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Supercharging Performance of a Gasoline Engine with a Supercharger

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Supercharging of intake air can improve the engine power and combustion characteristics by boosting the intake pressure above atmospheric pressure. In this work, the supercharging performance of a supercharged gasoline engine was discussed on the basis of experimental investigation. The investigation results showed that the output and torque performance of a supercharged engine were improved in comparison with the naturally aspirated engine. In the engine system with a supercharger, owing to supercharging of intake air into the cylinder, the combustion pressure, the rate of heat release, and the burning rate of fuel-air mixture were found to be higher than those of the naturally aspirated engine. In this paper, the effect of the drive pulley ratio and the pressure ratio of supercharger, and the other factors on the supercharging performance were also investigated.

Key Words: Supercharged Engine, Roots Type Supercharger, Combustion Characteristics, Engine Performance, Pressure Ratio

1. Introduction

In recent years, considerable research for the development of the supercharger has been made with various types of supercharger technologies in order to obtain the higher output performance of automotive engines.

Supercharging refers to increasing the air-fuel mixture density by increasing its pressure prior to entering the cylinder. The concept of supercharging has proved to be an efficient and effective method of increasing engine output. There are two types of these supercharging system. One is a turbocharged system, and the other is a mechanical supercharged system.

In the turbocharging system, the exhaust gas leaving an engine is further expanded through the turbine that drives a compressor. The compressor raises the density of inlet air so that more fuel and air can be delivered to an engine cylinder to increase the power output. From the thermodynamic point of view, the turbocharger system is attractive because it makes use of the exhaust energy. However, turbocharger performance has been influenced by the mass flow rate of inlet air and engine speed (Han, S. B. et al., 1994). At a low speed range of small size engine, it is difficult to obtain sufficiently high boost performance because of the insufficient energy of the exhaust gas. In addition, this system has a defect which is called a turbo lag. In order to optimize a supercharged engine system, it is important to select the adequate compressor type.

As compared with the turbocharged engine, a supercharger is mechanically driven by the engine crankshaft. Since the engine speed and supercharger speed are in a fixed ratio to each other, boost pressure change with engine speed much more rapidly than in the case of a turbocharged engine. Therefore, a supercharged engine has no

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time lag needed to raise the boost pressure. But this system has a defect that there is a mechanical loss to drive the supercharger.

About 90 % of all the passenger car models with supercharged engine are equipped with the Roots type supercharger. And the other types of supercharger are fitted vane of the screw type compressor. The main advantages of the Roots supercharger are the high level of rated speed and the excellent sturdiness of supercharging. But the flow characteristics of this supercharger are bad relatively.

A number of recent papers has reported the results of the application of supercharger to passenger car of diesel engine(Singer, 1985 ; Matsubara, et al., 1989).

Fort and Blumberg (1987) reported the comparative analysis between the screw supercharger and turbomachinery when applied to supercharging and waste heat recovery in diesel engines.

Recently, Kiyota, et al. (1989) developed a mechanically supercharged gasoline engine. But most of studies in improving the engine power and vehicle performance by boosting the intake manifold pressure above atmospheric pressure are the turbocharging effect of diesel engines. Among such technology, a mechanical supercharger has been recognized for its merits over the turbocharging system in terms of performance characteristics. The main advantages of the Roots supercharger are the spontaneous transient behavior during the acceleration under all conditions and favourable torque characteristic under the steady state conditions at low engine speed, especially in the small displacement engines.

As the boost pressure is increased, the adiabatic efficiency of the supercharger decreases due to the high outlet temperature of the compressor. The increase of inlet air temperature results in a decrease in engine output performance due to knock limited spark advance.

In general, many references (Uthoff and Yakimow, 1987; Lundstrom and Gall, 1986; Adams, 1984) deal with comparison of performance between the turbocharged and the supercharged engine, but there are not many such studies on the investigation of the mechanical supercharger in the spark ignition engine.

The aim of this investigation is to present the results of the supercharging effects of a small sized gasoline engine. Also, this work is to compare and investigate the effect of operating conditions and influencing factors on the performance characteristics of the supercharged gasoline engine with the Roots supercharger.

2. Experimental Apparatus and Procedures

2.1 Supercharger and test engine

In this investigation, the supercharging experiment was carried out using the Roots type supercharger. The supercharger mainly consists of the rotor housing, non-contact rotors, side housings and drive gear system.

The supercharger is a non-contact rotor type

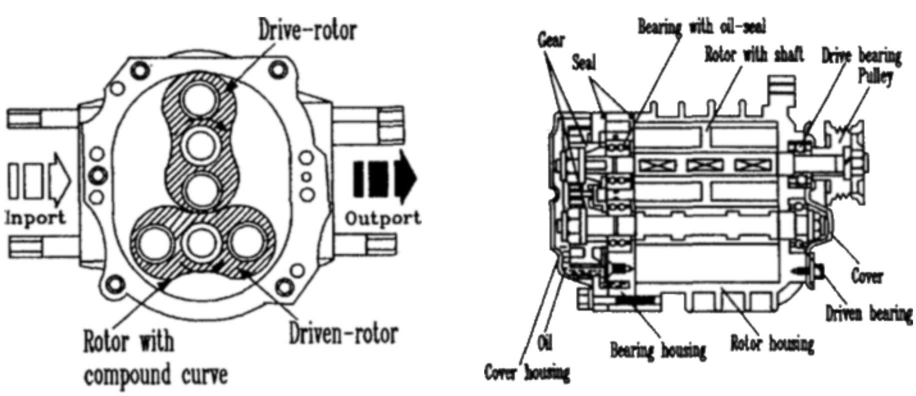

Fig. 1 Structure of supercharger

Table 1 Specification of test engine and Roots type supercharger

Engine	Type	4 stroke cylinder gasoline engine
	Number of cylinder	3
	Bore × Stroke	68.5 × 72.0 mm
	Maximum output	30.85kW/5,500 rpm
	Displacement	$7.96 \times 10^{-4} m^3$
	Compression ratio	9.3
Supercharger	Type	non-contact Roots type
	Flow rate	3.83×10^{-4} m^3/rev
	Maximum speed	15,000 rpm
	Number of rotor	2

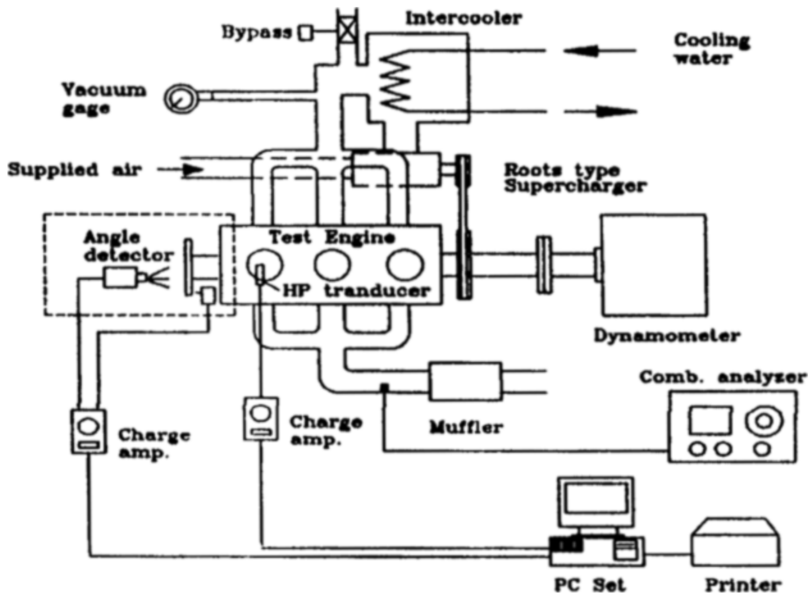

Fig. 2 Experimental apparatus of the supercharged engine

with theoretical flow rate of 3.83×10^{-4} m^3/rev. The structure of the Roots supercharger is shown in Fig. 1, and the specifications of test engine and supercharger are shown in Table 1.

The engine is a three cylinder, inline, overhead valve gasoline engine with a total cylinder displacement of 7.96×10^{-4} m^3. The rotor of a supercharger consists of a double-life section symmetrical about its rotating shaft. The rotation of rotors reduces the volume in which the air is trapped, producing a pressure rise. To maintain the rotors at their proper speed, one rotor shaft is driven by the other through a pair of gear train.

The gears are located in a closed chamber and lubricated with gear oil, which has been developed for high speed operation and high temperature conditions of the supercharger.

2.2 Experimental procedures

In order to obtain the performance characteristics of the supercharged gasoline engine, the experimental apparatus consists of test engine with supercharger, power measuring system and combustion analyzer system as shown in Fig. 2.

The experiments were performed on a supercharged gasoline engine directly coupled to an eddy current type dynamometer. The combustion analyzer system was composed of the crank angle position detector, pressure measuring system, and data processing device. The rotation of the test engine was controlled by an eddy-current dynamometer system.

The pressure history of the engine cylinder was obtained by using the high pressure transducer and A/D converter system.

In order to prevent the knock of the engine, the intercooler using water was adapted in this system for better cooling efficiency of the inlet air. The intercooler system is made of cooling water tubes and intake air passage in the intercooler.

In this investigation, the compression ratio and experimental conditions are as following;

Compression ratio : naturally aspirated engine (NA) 9.3, supercharged engine(SC) 8.3

Pulley ratio(Dc/Ds) : 1, 1.5(Dc: crank pulley diameter, Ds: supercharger pulley diameter)

Supercharger pressure ratio : 1.1, 1.2, 1.3, 1.35

Coolant water temperature : 70℃

Engine speed : 1,500 rpm～4,000 rpm

3. Experimental Results and Discussions

3.1 Performance characteristics of supercharged engine

The comparison between the two different compression ratio engines was initially performed to elucidate the effect of compression ratio on combustion characteristics. In this investigation, performance data such as brake torque, fuel consumption were obtained by the engine dynamometer system and data acquisition system.

Figure 3 shows the comparison of the engine torque curve against engine speed for the naturally aspirated engine with compression ratio of 8.3 and 9.3. The engine torque increases with the increase of compression ratio at all engine speed. Also, Fig. 4 shows the effect of compression ratio on the output performance characteristics of the test engine. It can be seen that the output power of engine increases in accordance with the increase of compression ratio. This is the reason why the thermal efficiency of the gasoline engine strongly depends on compression ratio. That is, an increase in compression ratio increases the compression temperature and pressure at TDC, which

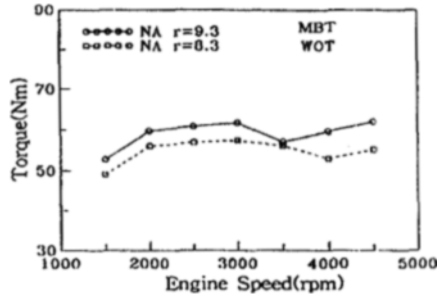

Fig. 3 Effect of compression ratio on the engine torque

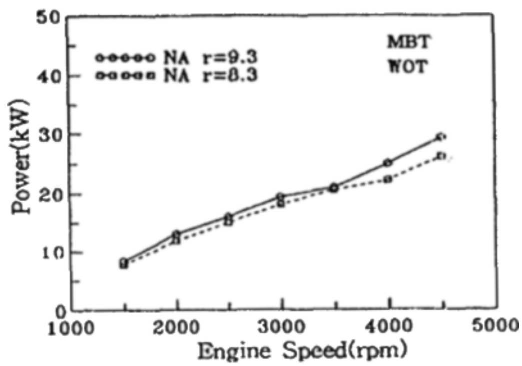

Fig. 4 Effect of compression ratio on the engine power

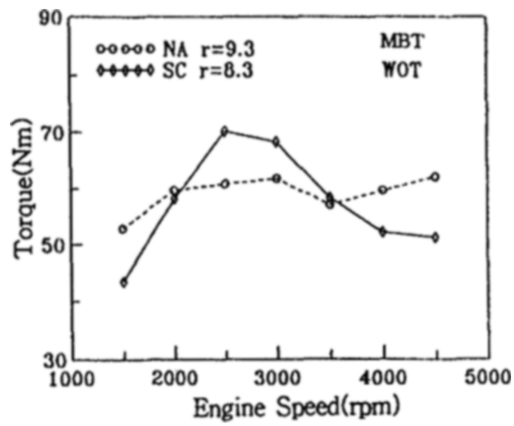

Fig. 5 Comparison of NA engine and SC engine torque

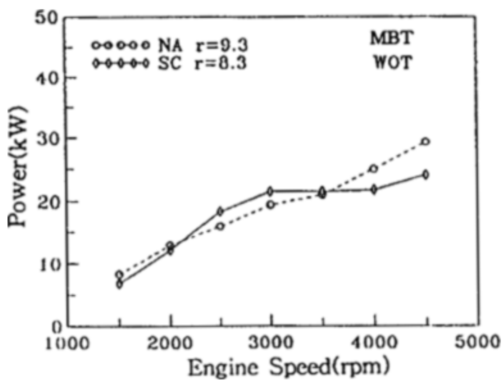

Fig. 6 Comparison of NA and SC engine power

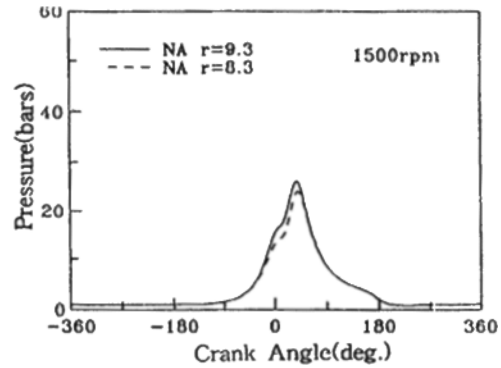

Fig. 7 Effect of the compression ratio on the cylinder pressure

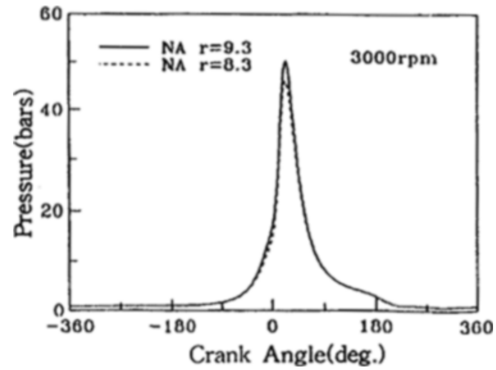

Fig. 8 Effect of the compression ratio on the cylinder pressure

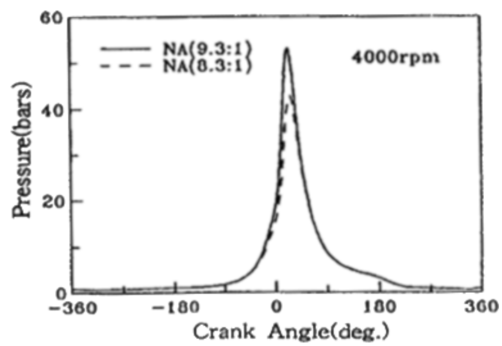

Fig. 9 Effect of compression ratio on the cylinder pressure

will increase the burning velocity for the same rpm. The increased compression ratio and the associated increased burning velocity will result in higher performance for the higher compression ratio engine compared with the lower compression ratio engine.

The effect of supercharging on the engine torque can be seen on Fig. 5. It was found that the effect of supercharger brought about the increase of the brake power torque at the range between 2,000 rpm and 3,500 rpm. At the low speed range less than 1,500 rpm, the engine torque was decreased due to friction loss and mechanical drive loss of the supercharger. In the case of high range more than 4,000 rpm, the engine torque also decreased with compression ratio decreasing.

An illustration of the engine power corresponding to Fig. 5, which is selected as the stabilized torque during two hundred cycles, is shown in Fig. 6.

The engine output was increased with the supercharger at the medium and high speed range. Therefore, if the operation of a supercharger is suspended by the electromagnetic clutch under low speed and high speed range except the above effective range of speed, the engine performance will be promoted by the charge of pressurized air into the engine cylinder.

3.2 The comparison of combustion characteristics between the naturally aspirated engine and the supercharged engine

In order to obtain the combustion characteristics and performance of the engine with supercharging, pressure data of engine was detected by the combustion analyzer system. The combustion characteristics of the supercharged engine for two hundred cycle conditions were evaluated by the pressure-crank angle data for each cycle.

The conservation of energy equation for a engine cylinder can be expressed as

$$\frac{dQ}{d\theta}=\frac{1}{k-1}\left[kP\frac{dV}{d\theta}+V\frac{dP}{d(\theta)}\right]$$

where,

k=specific heat ratio
Q=heat
θ=crank angle
P=pressure
V=volume

Figures 7, 8 and 9 show the results of pressure-crank angle data in the naturally aspirated engine. A standard production engine of compression ratio 9.3 : 1 was used for the naturally aspirated (NA) tests. The same engine fitted with the low compression gasket giving compression ratio 8.3 : 1 was used for the supercharged (SC) tests.

As shown in these figures, the lower compression ratio decreases the cylinder pressure due to the lower combustion temperature at all engine speeds. With the increase of the engine speed, the difference of cylinder pressure between two compression ratio engines became larger. These results indicate that the compression ratio has a great effect on the cylinder pressure of a naturally aspirated engine.

Figures 10, 11, and 12 compare the gas pressure in engine cylinder for the naturally aspirated engine and supercharged engine. In spite of the decreased compression ratio, this result showed that the cylinder pressure of a supercharged engine was higher than that of the naturally aspirated engine at the low engine speed (1,500 rpm).

A similar trend was applied to the cylinder pressure at the medium engine speed (3,000 rpm). However, at the high speed (4,000 rpm), this trend did not occur and the cylinder pressure of a supercharged engine was lower than that of the naturally aspirated engine.

From the above results, supercharging of a gasoline engine with the lower compression ratio of 8.3 improves the combuston characteristics such as cylinder pressure at the range of low and medium speed.

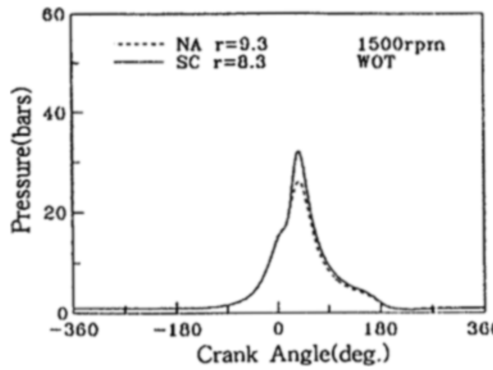

Fig. 10 Comparison of pressure between SC and NA engine

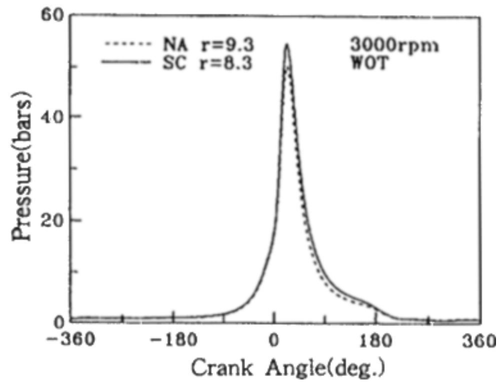

Fig. 11 Comparison of pressure between SC and NA engine

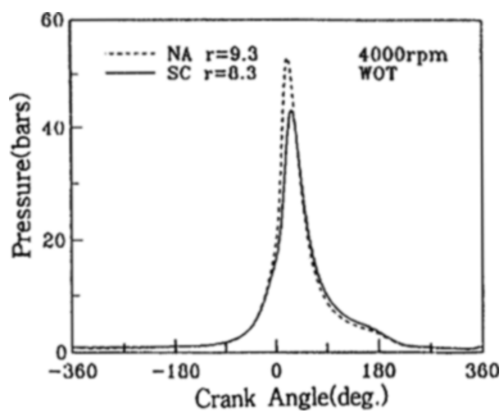

Fig. 12 Comparison of pressure between SC and NA engine

The supercharger effects on the rate of heat release in a engine were demonstrated in Figs. 13, 14, and 15. As it was known that the rate of heat release in a cylinder was related to the mass of

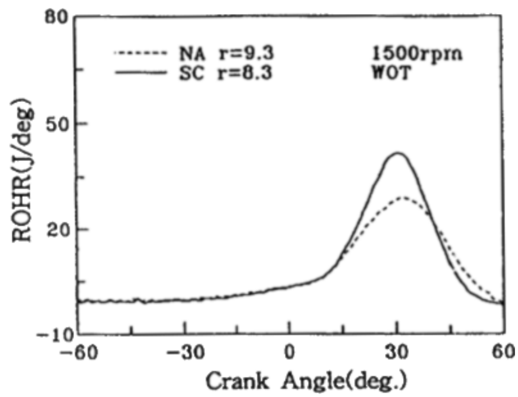

Fig. 13 Comparison of heat release rate between SC and NA engine

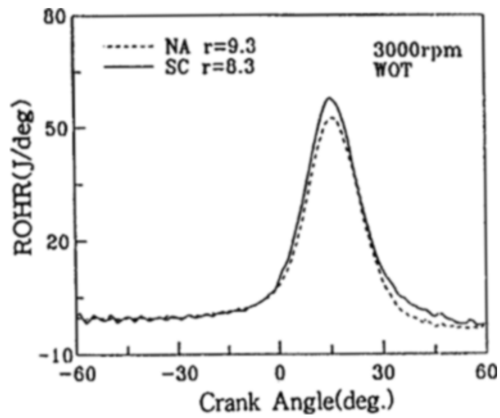

Fig. 14 Comparison of heat release rate between SC and NA engine

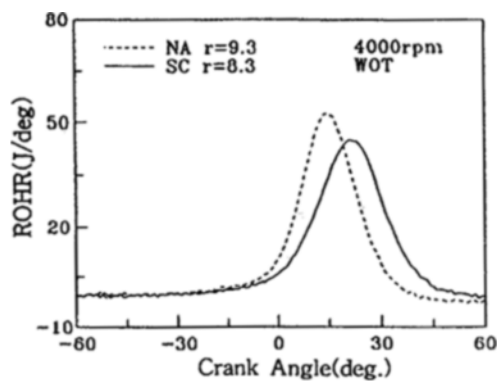

Fig. 15 Comparison of heat release rate between SC and NA engine

inlet air, supercharging of the air results in an increase of heat release because of the increase in inlet charge pressure. Therefore the rise of initial pressure in a cylinder brings about the improvement of combustion characteristics at the range of engine speed from 1,500 rpm to 3,000 rpm.

As shown in above figures, the dotted line shows the test results of the naturally aspirated engine with a compression ratio of 9.3. Supercharging the engine causes an increase in the heat release at low and medium speed, but the maximum rate of heat release at 4,000 rpm is decreased. The reduction of the heat release rate in higher engine speed range is due to the lowering of compression ratio. These combustion characteristics were used in analyzing the causes of a reduced supercharger performance in low and high speed region. Though the combustion characteristics such as cylinder pressure and rate of heat release of a supercharged engine were higher than for a naturally aspirated engine, the supercharged engine performance was lower than for a naturally aspirated engine as shown in Figs. 3 and 4. These results indicate that the supercharged engine performance was mainly dependent on the mechanical loss to drive the supercharger at low speed. In addition, at high speed, the supercharged engine performance was more influenced by the compression ratio than mechanical loss.

3.3 Effect of reduction ratio and pressure ratio on the supercharging effects

Figures 16 and 17 show the influence on the change of the reduction ratio for the drive system of supercharger pulley ratio on the brake torque and brake fuel consumption rate of the test engine with a supercharger.

In order to investigate the influence of the variation of pulley reduction ratio on the supercharging performance, the driving reduction ratio between the crank pulley and supercharger pulley was tested from 1 : 1 to 2 : 1.

As shown in figures, the supercharger pulley ratio had influence on the engine torque and fuel consumption. Especially, the torque of ranges between 2,000 rpm to 3,000 rpm dramatically increased for pulley ratios of 1.5 and 2.0 and the brake fuel consumption rate decreased at the same regions. Therefore the selection of the pulley ratio between a supercharger and an engine is impor-

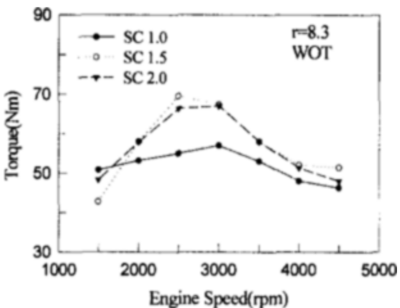

Fig. 16 Effect of pulley ratio on the engine torque

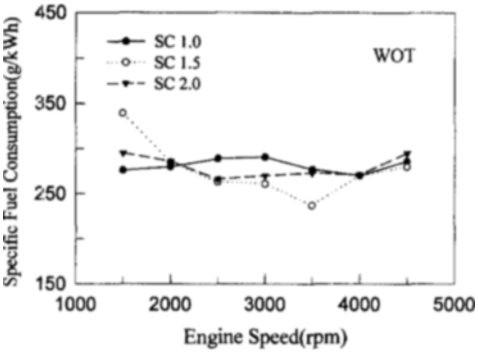

Fig. 17 Effect of pulley ratio on the specific fuel consumption

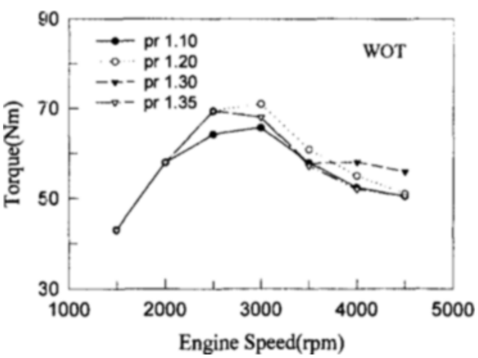

Fig. 18 Effect of pulley ratio on the engine torque

tant due to its influence on the engine performance as shown in Figs. 16 and 17.

The over-boost of inlet air is undesirable from the point view of engine performance. Boost pressure control can be made by release of compressed air, control of pulley ratio, and various inlet port system. As shown in above figures, the optimum pulley ratio and minimum consumption rate of fuel at a medium engine speed range was proved to be the pulley ratio 1.5 : 1

The effect of pressure ratio of the supercharger on the engine torque was investigated. Figure 18 showed how the engine brake torque versus engine speed plots changed with various pressure ratio of supercharger. It can be seen that maximum brake torque occurs in the operating range of medium speed from 2,500 rpm to 3,000 rpm under the condition of pressure ratio of 1.2.

4. Conclusions

The supercharging effects and performance characteristics of a spark ignition engine with the Roots type supercharger have been experimentally investigated.

From the analysis of experimental results in this work, the effects of supercharging on the engine performance and combustion characteristics can be summarized as follows:

(1) Engine performance investigations using the Roots type supercharger indicate that the output and torque performance can be improved in comparison with the naturally aspirated engine at speed range from 1,500 rpm to 3,000 rpm.

(2) At the range of low and high speed, the performance characteristics of the engine with supercharger were worse than the output performance of a naturally aspirated engine.

(3) The results of these investigation showed that the optimized pulley ratio were pressure ratio are 1.5 and 1.2, respectively.

(4) In the engine system with a supercharger, the combustion characteristics such as cylinder pressure, rate of heat release were found to be better than the corresponding rate characteristics of the naturally aspirated engine under the medium speed range.

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