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Investigations on performance of diesel engine by varying injection timings with design modification on piston crown

Vijaya K., Shailesh Palaparty, Raghavan Srinivasa, Ravi Kumar Puli,

Investigations on performance of diesel engine by varying injection timings with design modification on piston crown

Vijaya K.
National Institute of Technology Warangal, India
Shailesh Palaparty and Raghavan Srinivasa
Methodist College of Engineering and Technology, Hyderabad, India, and
Ravi Kumar Puli
National Institute of Technology, Warangal, India

Abstract

Purpose – Investigations are carried out with the aim of improving performance of a diesel engine with the design modification on piston crown to stimulate the uniform combustion by inducing turbulence in the incoming charge.

Design/methodology/approach – A stirrer is introduced at the top of the piston so as to inculcate more turbulence to the incoming charge by improving the rate of fuel vaporization. Whirling motion is created in the combustible mixture by providing rotating blades on the cavity/bowl of the reciprocating piston head. By putting a simple link mechanism, the oscillatory motion of connecting rod will rotate the blade by an angle of 60°.

Findings – The investigations are carried out with and without swirl piston at 17.5 compression ratio and 200 bar injection pressure by varying injection timings.

Originality/value – Finally, the result shows that by using the modified piston, nearly 3 per cent of efficiency increased and 31 per cent of NOx emissions are reduced compared to that of a normal piston with 80 per cent load at standard injection timing.

Keywords Turbulence, Piston, Diesel engine, Diesel

Paper type Research paper

Nomenclature

CR	= Compression ratio;
BSFC	= Brake specific fuel consumption;
HC	= Hydrocarbons;
A	= Advanced injection timing;
R	= Retard injection timing;
SP	= Swirl piston;
BTE	= Brake thermal efficiency;
CO	= Carbon monoxide;
NO_x	= Oxides of nitrogen;
S	= Standard injection timing; and
NP	= Normal piston.

1. Introduction

Internal combustion engines have become an important part of our day-to-day life, and it plays a major role in the field of automobile sector and agricultural sectors. Diesel engines are used in large numbers, and they offer a lot of opportunities to researchers to study them from the perspective of enhancing their performance and reducing emissions. The in-cylinder fluid motion in internal combustion engine is one of the most important factors controlling the combustion process. It governs the fuel-air mixing and burning rates in diesel engines. The fluid flow prior to combustion in internal combustion engines is generated during the induction process and developed during the compression stroke. Therefore, a better understanding of fluid motion during the induction process is critical for developing engine designs with the most desirable operating and emission characteristics. To obtain a better combustion with lesser emissions in direct -injection diesel engines, it is necessary to achieve a good spatial distribution of the injected fuel throughout the entire space. This requires matching of the fuel sprays with combustion chamber geometry to effectively make use of the gas flows. In other words, matching the combustion chamber geometry, fuel injection and gas flows is the most crucial factor for attaining a better combustion. In this scenario, Prasad *et al.* (2011, 2013a, 2013b) investigated the impact of swirling of the incoming charge on the emission and performance of the DI diesel engine. The more turbulence is induced in the charge by modifying the design of the piston head, that is, modification of combustion chamber to enhance the turbulence in the cylinder. The swirl is intensified by cutting grooves on the piston crown.

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Heywood (1988) studied the performance of 1.8 L single-cylinder diesel engine with an additional attachment of the swirl rate controller. This attachment allowed variation of the mean swirl ratio. Swirl level has a significant influence on the combustion process and exhaust emissions. When the swirl ratio increased to certain level, more intense premixed combustion phase is improved. By increasing the swirl ratio, pressure and temperature of the charge are increased because of premixed and controlled combustion in the engine cylinder which results the promotion of NOx formation and also reduces the soot production and increases the soot oxidation. The overall combustion duration was also shortened with reduced fuel consumption. Singh (2005) modified the combustion chamber by creating grooves on it, which will in turn improve the turbulence to the charge. They created a possibility of multiple flame fronts so as to improve the combustion efficiency and reduce the heat losses. Jeng *et al.* (1999) experimentally investigated the quality of the tumbling motion, especially for the engine with a bowl in the piston. It is observed that a small-scale vortex will be reserved inside the bowl in the piston. In their further investigation, the quality of the vertical flow in the axial plane with the generation of turbulence during the compression stroke is strongly recommended. The researchers (Yun and Lee, 2000) discussed the collective effect of tumble and swirl flows of charge at the inlet port. They noticed that swirl and tumble motions together are induced in the combustion chamber, and it is difficult to separate the influence of each on combustion and they also proposed new evaluation index to characterize the in-cylinder flow. Suzuki (1988) proposed baseline modifications in piston and cylinder liners to enhance mechanical and thermal loading on vital engine parts. Hard anodizing of the piston head, reinforcing the piston head with SiC whisker. He proposed a new process for improving the surface lubrication by introducing numerous finely distributed micro-pits. The researchers (Dembinski and Angstrom, 2012) studied by applying different inlet port designs and valve seat making, swirl and tumble. In their study, they measure the flow of charge at the TDC by capturing the combustion images by renounced software called velocimetry. They also estimated the swirl number from the same data. They concluded that swirling motion is progressed from compression to combustion process, whereas tumble motion plays a vital role at the final phase of combustion. However, this tumble effect will influence the swirl motion and offset its location during combustion.

Turbulence of charge plays a crucial role in the combustion in IC engines. Flame speed, mixing of unburned charge is relatively poor in case of transition and low-turbulent mixtures. However, homogeneous combustion can be attained by inducing turbulence either by changing the flow pattern or by changing the geometry of the combustion chamber. This will improve the performance of the engine. A higher turbulence in the charge can be created by changing the geometry of the combustion chamber that can be carried out either by changing the design of cylinder head or the piston crown. At a particular operating pressure, piston speed would proportionally increase the turbulence induced in charge. However, excessive turbulence is also undesirable. The effects of turbulence can be summarized as turbulence accelerates chemical action, so that the combustion time is reduced and hence minimizes the tendency to detonate. Even though the turbulence gives uniform combustion, higher turbulence may lead to flame extinguish. In the present work, experiments are conducted at a constant speed, with and without piston modification, 200 bar injection pressure and various injection timings at four different loads levels namely, 20, 40, 60 and 80 per cent of full load with 17.5 CR.

2. Experimental setup

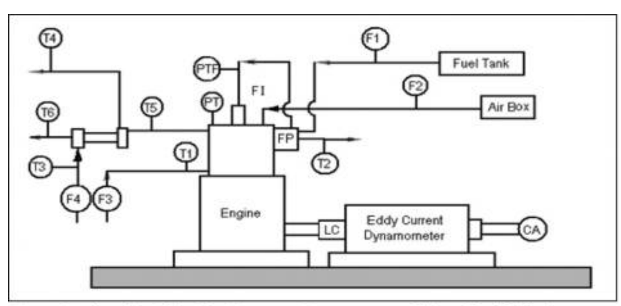
To induce the turbulence in charge, piston crown in re-designed and experiments are conducted to evaluate the performance. Schematic representation of the experimental test setup is presented in Figure 1. Experiments are conducted to study the influence of swirl and tumble on the performance of diesel engine. The engine specifications are presented in Table I. It is a computerized single-cylinder, four-stroke, water-cooled CI engine with an eddy current dynamometer. The engine is provided with chromium–aluminum thermocouples to measure the jacket water inlet and outlet (T1 and T2), calorimeter water inlet and outlet (T3 and T4) and exhaust gas inlet and outlet (T5 and T6) temperatures.

Engine is also provided with pressure sensors, the dynamic pressure with water-cooled piezo sensor, combustion gas pressure with differential pressure transducers and fuel injection pressure with differential pressure unit. Flow rate of the cooling water is measured using a Rota meter with stainless steel float. An encoder is fixed for crank angle record. The signals from all the sensors are interface with a computer to display P-θ, P-V and FIP-θ plots. A provision is also made in the measurement of volumetric fuel flow. A built-in program in the system calculates the indicated power, brake power and thermal efficiency.

2.1 Piston modification

Piston modification is an important strategy that has been followed since recent times by the research community owing to the performance of the diesel engine. Figures 2 and 3 show the normal piston and modified piston, respectively. In a

Figure 1 Schematic diagram of the experimental set-up



PT	Combustion Chamber Pressure Sensor	FI	Fuel Injector
PTF	Fuel Injection Pressure Sensor	FP	Fuel Pump
T1	Jacket Water Inlet Temperature	F1	Liquid fuel flow rate
T2	Jacket Water Outlet Temperature	F2	Air Flow Rate
T3	Inlet Water Temperature at Calorimeter	F3	Jacket water flow rate
T4	Outlet Water Temperature at Calorimeter	F4	Calorimeter water flow rate
T5	Exhaust Gas Temperature before Calorimeter		
T6	Exhaust Gas Temperature after Calorimeter	LC	Load Cell
EGC	Exhaust Gas Calorimeter	CA	Crank Angle Encoder

Table I Engine specifications

Sl. No.	Engine parameters	Specifications
1	Engine type	TV1(Kirloskar, Four stroke)
2	Number of cylinders	Single cylinder
3	Speed	1,500 rpm
4	Bore	87.5 mm
5	Stroke	110 mm
6	Swept volume	661 cc
7	Compression ratio	20.1:1
8	Dynamometer	Eddy current dynamometer
9	Type of cooling	Water cooling
10	Fuel injection pressure	300 bar
11	Fuel	Diesel

normal piston, piston crown has a simple bowl-shaped structure, while in the modified piston, it is made with three blades at 120° to each other. The same aluminum alloy is used in fabrication of chamber and 2-mm thick small strips are used to make the chamber. The modified piston assembly with the engine is as shown in Figure 4.

2.2 INDUS model PEA-205 five-gas analyzer

Emission analysis is carried out by using INDUS model PEA-205 five-gas analyzer is as shown in Figure 5. It has a provision for monitoring five gases, namely, CO, CO_2, HC, O_2 and NOx from the engine exhaust. It is made such that it meets the OIML Class I specifications. CO, CO_2 and HC (Hydrocarbon residue) are measured by NDIR technology, and O_2 and NOx are measured by electrochemical sensors.

Figure 2 Normal piston

Figure 3 Swirl piston

Figure 4 Modified piston arrangement in-cylinder

Figure 5 INDUS model PEA205 five-gas analyzer

3. Results and discussions

The experiments are conducted on a diesel engine fueled with diesel by varying three injection timings and 200 bar injection pressure at 17.5 CR with and without design modification on piston crown. The influence of load on the brake specific fuel consumption (BSFC) by varying the injection timings with and without modified piston design is as shown in Figure 6. It can be observed that the BSFC of modified piston is reduced compared to normal piston at all injection timings. The results show that the BSFC is minimum at advanced injection timing for modified piston at 60 per cent load 0.231 kg/kW-h, and it is maximum for normal piston at retard injection timing with 20 per cent load 0.554 kg/kW-h. The BSFC of the swirl piston engine with 80 per cent is 5.07 per cent lesser than compared to normal piston at advanced injection timing may be because of the homogeneous combustion that occurred by increasing the turbulence of the air.

The variation of brake thermal efficiencies with respect to load for modified piston and normal piston is shown in Figure 7. It can be noticed that the brake thermal efficiency (BTE) of modified piston increases with increase in load at all injection timings compared to normal piston may be because of the increase in combustibility of the mixture which can be

Figure 6 Variation of BSFC with load

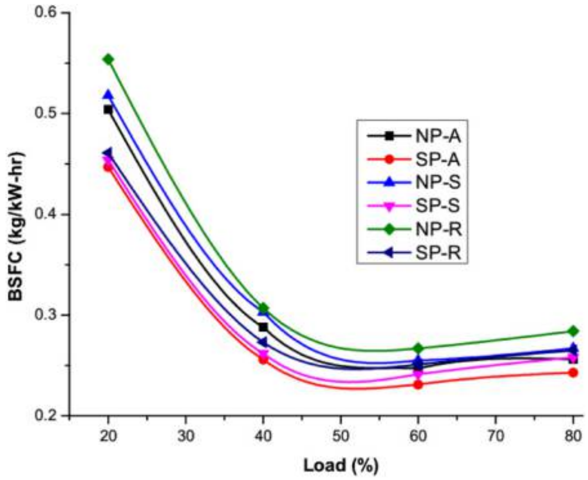
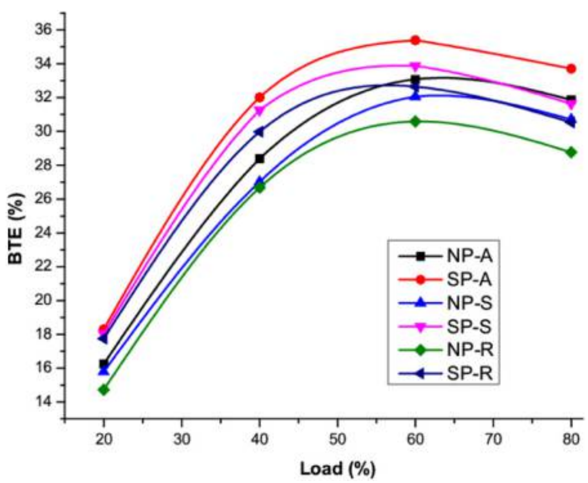


Figure 7 Variation of BTE with load



accomplished by turbulence in the engine. A similar trend in BTE can be noticed at all the loads. The results show that the BTE is minimum 16.25 per cent at advanced injection timing for the normal piston at 20 per cent load and maximum 35.39 per cent observed for the swirl piston with 80 per cent load at advanced injection timing.

Major constituents of engine emissions are CO, O_2, CO_2, unburned HC, NO_x and particulate matter. In Figure 8, it is observed that, as the emissions of carbon monoxide linearly decreased at all injection timings with respect to load, these emissions diminished with swirl piston compared to normal piston may be because of increasing turbulence because of which the more amount of oxygen will be available at the inlet of the engine. The results show that the CO emissions are minimum at standard injection timing for with and without modifying piston at 80 per cent of load, and it is maximum at retard injection timing for normal piston with 20 per cent of load. The effect of HC emissions using with and without modified piston is depicted in Figure 9. From the results, it can be observed that the unburnt hydrocarbons are diminished

Figure 8 variation of CO emissions with load

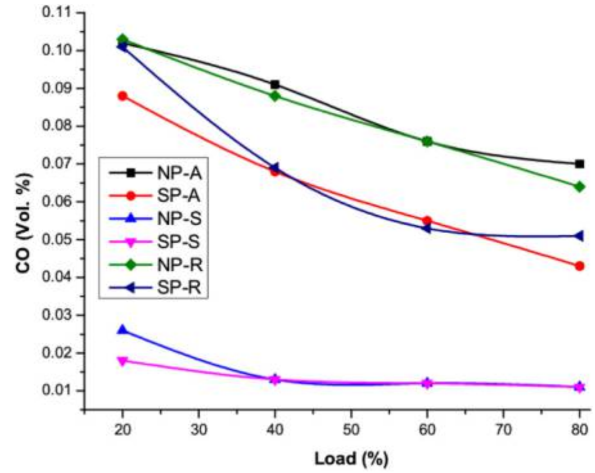
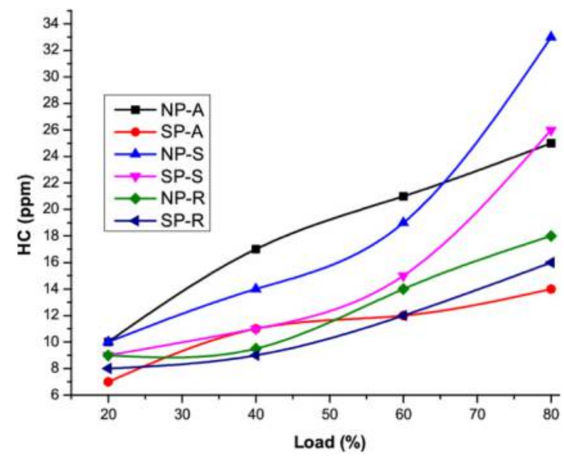


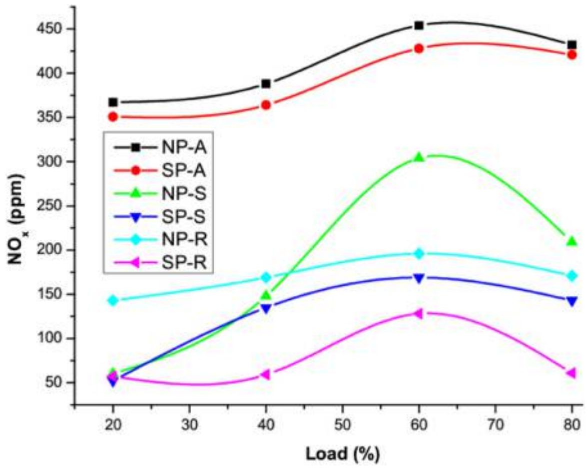
Figure 9 Variation of HC emissions with load



with swirls piston compared to normal piston at all loads because of uniform combustion of the charge by creating turbulence to the charge. From the results at full load, the HC emissions are decreased by 44 per cent with swirl piston compared to normal piston at advanced injection timing. This could be attributed to better air mixture formation, which resulted in ameliorated swirl motion within the combustion bowl.

The variation of oxides of nitrogen with respect to load can be observed for normal piston and modified piston is depicted in Figure 10. The NO_x emissions are increasing with uniform increase in the peak cylinder temperature by an increase in load for both swirl and normal pistons. It can be explained by higher mixing rate, which facilitates a better swirl motion and helps for better air-fuel mixture preparations, eventually leading to more complete combustion. It created higher engine cylinder temperatures which increases the NOx emissions with and without modified piston. From the results, it can be observed that at full load, the NO_x emissions are decreased with swirl piston compared to normal piston at all injection timings. The

Figure 10 Variation of NO_x emissions with load



minimum NO_x emissions is 52 ppm at standard injection timing for the swirl piston at 20 per cent load and maximum 454 ppm is observed for normal piston with 60 per cent load at advanced injection timing.

4. Conclusions

To improve the performance of the engine, several active and passive alternative techniques are available. Piston modification is a one of the active techniques to induce more turbulence and minimize the emissions. In this connection, the geometry of the piston is modified by accommodating rotating blades in the piston crown to induce turbulence by means of swirl motion of charge. The results are as follows:

- From the results, it can be observed that at full load, decrement of the BSFC is 3.37 per cent observed for swirl piston compared to normal piston at standard injection timing.
- The BTE observed with 80 per cent load is 3.02 per cent increased for swirl piston compared to normal piston at standard injection timing.
- The engine exhaust CO emissions by using swirl piston with standard injection timing 78 per cent decreased compared to retard injection timing and 74 per cent decreased compared to advanced injection timing at 80 per cent load.
- The engine HC emissions by using swirl piston at standard injection timing 21.2 per cent decrement was noticed compared to normal piston with 80 per cent load.
- The engine NO_x emissions by using swirl piston at standard injection timing 31.5 per cent decrement was observed compared to normal piston with 80 per cent load.

From the above, it can be concluded that with the use of swirl piston, there has been an improvement in BTE and decrease of BSFC and have a remarkable decrease in exhaust emissions. Also, the results obtained for the modified piston at standard injection timing performance and emissions are better compared to other timing operations.

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Corresponding author

Shailesh Palaparty can be contacted at: palapartyshailesh@gmail.com