한국액체미립화학회지 제20권 제3호(2015)
http://dx.doi.org/10.15435/JILASSKR.2015.20.3.195

A Comprehensive Study on Fuel Injector Test Bench for Heavy Duty Engine

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Key Words: Heavy duty injector, Injector test bench, Injection quantity, Injection pressure

Abstract

This study discusses a fuel injector test bench containing a mechanical type fuel supply system for heavy duty diesel engine. The main focus of this study was to evaluate the design stability of the test bench, which basically measures the injector durability of a multi-hole heavy duty injector by using pure diesel as a test fuel. In this experiment, diesel spray was controlled by a specially designed control box and all the experiments were carried out to measure e.g. fuel injection pressure and fuel injection quantity to understand the injection status which is interlinked with the stability factor of total test bench design. Also, the durability test was performed to understand the heavy duty operation lastingness of the designed system and the flow rate of the installed distributor pump in the fuel supply system of this studying test bench was compared with LO-1 and LO-2 pump. The results of the above mention tests revealed that the injector test bench design and control system can serve the purpose for heavy duty injector.

1. Introduction

Diesel engine plays a dominant role in the field of power, propulsion and energy. Today's diesel engine performance, power output economy is greatly dependent on the effectiveness of the fuel injection system. The fuel on injection system has to perform the important duty of initiating and controlling the combustion process[1]. In the off-highway diesel engine market, the traditional injection system is also gradually replaced by the high-pressure fuel injection systems[2]. In the present day's injection system of diesel engines are designed to obtain higher injection pressure[3, 4]. Also, the key goal to reduce the exhaust emission by increasing efficiency with the help of the advanced injection system[5]. When the injection pressure will increase, the fuel particle becomes small. If the injection pressure is too high, the ignition delay period becomes shorter and hence the possibilities of homogeneous mixture reduced and eventually the combustion efficiency dropped[6,7]. For lifetime verification of an automotive components it is important to simulate injection phenomena in a test bench that certainly regenerate some more boundary conditions to understand the fuel system design which will help researchers to elevate a more stable future test bench system. Again diesel fuel spray penetration depends to a great extent on injection pressure, fuel properties, and nozzle geometry. In a mechanically controlled fuel injection system, the injection pressure increases together with increasing engine speed and load[8].

For measuring the durability of a heavy duty injector for heavy duty engine, a test bed was designed along with a mechanical type distributor inline fuel supply system which can be controlled by pressing the buttons of a control box. This paper aims to com-

(Recieved: 12 Sep 2015, Recieved in revised form: 29 Sep 2015, Accepted: 30 Sep 2015)
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prehend about heavy duty engine fuel injection phenomenon e.g. fuel injection pressure and fuel injection quantity where the fuel was injected by manually adjusting the injector test bench and control system. As more reliable fuel injection pressure analysis indicates that the test system will work appropriately with heavy duty diesel system.

2. Experimental System Overview

2.1 Injector durability test bench system

The pictorial layout of the total test system is shown in Fig. 1. The total system was contained with a main test equipment, control box, a fixed injector, fuel tank and oil tank. Distributor type inline fuel supply pump and motor connection was controlled by engine fuel motor control box where both rpm and operating time can adjust. Also, a flywheel was installed with this system for smooth rotation where the flywheel was directly connected with the pump and flywheel has a cover for safety purpose. The control box can adjust the rpm of the installed motor in the main unit which also has the ability to run the test bench system either in automatic or manual mode. Control box design can control not only time, but also the operating condition as a number of revolutions. Injector used in this durability test was designed with fixed firm supports which make the injector more secure. Fuel from the pump is installed with main experimental equipment and fuel was sprayed through the injector where the injected fuel can collect separately. As a mechanically controlled fuel injection allowed to measure the pressure immediately after the pump and before the injector as well as the needle lift and fueling. Also a special cooling system was developed and attached to the test bed in order to maintain desired preset constant temperature condition. This in-line fuel injection pump was driven by a camshaft and a pumping element which mounted vertically in a straight line, side by side. The lower half of the pump housing supports and enclose a horizontally positioned camshaft, which has so many cam profiles. Each pumping element

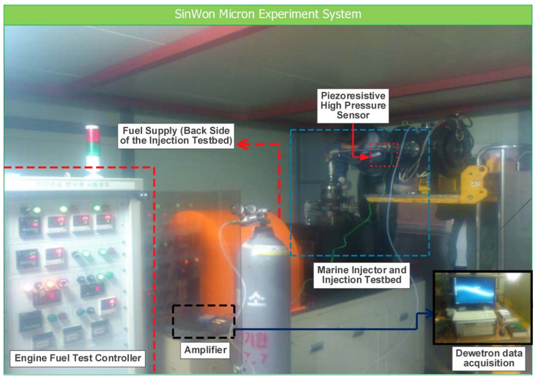

Fig. 1 Total arrangement of injector durability test equipment

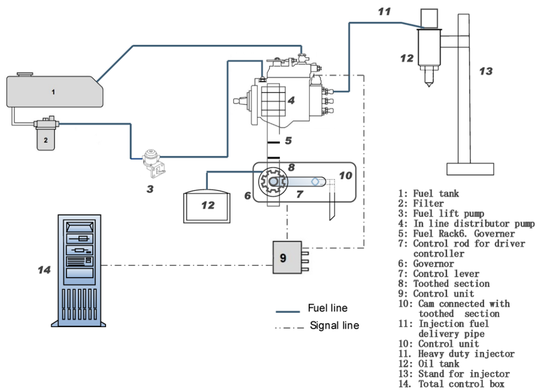

Fig. 2 Schematic diagram of test system

consists of a pump plunger which reciprocates in the barrel in depending on camshaft profile. The camshaft profile converts the angular movement of the camshaft into a linear plunger motion by the roller cam follower and a plunger return spring. The fuel enters the fuel ports at a pressure up to 1.5 bar, filling the space between the plunger and delivery valve. The plunger moves up by depending on camshaft rotation following the cam profile and cuts off the feed ports. Instantly, the in-barrel pressure collapses as fuel begins to escape down the vertical slot and exits through the feed/spill port. The pressure rise in the in-barrel results in a pressure wave traveling towards the injector. When this pressure wave reaches the injector nozzle the needle opens and the injection starts. After the fuel delivery ends, the pressure in the injector chamber falls, the needle closes, and the injection process terminates. Injection pressure is the fuel pressure just before the injector nozzle holes and the injection pressure history should in general exhibit a high mean/peak pressure ration, i.e., no extreme pressure peaks.

The fuel and oil tank used in this experiment was separated from the main test unit. Fig. 2 shows the schematic diagram of the full test system. To control the temperature of the fuel tank and oil tank, a heater is installed. For circulating both fuel and oil, a circulated pump were also installed. Also for the designed test bench the theoretical expectation of injection pressure is typically about 350 bar.

2.2 Total control system

Flow chart of the total control system is given in Fig. 3 where flow chart contains a gray part which represents the control box section, red area which represents camshaft box, oil tank, chiller and blue zone represents the injection pump, injector, fuel tank and chiller. Fuel tank and oil tank also have a different flow chart. Fuel tank and chiller have a thermocouple which was installed to control the temperature of the fuel with the help of a heater and then measure the temperature. When the fuel reached on the desired temperature, then the fuel supplied to the fuel supply pump and sprayed through the injector. During the fuel spray the pressure was measured at injector where the front end was designed to reduce the pressure through the relief valve when pressure is higher than optimum.

On the other hand, a thermocouple was also installed with an oil tank and chiller as a heating source for getting an appropriate temperature on the basis of temperature measurement. A thermocouple was connected with each injector pump and injector fuel tank, oil tank and chiller for measuring the temperature. The injector was connected with a pressure sensor, pressure relief valve and a pressure gauge to measure the pressure. The motor was designed in such a way so that the rpm of the motor can be controlled. Also, Flywheel was attached with the experimental apparatus which is directly connected with motor and pulley. A speed reduction ratio of 4:1 is maintained and for safety purpose flywheel has a cover.

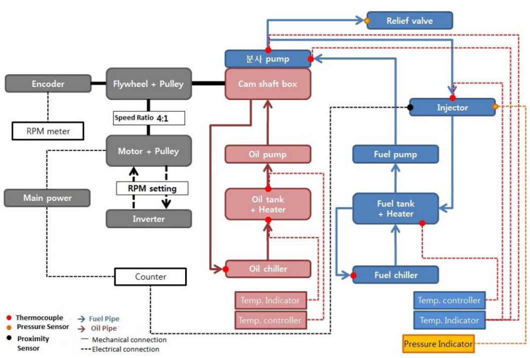

Fig. 3 Injector test durability control system flowchart

2.3 Spray visualization, injection quantity and injection pressure measurement

The spray visualization of this system was performed by black constant volume combustion bomb. A light source was used and the spray image was taken by a high speed camera (Photron Fastcam SA3) and for measuring injected fuel quantity the poured spray amount was collected in a test beaker and measured. For the injection quantity test, the pump ran for 1 min and then the fuel supply system was automatically stopped after 1 min. In the meantime, Piezoresistive Kristler Pressure Sensor 4067A and Amplifier were connected with the Dewetron Data acquisition platform to measure the injection pressure signal. RPM range is controlled by the control box where the range can be varied from 100 rpm to 400 rpm.

3. Test & Operating Condition

Pure diesel was used in the experiment of durability measurement and diesel fuel was injected through the injector and collected in a test beaker for measuring the injection quantity. Experimental condition is briefly mentioned in Table 1

When the test device starts its operation the following factor should be considered,

1. Automatic or manual option is only possible when each indicator light of the control box is ON.

Table 1 Experimental and operational condition

Nozzle opening pressure	360 bar
Test time	1 minute
Injection hole specification	0.41 × 13 holes
Standard of flow rate (100bar)	12,790 ml × 3% (12,406 ml ~ 13,174 ml)

2. The motor rotates when rotational light is turned on.

3. Timer operation is selected when the timer ON, counter OFF and counter operation is selected when counter OFF, timer ON and motor will operate only when the manual button is pressed.

4. Results and Discussion

4.1 Fuel flow measurement

For measuring the flow rate of the designed equipment, all other necessary equipment was gathered to make the flow measurement. Flow rate measurement is based on lift depth with a corresponding rack point which is related to pipe inner diameter. On the basis of rack point the flow rate was obtained and the comparison graph was shown in Fig. 4 where the flow rate of the current fuel supply pump used in the test bench was compared with L-orange pump sample no L3240 where LO-1 and LO-2 indicates different sample of L3240 fuel pump. When rack point is 25

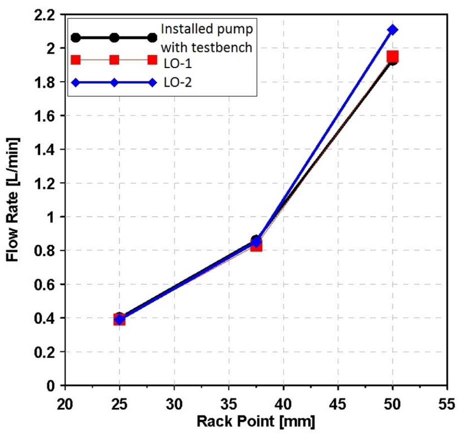

Fig. 4 Flow rate comparison of installed pump of current test bench vs previously used pump data

mm the result shows that the flow rate difference of three identical pumps is 2.5% which is almost negligible. When the rack point was further increased to 37.5 mm the flow rate difference among them is 3.6% which is almost similar. Finally, when the rack point is 50 mm the installed pump flow rate of the test bench was differ around 8.5% from LO-2 whether in compare to LO-1 the difference is still negligible

4.2 Method of spray visualization

A high speed camera is used to observe the characteristics of fuel spray for the heavy duty injector used in this study and fuel spray image were captured. Experimental images confirmed that the highly pressurized fuel spray appropriately inject through the injector and spray developed smoothly in all of the 13 holes. From the time interval count of the image it is clear that fuel vaporization starts from 9ms. Since this study mainly deals with an injector bench system for heavy duty engine so fuel injection pressure and fuel injection quantity was thoroughly investigated. However Fig. 7 represents the spray visualization image which indicates about the spray pattern correlation with each time frame increased.

4.3 Injection quantity measurement result

Fuel injection quantity was measured after the fuel injection happened for each specific rpm. Two experimental measurements were taken to evaluate the injection quantity. Each time the pump started within 100 to 400 rpm range and every injection quantity was measured very carefully when the fuel fume completely condensed. Since the observation was taken by human eyes so the margin of error is taken into account. From the graph it is obvious to see that margin of error is a bit high in 400 s but the overall graph from 100-300 rpm range indicates that the margin of error is not high for both experiments. In the first fuel injection quantity test the maximum quantity was 1775 mL which was measured when the rpm was 300 and the minimum quantity was 852 mL when the rpm is 100. But in second experiment 5 times measurement was taken for 400 rpm where the

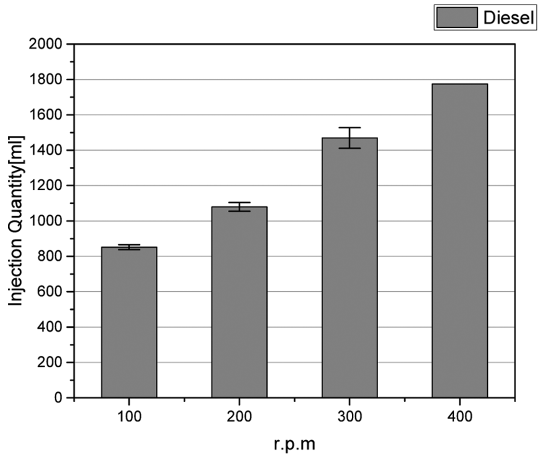

Fig. 5 First fuel injection quantity test

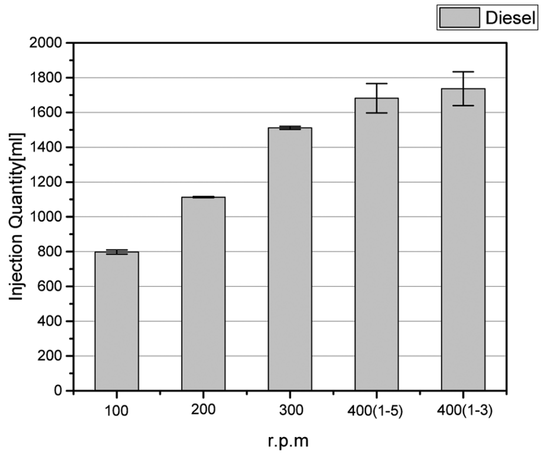

Fig. 6 Second fuel injection quantity test

overall injection quantity varies from (1610-1815) mL and minimum injection quantity in 790 mL. The difference between the average of minimum and maximum injection quantity between two experiments was 62 mL and 70.5 mL which is more coherent for a heavy duty injection system.

4.4 Fuel injection pressure measurement result

Figure 8 shows the fuel injection pressure for corresponding time. A Piezoresistive Kristler Pressure Sensor 4067A and amplifier connected with Dewetron data acquisition system to measure the injection pressure. Since all the previous measurements were taken in 1 minute time frame so this fuel injection pressure investigation was performed in the same time duration. When the fuel pump was running at a speed of 100 rpm three observations was taken, when 200 rpm around two observation was taken and for 300 rpm two observation was taken. For 100 rpm number of cycle varies from 94~97 and for 200 rpm number of cycle varies from 84~85 but for 300 rpm number of cycle are more than 200. Since the

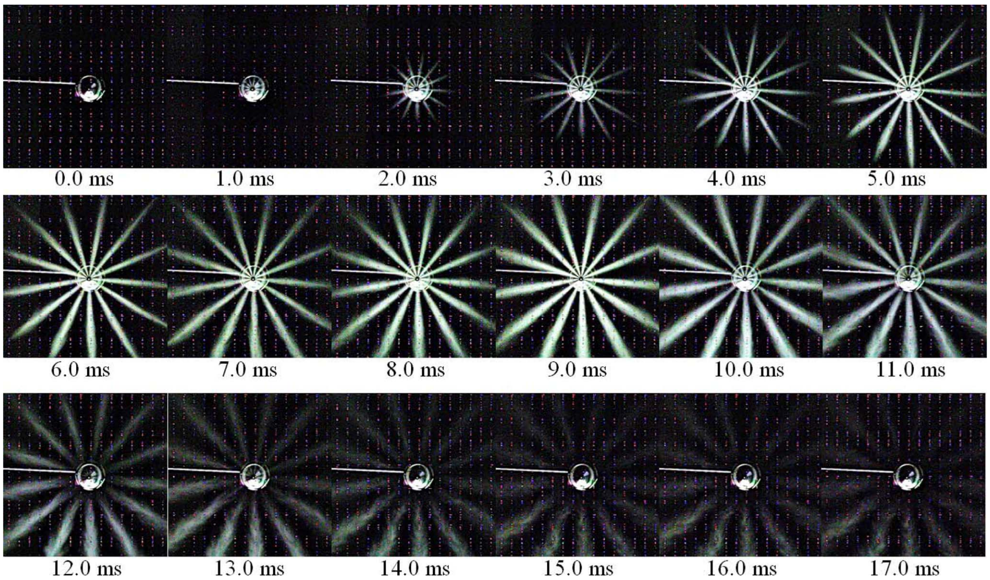

Fig. 7 Visualization of fuel spray for heavy duty injector

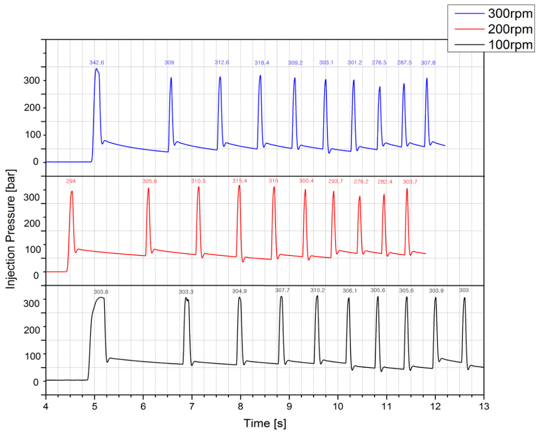

Fig. 8 Time domain injection pressure comparison for different rpm

pressure signal of each rpm is very long, so in which part where the average maximum pressure lie down that 10th cycle data was taken into consideration and presented in the graph. For 100 rpm, average maximum injection pressure is laid on 305 bar for 200 rpm average maximum pressure lie on 330 bar but in case of 300 rpm the average maximum pressure lie on 360 bar. Since it was a bit laborious to plot the whole data. For comparing the fuel injection pressure stability of the desire injection test bench first 10 cycles were plotted. However the total cycle average maximum pressure is same for first 10 cycles and the value are 305.39. On the other hand for 200 and 300 rpm for first 10 cycles the average maximum pressure is 300 and 306.79 respectively. Since the average maximum pressure for three different conditions didn't go under than 300 so it can be concluded that the injection pressure signal is continuous and injector test bench design is quite efficient to perform the action for heavy duty engine.

5. Conclusions

In a mechanically controlled fuel injection system, the injection pressure increases together with increasing engine speed and load. During the injection process, the maximum injection pressure can be more than double of the mean pressure. It has to be pointed out that the main goal was to increase the mean injection pressure to some reasonable maximum level. The maximum injection pressure is decisive for the mechanical loading of the fuel injection pump's components and drive. At a higher mean injection pressure the injection duration becomes shorter, if the fuelling is kept constant. So finally in this experiment, the designed fuel supply system for injector test bench keep maintains such a qualitative and quantitative injection pressure. As to understand the fuel injection more deeply, fuel spray was investigated and the spray image ensures a uniformly distributed fuel injection within 13 holes. Again from quantity test, the amount was slightly fluctuated on 400 rpm condition however the flow rate test measurement indicate the designed fuel pump is more stable than previous. However the fuel injection pressure comparison denotes a more stable fuel supply system which performs more steady operation and the quantity test imply that the injected amount of fuel maintains a harmony and the margin of error is almost negligible for 100-300 rpm. However the margin of error is a bit high for 400 rpm but it doesn't have any impact of the reliability factor of the design. With all this above information it can be concluded that the test bench design and fuel supply system is more stable to perform the operation of the heavy duty injector.

Acknowledgments

This research was financially supported by the Ministry of Education (MOE) and National Research Foundation of Korea (NRF) through the Human Resource Training Project for Regional Innovation and the Energy Efficiency & Resources (20122020100270) of the Korea Insitute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea government Ministry of Trade, Industry & Energy (MOTIE) and Business for R & D Technology Innovation funded Korea Small and Medium Business Administration in 2013 (Grants No. S2081559).

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