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CHARACTERISTICS OF K3-VEI4 ENGINE PERFORMANCE USING SWIRL GENERATOR, AIR INTAKE TANK AND EXHAUST GAS RECIRCULATION MODIFICATION

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ABSTRACT

The paper studies the characteristics of K3-VEi4 engine performance using swirl generator, air intake tank and exhaust gas recirculation (EGR) modification. Engine weight is reduced prior to the other modifications in order to reduce inertia loss. Then an air intake tank is mounted before the throttle body in order to increase the air intake pressure. A swirl generator is mounted at the air intake manifold to blend the air-to-fuel mixture. EGR is installed to improve the engine performance by reusing the unburnt fuel and increasing the air intake temperature. The effects of the engine modifications on the engine performance are analyzed on a chassis dynamometer. Performance parameters such as engine power and brake specific fuel consumption (BSFC) are then analyzed for each modification individually and then the whole system combined. The result shows that a gain of about 117% in terms of power can be achieved with the different modifications put together and a reduction of around 62% on the BSFC. These improvements are obtained at low rpm, corresponding to city driving. A more thorough study of the EGR tapping position would further improve its implementation to increase engine performance and fuel efficiency.

Keywords: Fuel consumption; swirl generator; exhaust gas recirculation; internal combustion engine.

INTRODUCTION

The world's crude oil supply is steadily reducing and the crisis is leading to the peak oil point phenomenon. Peak oil is the point at which the global output of conventional oil reaches its maximum level and after which flow rates decrease [1]. Among the affected consumers is the automotive industry, because automotive engines use petrol or diesel which is produced from petroleum. Continuous usage of this resource will be a problem in the future, since demand for oil will be growing by as much as 50% by the year 2025 compared to 2004 [2]. With the increase in demand, it is necessary to increase the efficiency of the engine, since well-to-wheel efficiency is only 14% [3]. The objective of this study is to increase engine performance and efficiency for city driving through several modifications. Much research is being done to improve internal combustion engine (ICE) performance and reduce fuel consumption, including using swirl generators, tumble devices, and exhaust gas recirculation (EGR) [4, 5]. Other research has found that EGR can reduce fuel consumption at low load [6]. EGR works by recirculating the exhaust gas into the air intake and increasing the specific heat of the air, and also has the benefit of reducing nitrogen oxide (NOx) emission [7-10]. The function of the swirl generator is to increase the air–fuel mixture to promote better combustion [11-13]. By generating turbulent kinetic energy (TKE) and velocity inside the combustion chamber and around the fuel-injected region, it can increase the chances of improving the performance of an ICE and reduce emissions. The high velocity and TKE accelerate the evaporation, diffusion and mixing processes of the ICE [14]. This can be done by installing the swirl generator at the intake manifold. The purpose of this is to swirl the air flow and make it turbulent. Studies conducted have explained that using the intake manifold boosting of turbocharged spark-ignited engines is the same idea as restricting the compressed air to allow it to swirl and become turbulent. This enables better fuel atomization and improved mixing of air and fuel. Therefore, it reduces the fuel consumption of spark-ignited engines while retaining the maximum power output and improving the downsizing [15]. Besides that, the turbulent flow causes rapid mixing of fuel and air if the fuel is injected directly into the cylinder.

Exhaust gas recirculation is a technique where a small amount of exhaust gas is taken back into the intake manifold to be mixed with fresh air–fuel mixture in the combustion chamber. Recirculated exhaust gas in a gasoline spark-ignition engine is used to reduce throttling loss [16]. This in turn can reduce fuel consumption and is secondly able to reduce NOx emission. Further opening of the throttle is needed to increase the trapped charge density, which can reduce pumping loss and reduce the fuel consumption [7]. To reduce the NOx emission from the diesel engine, exhaust gas recirculation was first adopted. This technique is very effective in reducing high NOx formation as it lowers the combustion chamber temperature by diluting the air–fuel mixture with small portions of recirculated exhaust gas [17]. Nitrogen reacts with oxygen in the combustion air usually above 1600 °C to form NOx. Nowadays, with increasing environmental problems and difficulties in the exploitation of energy, the exhaust gas recirculation system is commonly used in gasoline engines [18]. Using a higher performance air intake system can increase the volume of air available to the engine. Because an ICE runs on a mixture of air and fuel, the more air that is available to the engine, the better the combustion. By increasing the pressure of the fuel injection to its optimum, the engine performance is increased and the fuel consumption is reduced [19]. Another way to increase the pressure of the air flow intake is by increasing the temperature of the air that flows into the throttle body; when the speed of gas molecules increases, they hit their container more often. The more frequently the gas impacts the container walls, the higher the pressure. So, as the temperature increases, the pressure also increases [20].

In this particular study we want to see the effect of adding multiple modifications to the K3-VE engine, which are: reducing the weight of the engine; adding an air intake tank; putting in a swirl generator; and EGR. In other research, the swirl generators used are similar to a guided vane or a propeller [21-23], but the design is different here, focusing on disturbing the direct flow. Most of the studies reviewed focus only on one particular enhancement at a time, so investigating the final improvement if all the methods are implemented at the same time has also been the interest of this particular study. Performance parameters such as engine power and brake specific fuel consumption (BSFC) are analyzed for each modification first, and finally for all the modifications working together. The target is to allow improved city driving, which is usually limited to low rpm operation.

EXPERIMENTAL SETUP

Engine Modification

In the experiment, an engine from a Perodua Myvi is used, a four-stroke engine derived from the first-generation Daihatsu Sirion, 1.3 litre K3-VE engine with four in-line cylinders; both engines employ Dynamic Variable Valve Timing (DVVT) systems and conventional electronic fuel injection (EFI). Table 1 presents the engine specifications.

Table 1. Engine specifications for 1.3L K3-VE, UK spec Myvi.

Description	Types, Value and unit
Engine type	Water-cooled, 4-cycle, in-line 4-cylinder
Valve mechanism	DOHC DVVT
Bore	72 mm
Stroke	79.7 mm
Total displacement	1298 cc
Maximum output	64 kW @ 6,000 rpm
Maximum torque	116 Nm @ 3,200 rpm
Compression ratio	10:1

Lightweight engine

The first modification was to lighten the main moving part of the engine, the flywheel, the pistons and the pulley. This was to reduce inertial losses which can cost up to 5% in fuel consumption [24]. The engine weight was reduced by much as 3 kg from its original market condition. The moving parts such as the flywheel and crankshaft were lightened to reduce inertial and friction losses. The manufacturer's original crank pulley was replaced with a lighter and smaller aluminium pulley.

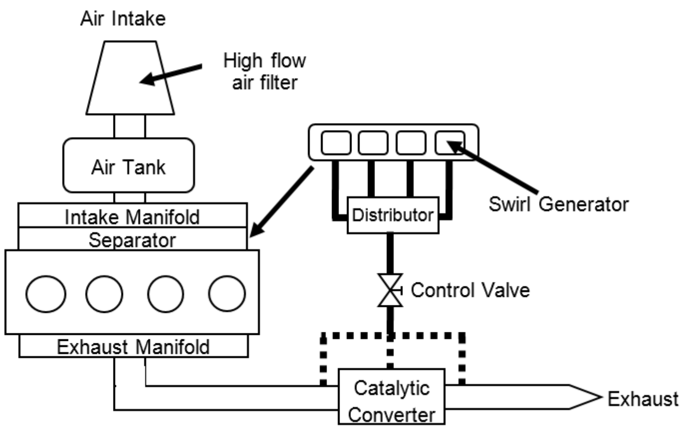

Figure 1. Schematic of engine modification with air intake tank, swirl generator and EGR.

Air intake tank

The air filter was a replaced with a high-flow air filter and was repositioned in front of the radiator fan in order to increase air intake naturally. Repositioning the air filter gives room to install an air intake tank downstream of the air filter. In general, when the intake air temperature is increased, the air density is decreased. Subsequently, the oxygen content is reduced. Therefore the fuel injector will inject less fuel to maintain the stoichiometric mixture. Adding the air intake tank will reduce the air velocity and increase the air intake pressure. Thus, the pumping work can be improved. Figure 1 shows the location of the air tank and also the positions of the other modifications.

Exhaust gas recirculation

In the third modification, the exhaust gas recirculation (EGR) is used as shown in Figure 2(a), where a separator is mounted in front of the intake manifold to recirculate the EGR gases from the exhaust to the intake manifold in small quantities. Tappings are made along the exhaust and then circulated to a distributor in Figure 2(b), and then they distribute the exhaust gas into each hole on the inlet manifold. The purpose of this modification is to recirculate the unburned fuel and to increase the air inlet temperature.

(a) (b)

Figure 2. Separator for the EGR (a) positioned before the intake manifold; (b) mounted with the distributor.

Swirl generator

Finally, a swirl generator in Figure 3(a) is placed at the intake manifold as shown in Figure 3(b). This swirl generator is expected to swirl the flow of the intake air before it goes into the combustion chamber to generate TKE. With optimal turbulence, better mixing of fuel and air is possible, which leads to effective combustion [25].

(a) (b)

Figure 3. (a) Swirl generator; (b) placed at the intake manifold.

Data Collection

The testing used a chassis dynamometer with direct coupling to eliminate the wheel slip effect. The parameters of the experiment were set up in the Dynapack dynamometer software. The speed range during the testing of the engine using the chassis dynamometer is within 2000 to 5000 rpm. A drive ratio of 5.02 was used to simulate third gear loading. The performance parameters to be characterized are brake specific fuel consumption (BSFC) and torque.

RESULTS AND DISCUSSION

Lightweight Engine

Figure 4 compares the engine power and BSFC versus engine rpm obtained from the engine testing for the baseline engine and the lightweight engine. The engine testing was conducted from 2200 rpm to 5000 rpm. Figure 4(a) shows that the lightweight engine improved by as much as 90% when the engines were tested at 2750 rpm. However, the improvement is less significant at higher engine speed. This is due to the reduced mass in the flywheel, as the lesser mass reduces the initial inertia, making it easier to start turning, although unfortunately the capability of storing inertia is also reduced [20]. When the engines were tested beyond 4000 rpm, the lightweight engine produced less power than the baseline engine. This is because of the lightweight engine's smaller inertia.

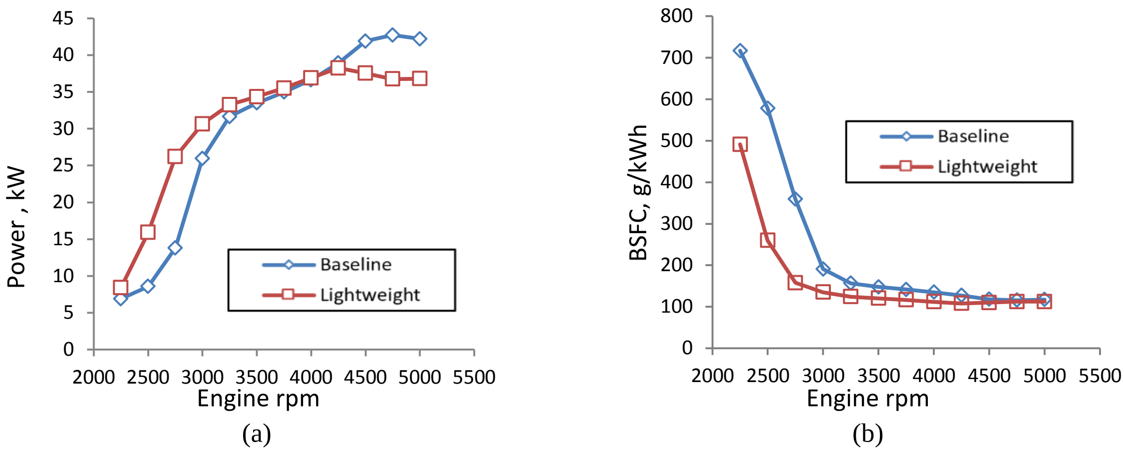

Figure 4. Comparison of (a) engine power and (b) BSFC between baseline and lightweight engine.

Figure 4(b) shows a comparison of the BFSC for the lightweight and baseline engines. A significant improvement of the BSFC is observed during low engine speed operation. The maximum reduction of BSFC of approximately 56% is found at the engine speed of 2750 rpm. This is because the engine efficiency was improved by changing part of the engine such that the engine is lighter and has improved quality material which promotes an efficient engine [26, 27]. The BSFC reduction is less when the engine speed is increased. When the engine speed is higher than 4500 rpm, no BSFC improvement is found.

Air Intake Tank

Figure 5(a) shows the comparative power versus speed for the engine fitted with the air intake tank and the baseline engine. Insignificant improvement of engine power is observed, but the power is increased when the engine is operated between 2000 rpm and 3250 rpm. The engine power is increased by approximately 66% at the engine speed of 2750 rpm. The engine power improvement is reduced beyond 2750 rpm until it reaches 3250 rpm. Then a significant engine power reduction is observed when the engine speed exceeds this limit. The air intake tank acts like a store to increase the air pressure, as in other research, where boosting increases the power output of the engine [28, 29]. At high rpm the air stored is reduced significantly and thus reduces the air pressure in the tank, which diminishes the effect of the boost pressure.

Figure 5(b) indicates that the BSFC is reduced when the engine is operated at lower engine speed. Once it achieves its maximum reduction of around 58% at the engine speed of 2750 rpm, the BSFC reduction is then decreased, until it reaches 4000 rpm. Beyond that engine speed, the BSFC for the lightweight engine with the air intake tank is higher than the baseline engine. With the increased air intake pressure caused by the air intake tank, in order to improve the cylinder filling at high rpm, the air–fuel mixture is forced in and creates rich combustion which consumes more fuel [30].

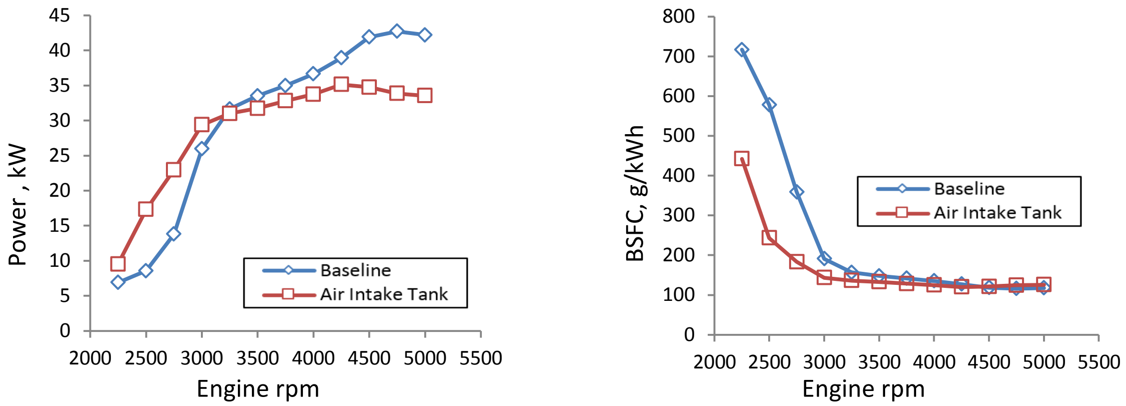

Figure 5. Comparison of (a) engine power and (b) BSFC between baseline and engine with air intake tank.

Swirl Generator

The result obtained by adding the swirl generator to the lightweight engine is shown in Figure 6. Figure 6(a) shows the comparison of engine power versus engine rpm between adding the swirl generator tank and the baseline engine. As can be seen, the engine power increased between 2250 rpm and 3250 rpm. The maximum power gain of about 60% is achieved at 2750 rpm and starts to decline beyond this point. After 3000 rpm the power starts to decrease compared to the baseline engine and becomes very significant at maximum rpm. Other studies [4, 31] have shown that swirl generators should increase the flow mixture and result in better combustion; however, a swirl generator that creates resistance to the air flow reduces this effect. Due to the design of the swirl generator, it can be said that the shape obstructs the flow required for a proper air–fuel mixture. Comparison of the BSFC against the baseline can be seen in Figure 6(b). It can be seen that the BSFC is significantly reduced before 3500 rpm with the maximum drop of around 59% at 2500 rpm. The BSFC shows no improvement compared to the baseline after 3250 rpm and the reduction decreases considerably at the limit of engine speed. With restricted flow caused by the design of the swirl generator, the availability of oxygen (O_2) is reduced, creating high BSFC values.

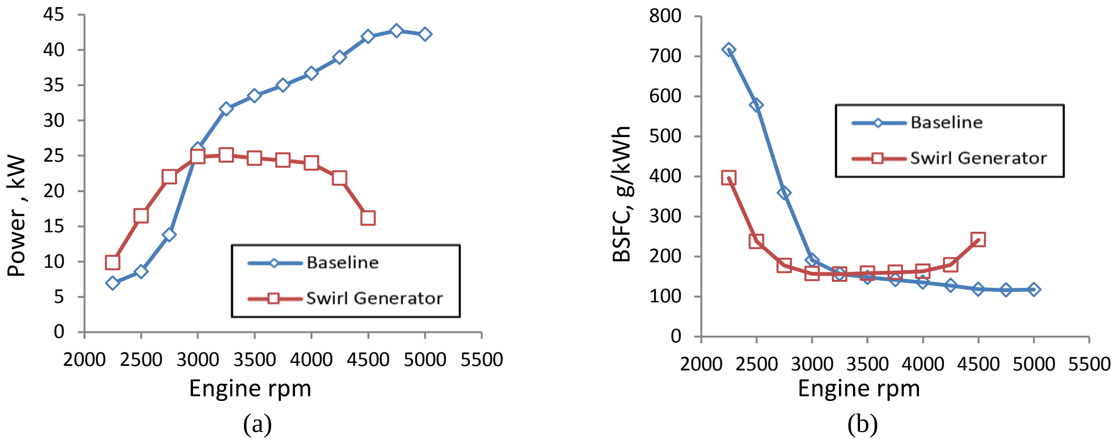

Figure 6. Comparison of (a) engine power and (b) BSFC between baseline and engine with swirl generator.

Exhaust Gas Recirculation

Figure 7(a) presents the engine power versus engine rpm for comparison of the engine installed with EGR and the baseline engine after weight reduction. The power increase can be seen for engine speeds below 3500 rpm. The most prominent improvement is at 2750 rpm with approximately 70% increase in performance. At part loads, the exhaust gas has a fairly high amount of O_2 with the recirculated unburnt fuel, which improves the power output [32]. This trend of improvement stops after 4000 rpm and becomes very poor at higher rpm. Since less O_2 is available at higher engine loads, the increase in performance is diminished.

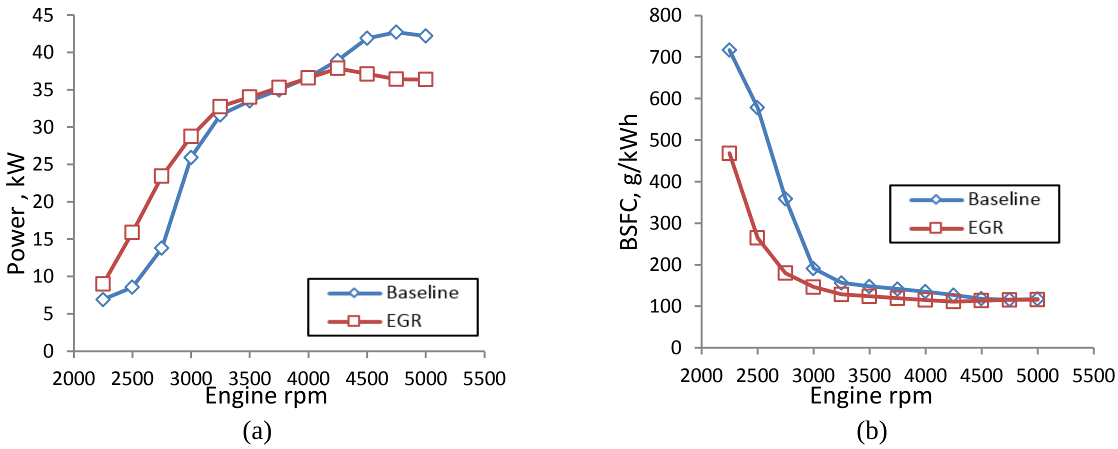

Figure 7. Comparison of (a) engine power and (b) BSFC between baseline and engine with EGR.

Comparison of the BSFC between the baseline and the addition of EGR is shown in Figure 7(b). Like the others, major improvement can be seen at the lower rpm, with nearly 54% at 2500 rpm. This is in correlation with a finding that EGR reduces the

BSFC at low engine load [6]. The improvement is somewhat constant between 3250 rpm and 4250 rpm and stops thereafter. Beyond 4250 rpm of engine speed, no increased reduction of the BSFC is observed compared to the baseline engine. This is similar to the findings of Agarwal et al. [23] that the amount of fuel supplied to the cylinder is increased at a higher rate during high load, and the availability of oxygen is reduced, resulting in an increase in BSFC.

Exhaust Gas Recirculation (EGR), Air Intake Tank and Swirl Generator

The results shown in Figure 8(a) and 8(b) are the implementation of the three modifications together with the lightweight engine. Figure 8(a) compares the engine power versus engine rpm. The results can be correlated to the finding before, where the major improvement is at the lower rpm. The combination gives the best increase at 2500 rpm, with an approximate value of 117%. However, the decrease in engine power is also amplified at higher rpm. The point of inflection is situated at 3000 rpm.

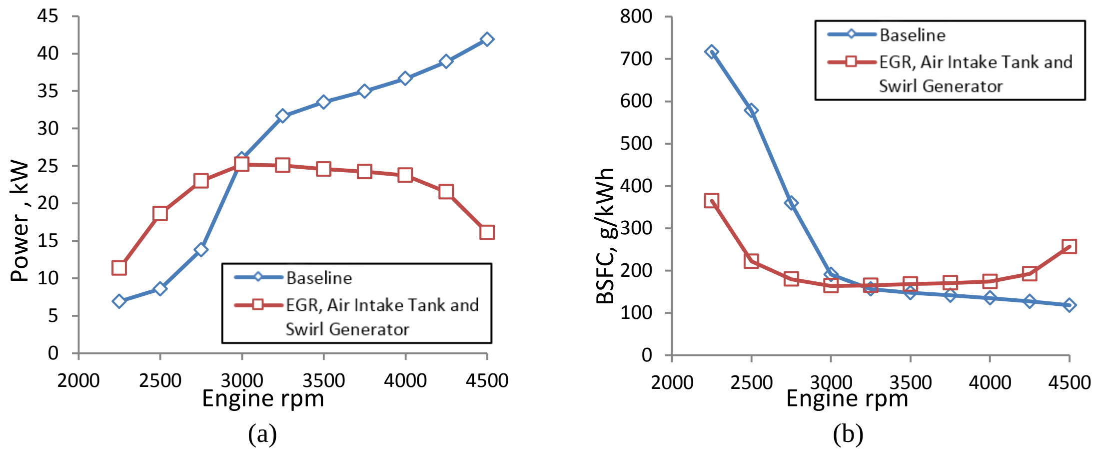

Figure 8. Comparison of (a) engine power and (b) BSFC between baseline and engine with EGR, air intake tank and swirl generator.

The same can be said of the comparison of the BSFC and the baseline in Figure 8(b). Major improvement can be seen at lower rpm and drops below the baseline in terms of BSFC reduction after 3250 rpm. The BSFC shows a trend of being constant between 3000 rpm and 4000 rpm. The maximum gain in BSFC with the three modifications combined is around 62% at 2500 rpm. It is worth mentioning that when a gasoline engine works at full load the throttle has reached its maximum opening. In this case, the throttle cannot be opened any more to increase the intake density. Therefore, boosting the intake pressure is necessary to gain the same level of torque or power output. Therefore, the air intake tank system is used here to increase the pressure of the air entering the intake manifold. Further air flows through the swirl generator, promoting better fuel atomization and increased air flow pressure in the combustion chamber [26]. EGR tends to influence combustion stability, so when idle it is better not to open the EGR.

CONCLUSIONS

Of the modifications made to the engine, the most significant improvement was contributed by decreasing the engine weight, and specifically the rotating part. By reducing the inertia of this part, an improvement of around 90% was exhibited. Other improvements added to the lightweight engine saw an improvement of around 65% for engine power and around 55% on reduction in BSFC at low rpm. Implementation of EGR helps to improve the power and BSFC at speeds up to 3750 rpm. The swirl generator increases the power and reduces BSFC, but it is less significant than the other modifications. The shape of the swirl generator could be optimized to increase its performance. The overall improvement gain was about 117% in terms of engine power and around 62% of reduction in BSFC. Further improvement to the EGR can be made by studying the position of the tapping for the EGR. The quantity of the recirculated gas was not controlled in this study, which can also be evaluated in future improvements. Even though all these improvements were situated under 3000 rpm, the findings are still valid for city driving, which involves a lot of stop-and-go events.

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