⦿ 研究論文

A Study on the Response Characteristics of a Turbocharged Diesel Engine under Operation Conditions of Rapid Acceleration

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터보과급기 부착 디젤기관의 급가속 운전시 응답특성에 관한 연구

최 낙 정 · 전 봉 준

Key words : Turbocharged diesel engine(터보과급디젤기관), Transient response characteristics(과도응답특성), Rapid acceleration(급가속), Air injection(공기분사), Air Injection period(분사기간), Acceleration time(가속시간), Acceleration rate(가속률)

Abstract

본 연구는 터보 과급기 부착 디젤 기관의 급가속 운전시 기관과 과급기의 과도 응답 성능을 규명하고 이를 개선하기 위한 실험을 수행하였다. 과도 응답 성능 규명은 일정한 회전 속도로 정상 운전 중인 기관의 연료 펌프 랙을 10%에서 40%까지 일정시간동안 급가속하였을 경우에 대하여 수행하였으며, 이 때의 과급기 응답 지연 현상을 개선하기 위한 실험은 급가속과 동시에 압축기 출구의 흡기 메니폴드 내에 일정한 압력의 공기를 추가 분사하는 방법을 이용하였다. 그리고 공기 분사 압력, 공기 분사 기간, 가속률, 가속 시간 등이 압축기 출구의 압력과 온도, 터빈 입구의 압력과 온도, 실린더 압력, 기관과 과급기 회전 속도 등의 응답 성능에 미치는 영향을 가속전 정상 상태의 기관 회전 속도와 적용 부하의 변화에 따라 시간의 함수로 나타내었다.

1. Introduction

Recently, the turbocharger which is driven by the exhaust gas from the cylinders is universally used for automotive engines in order to increase the power output and to save the energy. A turbocharged diesel engine which is constructed with the turbocharger has a good characteristics that can improve the rate of fuel consumption and exhaust emission as well as the performance of power output of the engine under steady state speed. But these engines

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occur turbocharger lag in the case of the transient conditions such as a rapid acceleration or a sudden large load application, and then result in a worse response performance than those of naturally aspirated engine[1]. This is the because the turbocharger is powered by exhaust gas energy and its steady state speed varies with the position of the fuel - pump rack and engine speed. Quick changes in rack position do not result in instantaneous response of the turbocharger, due to its inertia and compressibility of the exhaust gas link from the engine. Thus the air fuel ratio quickly falls to a very low value and combustion becomes poor; although more fuel can be rapidly injected in the cylinders, the turbocharger is slow to respond and to provide a corresponding increase in air for combustion. For this reason, a study on the investigation and the improvement of transient performance is to be a very important subject. Many studies were reported to the transient characteristics of turbocharged diesel engines such as load acceptance of medium - speed industrial engine[2~3], computer simulation for the electric power unit[4], starting characteristics[5], response performances under a application of a sudden large load[6~9], etc.[10~12].

However, most of these papers have described the simulation studies for turbocharged diesel engine and an experimental study for improvement of response performance is scarcely reported[13].

Improvements of these transient performances can be achieved both by controlling the fuel flow and by consequently supplying air in the cylinder by some external means during the period of the transient conditions. In order to examine the feasibility of this approach, this study carried out an experiment to inject air in the inlet manifold of compressor exit when a rapid acceleration was applied to a turbocharged diesel engine.

And then this study inevestigated the effects of air injection on the response performances of the pressure of turbine inlet and compressor exit, cylinder pressure, engine speed and temperature of turbine inlet with the changes of operating conditions described previously.

2. Experimental Apparatus and Method

In order to investigate the response performance during the transient conditions, a four - cylinder four - stroke turbocharged diesel engine was used for the test. The turbocharger of the test engine was constructed with the radial turbine and centrifugal compressor. The details of the engine and turbocharger are shown in Table 1. The main test apparatus which was used for this study, as shown schematically in Fig. 1, was composed of the test engine, dynamometer, equipments for controlling fuel - pump rack and for injecting air,

Table. 1 Specification of experimental engine

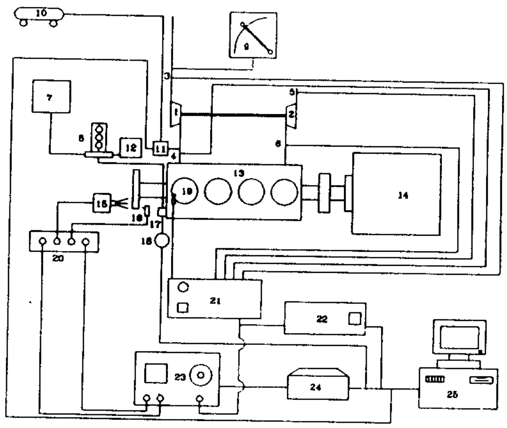
Item			Specification
Engine type			4 stroke, turbocharged diesel engine
Number of cylinder			4
Combustion chamber			indirect injection
Bore × stroke			91.1 × 95.0(mm)
Piston displacement			2476(cc)
Compression ratio			21.1
Connecting rod length			158.4(mm)
Valve timing	intake	open	BTDC 20°
		close	ABDC 48°
	exhaust	open	BBDC 54°
		close	ATDC 22°
Max. power			85PS/4200rpm
Vol. of intake manifold			0.00118(*l*)
Vol. of exhaust manifold			0.00104(*l*)
Dia. of turbine blade			39(mm)
Dia. of compressor blade			33(mm)
Number of blade	turbine		12
	compressor		12

sensor elements for measuring, and data aquisition system.

Fuel – pump rack was connected to the pulley fitted to the rotative shaft of step motor and an reduction gear of gear ratio 10 : 1 was used to increase torque at low speed, as shown in Fig.2. A rapid acceleration was conducted with the rotation of step motor which rotates 0.9 degree per pulse, and its pulse per second(pps) was controlled by means of microcomputer. The system of air injection in the inlet manifold of compressor was composed of the air receiver, regulator valve, timer switch and pipe of air supply. The nozzle for injecting air in the inlet manifold was embedded in hole of 7.6mm diameter and 3mm deep, which was drilled at gradient of 30 degree on the surface of compressor delivery pipe. Air generated from air compressor was injected in the inlet manifold through the nozzle diameter of 6mm with constant pressure. Air injection angle and position of air nozzle are shown in Fig. 3. Air injection period was operated by using the microcomputer, and air injection pressure was controlled by use of the hand opperated gate valve.

Pressure sensors of strain gauge type were used for the measurement, and installed to the compressor inlet and outlet, turbine inlet and outlet, and No.1 cylinder.

Experiments were carried out at two engine speed of 1000rpm and 2000rpm with and without the air injection during the transient conditions of a rapid acceleration, and their results were compared as to the response characteristics of a turbocharged diesel engine.



1. Compressor
2. Turbine
3. P. T. sensor(comp. inlet)
4. P. T. sensor(comp. exit)
5. P. T. sensor(turb. exit)
6. P. T. sensor(turb. inlet)
7. Fuel tank
8. Burette
9. Manometer
10. Air compressor
11. Air pressure regulator
12. Fuel consumption meter
13. Diesel engine
14. Eddy current dynamometer
15. Light source
16. Optical sensor
17. Fuel rack
18. Stepping motor
19. Pressure transducer
20. Signal controller
21. Charge amplifier
22. A/D converter
23. Combustion analyzer
24. Printer
25. IBM – PC/AT

* P : Pressure transducer T : Thermometer

Fig. 1 Schematic diagram of experimental apparatus

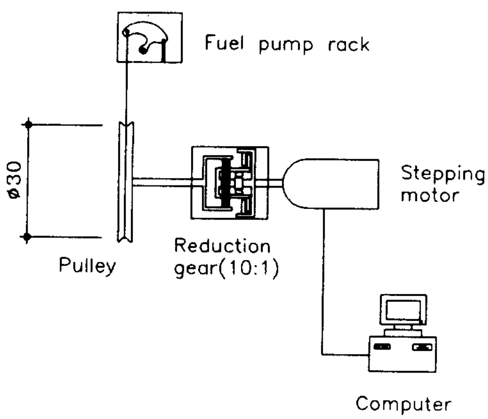


Fig. 2 Acceleration system of fuel – pump rack

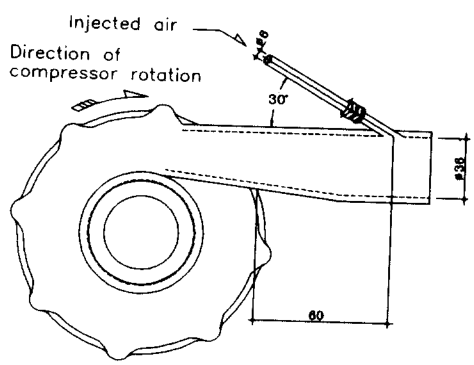


Fig. 3 Position of air injection

The major parameters measured under subjected transient operating conditions were engine speed, boost pressure, rack position, turbine inlet pressure and temperature, compressor outlet temperature, and cylinder pressure. The outputs of sensor elements used for measurement of these parameters were connected with each channel of digital memory, and their data were transferred to a microcomputer and processed.

Steady tests were carried out at an early stage in the investigation to obtain the engine data and these data were used to define the transient tests. These were repeated at the same time as the transient tests.

3. Experimental results and discussion

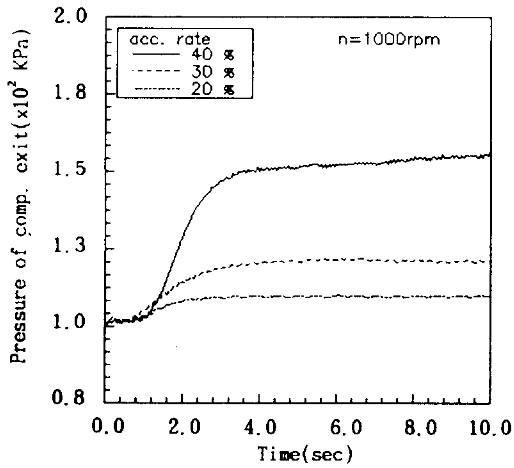
In order to investigate the response performance of a turbocharged diesel engine, the experiment was carried out at subjected engine speed with the changes of transient performance factors such as the rate of a rapid acceleration, accelerating time, air injection period, air injection pressure and load.

A rapid acceleration was applied to the fuel - pump rack of the engine from 0 - 10% to 0 - 40% in steps of 10%, and accelerating time of 1, 2 and 3seconds was subjected to the engine.

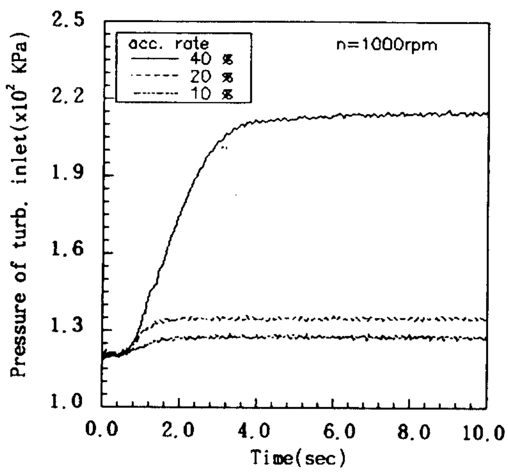
Air injection pressure was changed on the nozzle with no air injection and 300kPa as a gauge pressure, and air injection period also was applied to that for 1, 3, 5 and 10seconds.

Total length of fuel - pump rack which is able to be moved was 36mm at 1000rpm of no load and 26mm at 1000rpm of 163N · m load.

Fig. 4 shows the relations between the rate of a rapid acceleration and the response performances on the pressures of turbine inlet and compressor exit, when the rapid acceleration



(a) Compressor exit pressure



(b) Turbine inlet pressure

Fig. 4 The effects of a rapid acceleration on the pressure of turbine inlet and compressor exit

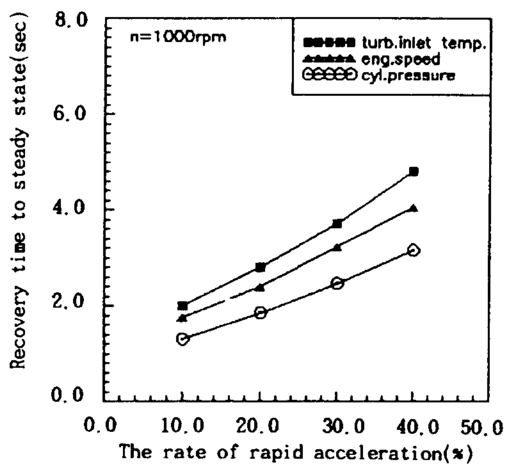


Fig. 5 The relations between a rapid acceleration and recovery time

from 0 to 40% was applied to the engine at 1000rpm of no load. Where, accelerating rate means the percentage of accelerated length on the total length of fuel - pump rack at setted

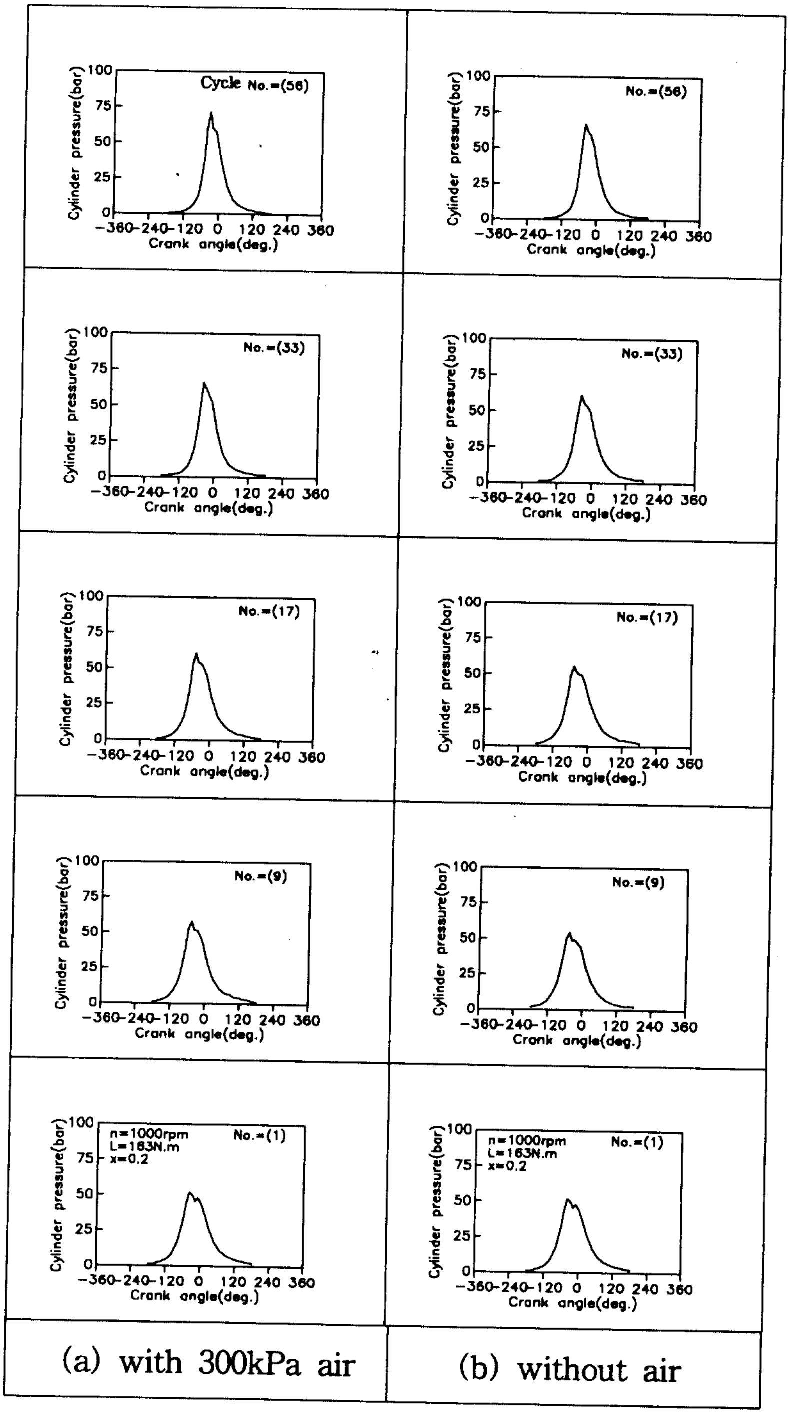


Fig. 6 The effects of air injection on the cylinder pressures measured during the period of acceleration

engine speed. As shown in this Figures, the pressures of those were slowly recovered to their steady state in accordance with the increase of accelerating rate.

Fig. 5 shows recovery time of cylinder pressure, engine speed and turbine inlet temperature during the period of transient condition.

The response characteristics of these factors that affect to the transient performances of the test engine also show the similar trends as shown in Fig. 4.

From above Fig. 4 and Fig. 5, it is obvious that as the acceleration is applied, the cylinder pressure responds at first, and in sequent engine speed, turbine inlet temperature, turbine inlet pressure and compressor exit pressure are responded in turn.

When the fast change of fuel - pump rack from 0 to 20%(x=0.2) for 1second was applied to the engine at 1000rpm with the setted load of 163N · m, Fig. 6 shows individual cylinder pressure - crank angle diagrams recorded according to the progress of cycles in order to investigate the influence of air injection on the cylinder pressure.

As shown in above cycle diagrams, the cylinder pressures increase in proportion to the fuel supplied as soon as the fuel - pump rack has responded, and at the same cycles the cylinder pressures with 300kPa of air injection recover more quickly and increase greater than the case without air injection.

It is clear that air injection in the inlet manifold during the period of the rapid acceleration improve greatly the combustion performances of a turbocharged diesel engine.

Fig.7, when the acceleration of 40% at 1000rpm of no load was applied to the engine for 1second, shows the comparisons of the pres-

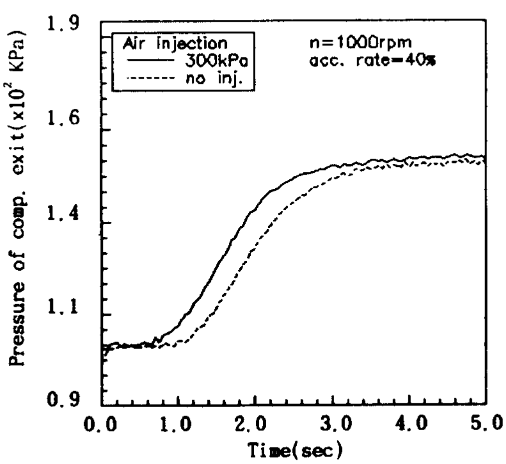
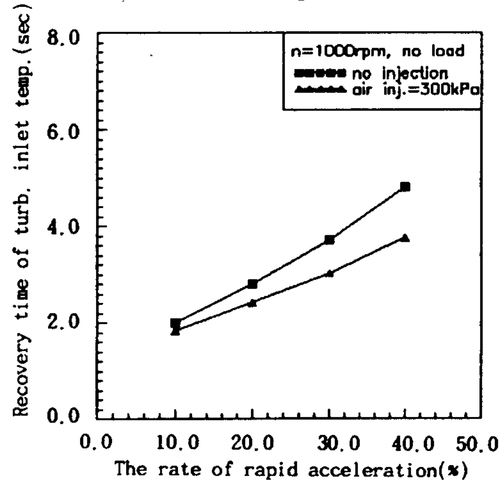
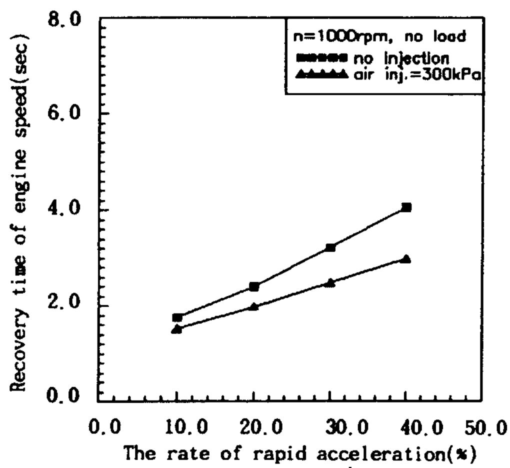


Fig. 7 The effects of air injection on the compressor exit pressure



(a) Turbine inlet temperature



(b) Engine speed

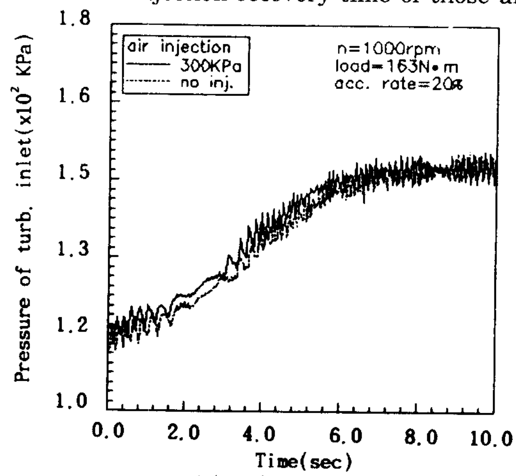
Fig. 8 The effects of air injection on the recovery time

sure of compressor exit on the with and without air injection.

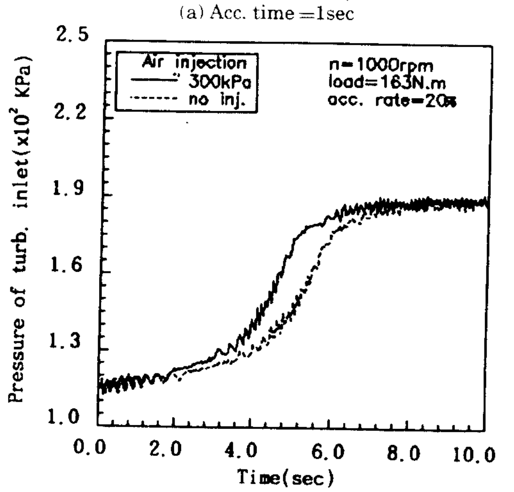
As shown in this diagrams, with air injection of 300kPa the pressure starts the rise of that earler about 1second than the case without air injection and reachs more quickly to the its final steady state pressure in direct propotion to the time.

Fig.8 shows the effects of air injection on the recovery time of turbine inlet temperature and engine speed under the same operating conditions as subjected in Fig.7 previously.

With air injection recovery time of those are



(a) Acc. time=1sec



(b) Acc. time=2sec

Fig. 9 The relations between air injection and accelerating time on the response performance of turbine inlet pressure

all short, and by increasing the rate of acceleration, the effects of air injection also increase in accordance with the increase of rapid acceleration.

On the other hand, the effects of air injection and accelerating time on the response performances of the turbine inlet pressure when the acceleration of 20% for 1second and 2second at 1000rpm of 163N · m load were applied to the test engine are compared in Fig.9.

As shown in these Figures, with the 300kPa of air injection for 2second air effects on the turbine inlet pressure appeared a greater than for 1second.

That is, the longer the accelerated time in the engine, the better results in the improvement for the response performance.

Fig. 10 show the effects of air injection period on the pressure of compressor exit. From these diagrams, it is observed that the increase of injection period brings about the pressure rise as well as the short of recovery time.

When the changes of accelerating time for 1, 2 and 3seconds were subjected to the engine on the various engine speed, Fig.11 show the influences of accelerating time on the transient

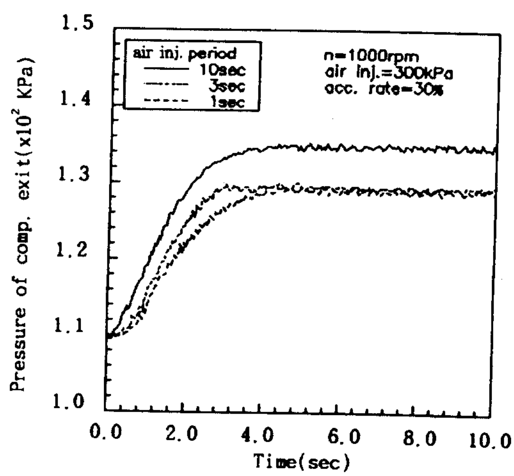
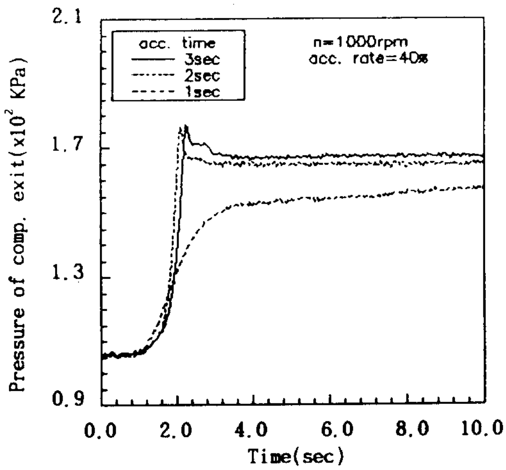
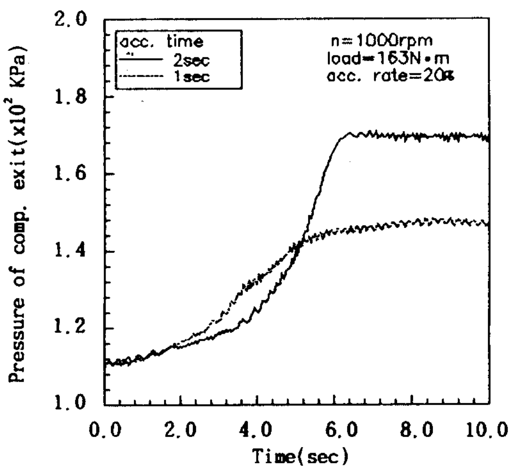


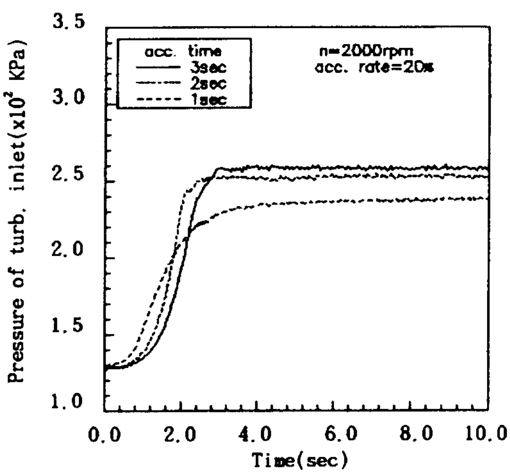
Fig. 10 The effects of air injection period on the response performances of compressor exit pressure



(a) n=1000rpm(no load)



(b) n=1000rpm(163N · m)



(a) n=2000rpm(no load)

Fig. 11 The effects of accelerating time on the response performances of compressor exit and turbine inlet pressures.

response performance of compressor exit and turbine inlet pressures.

As shown in these figures, all pressures of each engine speed are largely ıncreased in accordance with the application of slow accelerating time and recovered quite fastly to the range of their steady state pressure.

It is clear from these results that the rapid accelerating time is the main cause of turbocharger lag, which is closely related to the transient response performances of a turbocharged diesel engine.

4. Conclusions

This study was performed to investigate the transient response characteristics of a turbocharged diesel engine when the rapid acceleration was applied to the test engine. From the results obtained throughout this study, the following conclusions may be summarized.

1. when the rapid acceleration was applied to the test engine, first of all cylinder pressure responded, and sequently engine speed, temperature and pressure of turbine inlet, engine speed and compressor exit pressure were responded in turn.

2. As the rate of a rapid acceleration increase, the transient performance factors of test engine began the response lately and required a long time to reach to their stesdy state condition.

3. Air injection in the inlet manifold of compressor exit during the period of the rapid acceleration brought about the improvement on the transient resronse performances of a turbocharged diesel engine.

4. Accelerating time of fuel - pump rack was the main cause of the turbocharger lag, which had largely influence on the response performances of the test engine.

5. When the engine with the application of 163N · m load at 1000rpm was rapidly accler-ated, recovery time was a very longer than the case without the load.

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