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Study of the Effect of the Supercharger on the Output Power of Gasoline Injection Engine

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ABSTRACT

The study focuses on experimental research on the operation of a gasoline injection engine combined with an electric supercharger. In which, the effect of the supercharger on the output power of the engine was considered. 1NZ-FE gasoline injection engine with the supercharger was used for the experiment. In experimental operation, the engine speed got the value in the range of 1000 – 4500 (rpm), and the supercharger's motor speed was 1000, 1500 and 2000 (rpm). The parameter of output power corresponding to operating modes of the engine was collected to analyze and evaluate the effect of the supercharger. The experimental results showed that when the engine operated with the support of the supercharger, the output power was significantly improved as compared to the engine without supercharger. The increase in the supercharger's motor speed would increase the output power of the engine. At low engine speed of 1000 (rpm) the output power increased slightly by 5.1; 7.8 and 10.3% corresponding to supercharger's motor speed of 1000, 1500 and 2000 (rpm). The highest increase of the output power occurs at the engine speed of 3000 (rpm). At this engine speed, the output power was improved by 7.9; 11.7 and 14.8% corresponding to super charger's motor speed of 1000, 1500 and 2000 (rpm).

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1. Introduction

The conventional fuel sources used for internal combustion engines such as gasoline and diesel are increasingly scarce. Many scientific and technical solutions have been studied to apply alternative fuels such as NG, PNG and Hydrogen. Therefore, technical improvement solutions for internal combustion engines to improve the efficiency of engine power and save fuel would be highly scientific and practical. Besides, the problem of reducing environmental pollution caused by exhaust gases from automobile engines has been one of the urgent problems nowaday. In the past decades, many innovations and improvements have been made in the automotive field such as: electronic fuel injection [1] to increase power and reduce pollutant emissions, reduce engine size [2], applying the supercharger to increase fuel economy and vehicle torque at low engine speed to maintain a suitable power level [3 – 6].

The technical solutions mentioned above continue to be researched, improved and practically applied to automobiles to achieve the effective engine power and reduce environmental pollution emissions. Verhelst et al., (2009) studied the effect of supercharger driven by engine on the power and emission concentration of internal combustion engines using Hydrogen fuel. The results showed that the engine power increased significantly and the NOx emission concentration was reduced [7]. Pipitone et al (2017) studied NG and LPG spark ignition engines with supercharger driven by engine combination. The power and efficiency of the engine increased with the support of supercharger, in which, at the highest compression ratio of the supercharger of 1.6 bar, the engine reached the highest power and at the compression ratio of 1.2 bar, the highest engine efficiency was obtained [8]. Stefano and Emiliano (2019) studied the performance of electronic fuel injection engines equipped with supercharger driven by the engine with the improving fuel economy and reducing exhaust gas concentrations causing the environmental pollution such as CO and HC [9]. An (2012) conducted the experiment of installing an electric supercharger to support the engine with improving the output power and the engine could reach

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the highest speed in 0.7 seconds [10]. Wang et al., (2016) studied the technology of applying electric supercharger to diesel engines with the results showing that supercharger could improve the intake air flow at the beginning of acceleration as compared to engines using turbocharger [11]. Pierre et al., (2020) experimentally evaluated the efficiency of electric supercharger with the results showing that the engine could achieve the high torque even at low engine speed. This could also overcome the drawback of turbochager's lag [12]. Bisane and Kale (2021) experimentally operated a diesel engine supported by the combination of a turbocharger, belt-driven supercharger and electric supercharger. This combination has improved thermal efficiency by 0.41% and 0.78% at medium and full load, respectively. While the exhaust gas concentrations of CO, HC, and NO_X decreased by 0.38, 0.73 and 0.53% [13]. Huang et al., (2022) studied the effect of electric supercharger on the operating efficiency and emissions of direct gasoline injection engine with the experimental results showing that the supercharger significantly improved the engine dynamic power at low speed and significantly reduced NOx emission [14].

As presented, the results of the previous studies showed that helps the engine power increased and reduces the harmful exhaust gas concentration decreased significantly with the support of supercharger. Meanwhile, engine power and emissions were two important parameters that the researchers and manufacturers were always interested in to improve and upgrade engines. If the supercharger was installed and applied with the right technology, it would be an effective improvement in the automotive field. This study focuses on the experimental operation of 1 NZ-FE gasoline injection engine combined with electric supercharger. In which, the output power of the engine was measured and collected to compare and evaluate the efficiency of the engine with and without supercharger support.

2. Material and Methods

2.1. Material

The 1NZ - FE engine model with an electric supercharger installed was used for experimental operation in order to measure and collect output power data during operation. In which, the technical parameters of the 1NZ - FE engine were presented in Table 1.

Table 1. *Specifications of 1NZ – FE engine*

Technical parameters	Description
Number of cylinders and layout	4 cylinders, in line
Valve structure	16 Valves, DOHC
Cylinder working capacity (cm^3)	1497
Diameter x stroke of piston (mm)	75.0 x 84.7
Compression ratio	10.5:1
Maximum output power SAE-NET (kW/rpm)	80/6000
Maximum torque SAE-NET [N.m/rpm/ (ft.lbf/rpm)]	141/4200 (105/4200)
Fuel	A95 gasoline
Lubricant	API Sm, SL, or ILSAC

The general operating principle of the electric supercharger was shown in Figure 1. When voltage was applied by the battery, the electric motor would rotate according to the modes of the speed controller. The propeller shaft was rotated, and the rotating propeller would draw intake air into the suction end. The intake air would be compressed at high pressure into the the suction end before the throttle valve of the intake manifold to supply the air to the engine combustion chamber. The supercharger operated with specific specifications such as: rated operating voltage for motor speed controller was 10 - 50 VDC, rated current was 60A, controlling frequency was 15 kHz, motor power was 600W, fan speed range was from 1000 to 3000 (rpm).

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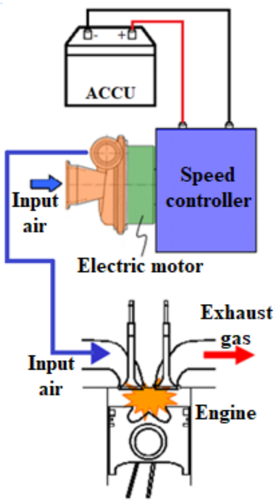

Figure 1. *Working principle diagram of supercharger*

The operating principle diagram of 1NZ-FE fuel injection engine combined with supercharger was presented in Figure 2. In which, 1. Fuel tank; 2. Gasoline filter; 3. Pressure regulator valve; 4. Flowmeter; 5. Input air filter; 6. Input air; 7. Exhaust gas; 8. Injector; 9. Combustion chamber

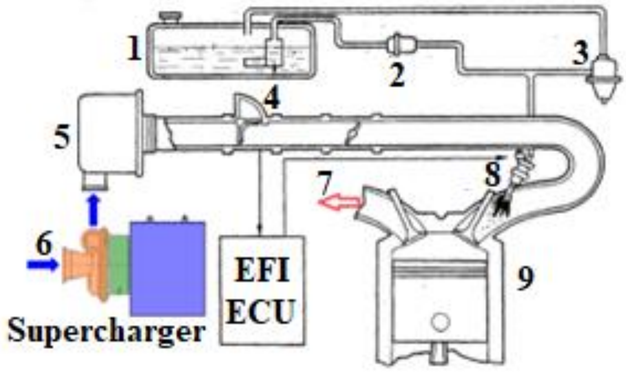

Figure 2. *Diagram of operating principle of 1NZ-FE fuel injection engine combined with supercharger*

The model of 1NZ-FE fuel injection engine combined with supercharger that was used for experiment was presented in Figure 3.

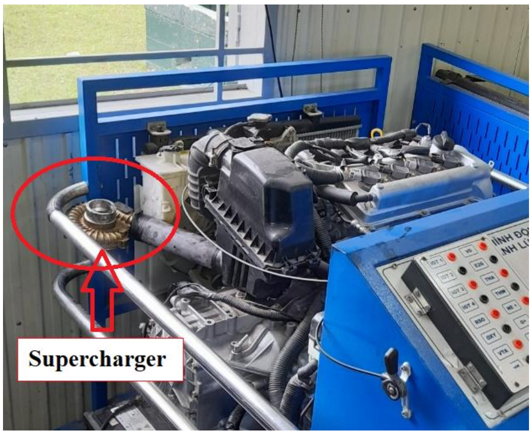

Figure 3. *The model of 1NZ-FE fuel injection engine combined with supercharger*

2.2. Experimental Methods

The engine was experimentally operated with two modes: 1) the engine operates without the support of a supercharger; 2) the engine operates with the support of a supercharger.

The engine speed was adjusted with the operating values of 1000, 1500, 2000, 2500, 3000, 3500, 4000 and 4500 (rpm). The motor speed of the supercharger was adjusted to 1000, 1500 and 2000 (rpm). The engine speed and motor speed were measured by the tachometers and displayed on the digital meters.

In each operating mode, the output power of the engine would be measured and collected by KOEN engine power testing system to analyze, compare and evaluate the engine's operating efficiency.

KOEN engine power testing system was a product of KOENG company LTD., Korea. The diagram of the working principle of the engine power testing system was shown in Figure 4. As in Figure 4, the power engine testing system includes a fuel tank, a dynamometer, a load cell, a data logger, and a computer. The fuel tank has the function of supplying the fuel for operating the engine. The dynamometer is an electric braking unit, which causes the load for the engine. The load cell is a force measuring device from the dynamometer. The data from the speed sensor and load cell were transferred to the computer via the data logger. The computer would process the data and display the data set of the output engine power.

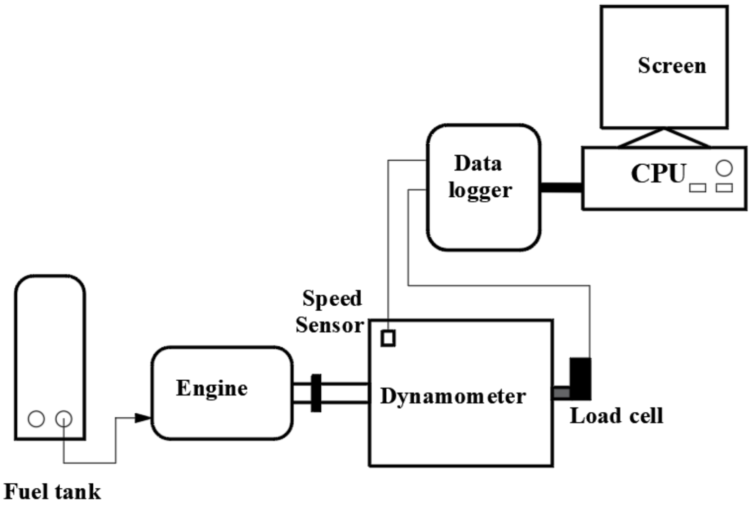

Figure 4. *Diagram of the engine power testing system*

In each operating mode, the output power of the engine would be measured and collected by KOEN engine power.

The engine power measuring equipment used for the experimental process was shown in Figure 5. In which, 1. Engine, 2. Dynamometer; 3. Data logger; 4. Computer.

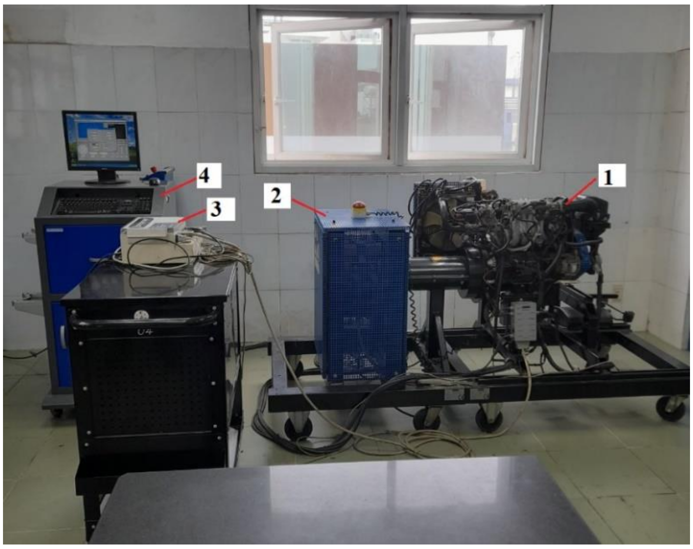

Figure 5. *Diagram of the engine power testing system*

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The engine power measuring process was conducted as following:

- Check the electric safety for the system.
- Operate KOEN engine power testing equipment and start the engine.
- Adjust the engine speed and motor speed of the supercharger following the experimental modes required.
- Operate the dynamometer to cause the load for the engine.
- Obtain the experimental data on computer for data processing.

3. Results and Discussion

3.1. Analysis of Variance for Drying Time and Color Change Index

The value of 1NZ-FE engine power was measured by the power engine testing with the different engine's operating modes at different engine speed and supercharger's motor speed. The data results were collected and processed by the computer software. The measurement data of engine power were graphically shown as in Figure 6.

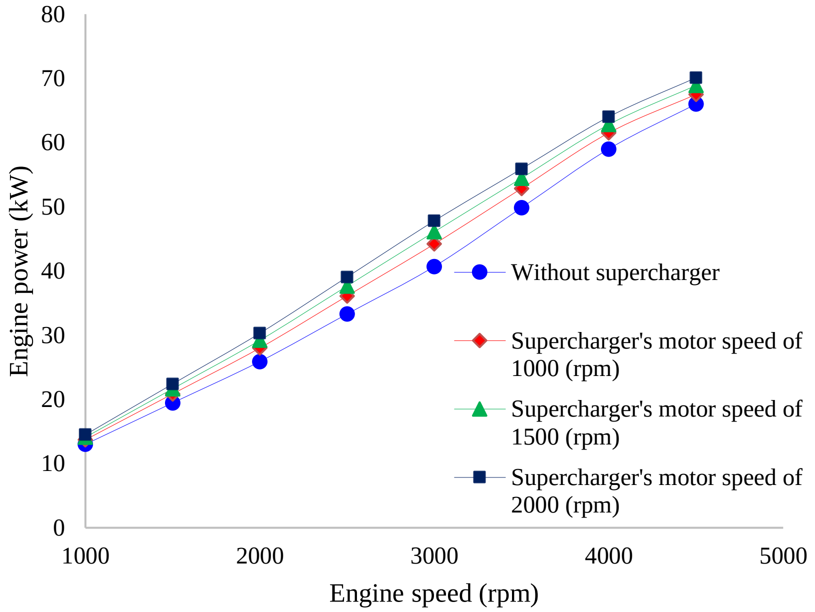

Figure 6. *The output engine power corresponding to different operation modes*

Figure 6 showed that with the support of the supercharger, the engine power during operation at all operating modes improved significantly. This could be explained by the fact that the supercharger clearly affected the air-fuel ratio. Supercharger support could increase intake air pressure and flow for more efficient and cleaner combustion process than the mode without supercharger support. As a result, engine power was improved during engine operation.

At low engine speed of 1000 (rpm), compared with the mode without supercharger, the power of supercharger assisted engine would increase about 5.1, 7.8 and 10.3% corresponding to supercharger's motor speed mode of 1000, 1500 and 2000 (rpm). As the engine speed increased, the power was improved more. At engine speed of 3000 (rpm), power had the best improvement, the power increased by 7.9, 11.7 and 14.8% corresponding to supercharger's motor speed mode of 1000, 1500 and 2000 (rpm).

However, as the engine speed continued to increase, the degree of engine power improvement of the supercharger engine as compared to the engine without supercharger would gradually decrease. At the engine speed of 4500 (rpm), the power had the lowest improvement, the power slightly increased by about 2.2, 4.2 and 5.8% respectively with supercharger's motor speed mode of 1000, 1500 and 2000 (rpm). This proved that when the engine was operated stably at high engine speed (> 3000 (rpm)), the air-fuel ratio as well as the intake air pressure and flow could be achieved at a optimum high value and the engine power reached the optimum high value. Therefore, at this operating mode, the supercharger would have a small support of improving the engine's output power.

As mentioned, with the improvement of the air-fuel ratio as the intake air pressure and flow increased, the combustion process was more efficient and cleaner, and the engine with the supercharger could be significantly improved with the output power during operation process. Besides, it was certain that in addition to improving engine power, it was also possible to reduce the concentration of harmful exhaust gases such as CO and HC [15]. The engine power and concentration of exhaust gases were two of the most important output parameters during engine operation. This was also the output criteria in the process of researching and improving internal combustion engines

4. Conclusions

The study evaluated the effect of supercharger on the power of gasoline injection engine. The power of the engine during engine operation was significantly improved with the support of supercharger. The engine power increased as increasing the engine speed and the supercharger's motor speed. With the support of supercharger, the engine power could increase up to 14.8% at engine speed of 3000 (rpm), and supercharger's motor speed of 2000 (rpm). This proved the significant improvement in engine power during the operation process of supercharger assisted engine. While the output engine power improvement as well as the reduction of concentration of harmful exhaust gases are two of the most important factors in automotive engineering.

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