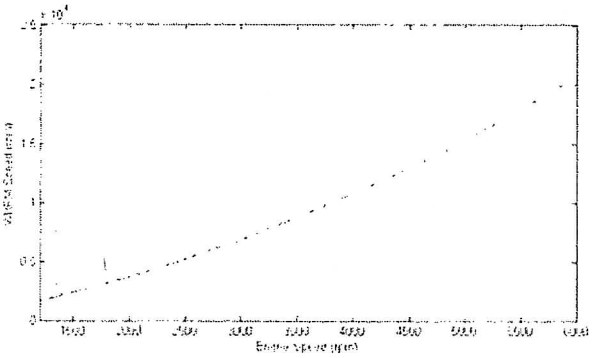

Figure 8. WHRM Speed vs Engine Speed

As shown in Fig. 9, the torque generated by WHRM will raise when the engine speed raise. At 4000 rpm, the torque is at the maximum value, and remains constant with increasing engine speed. The WHRM torque is very important parameter to determine the sufficient power and torque for running the generator/alternator.

The maximum torque of WHRM is 4.5 Nm at 4000 rpm. This figure shows that the torque is not sufficient to drive the alternator based on Fig. 8. Therefore, it is not comply when the pulley of WHRM is coupled with the pulley of alternator by 1 to 1 ratio.

To overcome the problem with regards to insufficient torque to drive the alternator, the speed of alternator shaft should be reduced. In this way, the torque applied on alternator shaft can be increased. By changing the pulley ratio between WHRM pulley and alternator pulley such as ½, 1/3, ¼, 1/5, and 1/6, the alternator speed and the torque are summarized in Fig. 10 and Fig. 11, respectively.

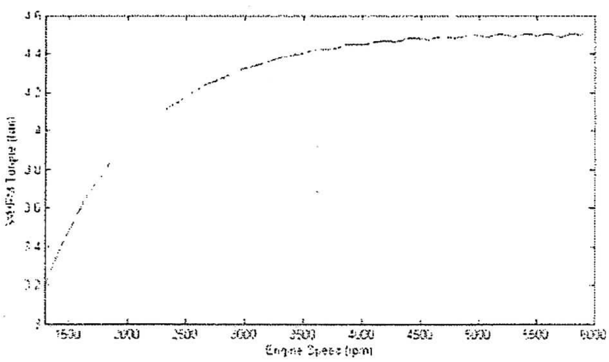

Figure 9. WHRM Torque vs Engine Speed

It is clearly shown that the smaller ratio can reduce the alternator speed and the same time, can increase the torque. For ratio of ½, 1/3, and 1/4 as shown in Fig. 11, the torques are not sufficient to overcome requirement of minimum torque of the product to drive the alternator. Therefore, the ratio of 1/5 and 1/6 are pass the requirement of minimum torque of the product.

However, to gain more output current, the alternator shaft speed should be higher. Since the ratio of 1/5 has a higher alternator speed compared to 1/6, therefore, the ratio of 1/5 is the optimum choice to use for running the alternator.

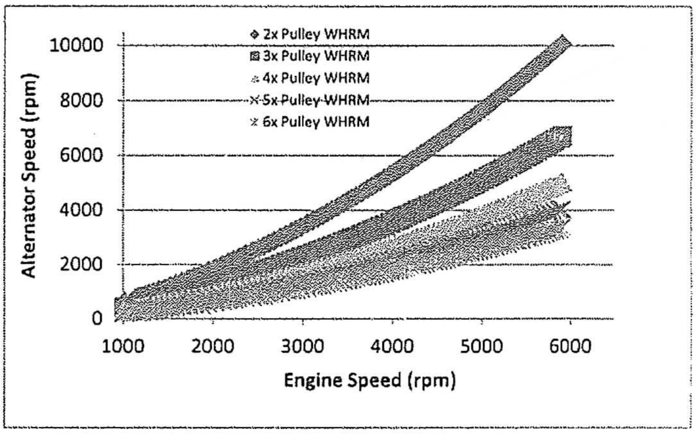

Figure 10. Alternator Speed vs Engine Speed for 5 Different Pulley Ratio

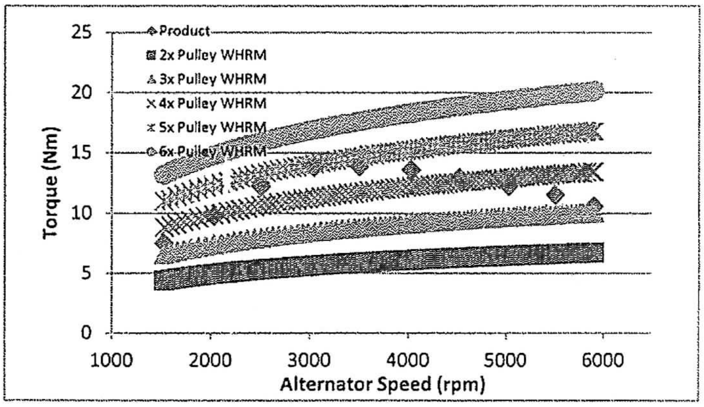

Figure 11. Alternator Torque vs Engine Speed for 5 Different Pulley Ratio and Product

Fig. 12 and Fig. 13 show the current that generated by alternator for 1/5 ratio and 1/6 ratio, respectively. While, Fig. 14 and Fig. 15 show the power output by alternator for 1/5 ratio and 1/6 ratio, respectively.

It is clearly shown that the ratio of 1/5 can generate higher current as well as power compared to the ratio of 1/6. The reason is the 1/5 ratio has higher alternator shaft speed than 1/6 ratio. Even though, the torque of 1/6 ratio is higher than 1/5 ratio.

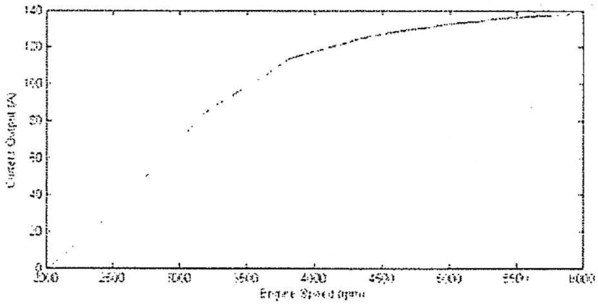

Figure 12. Current output vs Engine Speed for 1/5 ratio

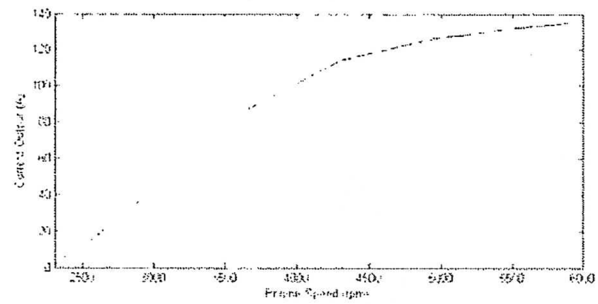

Figure 13. Current output vs Engine Speed for 1/6 ratio

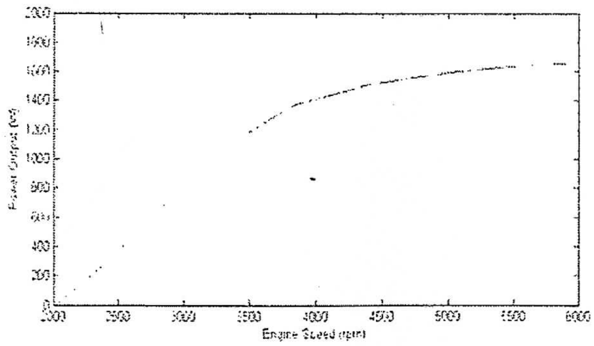

Figure 14. Power output vs Engine Speed for 1/5 ratio

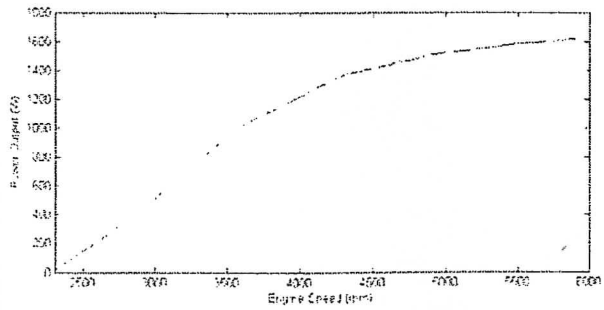

Figure 15. Power output vs Engine Speed for 1/6 ratio

By using Fig. 14, which is an optimum choice for the system, the power output can be recovered is around 200 W up to 1600 W. In the normal driving, the engine speed is around 1500 up to 3500 rpm, this system can produce the power up to 1.2 kW.

IV. CONCLUSIONS

The simulation work of waste heat recovery mechanism for an auxiliary power unit in automotive vehicle has been presented. It is shown by the simulation that waste heat from exhaust gas can be recovered. The results show the output power is not so huge, however the condition on experimental work and simulation work are on the free engine load. Therefore by applying the engine load, the results of output power will become greater.

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