Effect of Injection Timing of DI Diesel Engine on Engine Performance Parameters: A Review

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Abstract

Diesel motors have included an eminent spot in the field of traveler vehicles because of its consistent advancement close to designing clean air. This audit condenses the advancement on distributed writing with respect to the impact of different motor equipment and working requirements on residue creation and its result on motor execution. This work outlines the effect of injection timing of various hardware and operational parameters of DI diesel engine, like speed, load, combustion chamber design, intake temperature and pressure, injection pressure, injection timing, lubricating oil, and fuel on soot creation is broadly reviewed. We conclude by finding major parameters affecting the soot performance and engine performance on engine life.

Keywords: Injection Timing, Diesel Engine, Performance parameters.

Introduction

In the last few years, diesel engines have gained remarkable position in the field of passenger cars due to its continuous improvement towards engineering clean air. For virtual elimination of key pollutants from the diesel exhaust emissions, technologies have been developed which improves engine's thermal efficiency, volumetric efficiency, fuel economy, speed, power, and performance of after treatment devices. One of the prominent factors in controlling the efficiency of the engine is injection timing and engine load.

In this review, efforts have been made to review the effect of injection timing on engine performance and exhaust emission, opening ranges of waste-gate, with synthetic fuel blend, with methanol fumigated diesel engine at part load, particle size distribution from diesel engine, multiple injection etc is made**.** The effect of injection timing on various hardware and operational parameters are discussed as follows:

A). Effect of injection timing

i. On engine performance and exhaust emission

Experiments performed by Cenk Sayin et al [1] to investigate and evaluate the engine by using ethanol blended diesel fuel at two different loads (15 and 30 Nm) and five different injection timing (21°, 24°, 27°, 30° and 33° CA BTDC) on the basis of injection timing on single cylinder diesel engine and reported that when the injection timing was retarded 6° (from 27° to 21°) CA BTDC),at 15 Nm load and 1800 rpm, the unburned HC increased by 51.2% and when injection timing was increased 6° from main injection timing (from 27° to 33°) then at E15 at 30 Nm emission of unburned HC to decrease by 18.8%

ii. different opening ranges of waste-gate on the exhaust soot emission of a turbo-charged DI diesel engine

To investigate the effect of different opening ranges of waste-gate on the exhaust soot emission of turbo-charged DI engine M. Ghazikhani et al [2] performed experiments under the ECE-R49, 13 mode standard test at four different waste-gate (0.1 bar, 0.23 bar, 0.26 bar and 0.52 bar over atmosphere) and reported that when increasing manifold pressure increased from 0.1 bar to 0.23 bar, soot emission rate decreases due high intake air temperature but when manifold pressure reached maximum from 0.26 bar to 0.52 bar cylinder gas temperature reduced due to this late combustion take place and soot emission rate is high.

iii. synthetic fuel blend

To investigate the effect of injection timing **Arun et al [3]** performed experiments on a single cylinder four stroke direct injection diesel engine on fuel which contain 10% CB and 90% diesel at four different injection timing (20°,21.5°,23°,24.5° &26° CA BTDC) in which they considered 23° CA BTDC as a main injection and conclude that fuel consumption decreased by 11.9% whereas thermal efficiency increased by 6.4% at 26° CA BTDC. NOx emission increased by 23% while smoke emission reduced by 13.5% from the main injection timing.

iv. methanol fumigated diesel engine at part load.

To investigate the effect of intake preheating on combustion and emission of methanol fumigated diesel engine **Wang et al [4]** performed experiments on 4-cylinder methanol fumigated diesel engine which consist of direct injection system and whose compression ratio is 17:1 at intake temperature 35°-115° C and at 25% of full load and reported that BTE (brake thermal efficiency) increased when intake temperature increased above 75°C and with increasing the intake temperature combustion delay decreased and combustion rate of methanol by flame propagation increased.

V. effect of injection timing on particle size distribution from diesel engine

To investigate the effect of injection timing on size distribution of soot particle **Li et al [10]** performed experiments on four –Cylinder, four stroke diesel engine which have turbocharger and common rail injection system by varying injection timing 23CA before TDC-8CA after TDC at 0%EGR and 40% and concluded that at 0% EGR cylinder pressure decreases with increase the injection timing and low ignition create high soot and emission of NO decreases with decreases the injection timing, as shown in table 1.

Table 1: Effect of various hardware parameter on engine performance.

Engine specification	Injection pressure	Intake air, coolant, lubricant temperature	Injection timing	AT 0% EGR	AT 40% EGR
4-cylinder 4-stroke with turbocharger & common rail injection system	80mpa	40 80 87	23CA before TDC -8CA after TDC	Low emission of CO & HC, NOx emission decreases with decrease the injection timing	Dominated by NM. Mass concentration decreases with increases the injection

vi. Fuel Injection Rate Effects on Engine Performance and Emissions

It has been proved that direct -injection diesel engines are the helpful option where our major worry is fuel utilization at low speed and high load. **J.B. Heywood [11]** said that at initial injection event less amount of fuel reached in combustion chamber where they mixed with air and burnt .further **Beck et al[12]** performed experiments on commercial engine which consist of jerk type PLN .To analysis the effect of injection rate on combustion he subsequently replaced PLN with G-4 electronic unit injector and restricted the motion of needle in unit injector and produce boot injection pressure and reported that on the cost of 1% BSFC emission of NOx reduced equal to 50% with increase burning time from 26 to 42 crank angle degrees**. J.M. Desantes et al [13]** performed experiments to discover the effect of fuel injection system medication in direct diesel engine at four types of injection and three types of engine condition and reported that boot injection reduces the NOx but it also increases the fuel consumption and dry soot emission. The injection fuel system tested only useful for high load where reduction in NOx is acceptable at the cost of large dry soot emission. Further **H.**

Erlach et al [14] changed the injection system by introducing two solenoid valves and tested upon a single cylinder diesel engine at operation condition (1000 rpm and 75% of full load fuelling) and concluded that at constant value of soot and BSFC, emission of NOx reduced equal to 14%..After that with the intention of efficient diesel engine **T.kato et al [15]** performed experiments and concluded that nozzle diameter reducing is the effective way to reduce fuel consumption at initial condition without increasing the black smoke quantity d but black smoke emission increased due to the rate shaping .**M. Ghaffarpour [16]** suggests that the use of a boot injection is not very efficient at medium speed and low load. This investigation further investigated by **J.M. Desantes [17]** et al at three different load(50%,90% &100%) in single cylinder diesel engine, two nominal boot pressure (low & high) and three nominal boot length and concluded that NOx emission reduced by increasing boot length or reducing boot pressure but increase of dry soot with respect to reducing of NOx in case of medium load is worst effective.

vii. Effect of multiple injection on performance and emission of diesel engine

To compare between single, double and triple injection for reducing dry soot and nitrogen oxide emission in heavy-duty direct injection engine **Tow et al.[18]** performed experiments on caterpillar 3406 heavy duty DI engine with electronically controlled common rail fuel injection system at two different load (25% &75%) and at constant speed 1600 rpm and reported that in double injection system dry soot reduced by a factor of three but in case of triple injection system dry soot reduced by the factor of two without greater than before emission of **NOx** but BSFC increased 2.5% and 1.5 % respectively. Further **Han et al. [19**] studied numerically by using KIVA-II code for combustion simulation and RNG k-ε turbulence model for compound injection combustion calculation and reported that compound injection system breaks the dry soot production region at spray tip due to this at next injection combustion was leaner. To display the effect of injection rate on exhaust emission. **Ikegami et al [20]** performed experiments on HSDI single cylinder DI engine which consist **of high-swirl** deep bowl combustion chamber with displacement of 0.857 liters and a high pressure injection system with variable injection rate at two different speed(900 rpm &1800 rpm) with two equivalence ratio(0.64&0.84) and reported that at 900 rpm lowest injection take place which produce highest smoke concentration and lowest NOx concentration at smallest pilot quantity and at long interval of injection. Further to analysis the effect of increased rail pressure with different nozzle geometry on performance of DI engine **Schommers et al [21**] investigated on single cylinder DI engine which consist of EGR and multiple injection system used at two different load(high load & partial load) and at low speed and reported that at high rail pressure emission of soot is bargain by 40-60% and smoke intensity decreases with respect to high rail pressure and less hydraulic flow by nozzle without any disturbance with NOx .Next to characterize the effect of pilot injection timing, fuel consumption and quality of soot in DI engine **M.Badami et al [22**] had done experiments on four cylinder DI engine with EGR fitment and with common rail fuel injection system at three different speed(1500,2000& 2400 rpm) and at three different pressure (5 bar,2 bar and 8 bar) respectively and injection timing varied between **32°** and **1°** crank angle degrees and reported that pilot injection increased the combustion energy which results pressure and temperature in combustion chamber increased before main injection and due to this nitrogen oxide emission reduced. To identify the effect of pre and post injection on DI engine efficiency **J.M. Desantes et al [23]** performed experiments on 1.8-liter single cylinder with electronically operated common rail injection which is used for multiple injection under four engine operating condition and concluded that: by pre injection systems we can possibly reduce the fuel consumption at the coast of little dry soot emission but NOx level will be increased. on the other side post injection reduced the amount of soot emission without NOx emission and fuel consumption. To define the effect of multiple injection in HSDI engine **Hotta et al [24]** performed experiment on single cylinder which consist of supercharger and EGR system on three injection condition (early pilot injection, close pilot injection and after –injection) at three different load(low, medium &high) and concluded that under light load and low speed at early pilot injection decreases soot emission and early injection reduces the quantity of fuel adhering to the cylinder wall.

viii. Post Injections for Soot Reduction in Diesel Engines

After multiple fuel injection and injection pressure injection scheduling strategies plays an efficient role to reduce the emission of soot in diesel engine. In injection scheduling post-injection is one of the most typical strategies to reduce the soot emission. **Vanegas et al [25]** took a 4 cylinder DI engine which consist of second generation Bosch common rail injection system and with no external EGR and fuel injection rate was 15 mg/cycle at three different injection event (single injection, , pilot injection +main injection, and pilot injection + main injection + post injection) under partial load at 2000 rpm and used variable sampling smoke meter (AVL 145) to measure the quantity of smoke produced during combustion and reported that and pilot injection + main injection + post injection reduced the amount of emission of soot as well as nitrogen dioxide due to late combustion interval.

Engine specification:

Further this investigation has been carried out by **Bobba et al [26]**, to define the effect of post injection on soot reduction performed experiments on single cylinder,4 stroke engine at given operating situation:

Table 2: Operating parameters conducted for soot reduction

Engine type	Compression ratio	Intake pressure and temperature	Speed and load range
Cummins N-14 DI engine	16:1	276KPa, 389.5K	1200rpm, 9-10 bar gIMEP

and used 2-color soot thermometry and filter paper blackening, to measure the quantity of soot and reported that at low temperature combustion post injection play and key role to minimize the emission of dry soot. Further **DA Nehmer et al [27]** to investigate the effect of different scheme of Injection on dry soot emission performed experiments on a single cylinder which is proficient to produce 54Kw at 2100rpm and test at given condition

And reported that spilt injection is the better way to make the most of air charge and consent to further combustion without increasing the quantity of soot. To differentiate the effect of pre and post injection **Benajes et al[28]** performed experiment on heavy-duty 1.8-liter single-cylinder engine and the fuel quantity of the pre- and post-injection varied between 12 and 20 mg/cc, and the postponement of the pre- and post-injection respect to the main injection and concluded that pre injection reduced the fuel consumption at the cost of soot and nitrogen di-oxide emission but post injection method is the better to reduce dry soot emission.

ix. The effect of soot contaminated engine oil on wear and friction

To investigate the effect of soot particle on lubricating oil and friction green et al[1] performed experiments by using three types of lubricating oil (1) used engine oil (2)extracted engine soot mixed with fresh engine oil (3) carbon black mixed with fresh engine oil and reported that carbon black mixed oil is more inexpensive and quick and produced high soot at fuel rich and high load condition. Soot either exhausted by tailpipe or absorbed by lubricating oil and when it absorbed by lubricating oil it increased the viscosity and coefficient of friction. Soot contaminated lubricating oil increased the wear when oil film thickness diameter in greater than primary soot particle.

B). Effect of engine load on

i. Number distribution of particulate matter emitted from direct injection compression ignition engine

To investigate the effect of engine load and number distribution of particulate matter **Srivastava et al [5]** performed experiments on three different loads(0 KW,3 KW&5 KW) at constant speed(1500rpm) by using Engine Exhaust particle seizer (EEPS) whose working principle described by **Gupta et al [6**] and reported that size range decreases as load increases at highest load particle size observed 60-70nm and temperature of combustion chamber and fuel consumption also increases with increases the load. **Kittelson, 1988 [7]** reported that surface area is a function of individual nuclei in the agglometers rather than agglomerates size. Smaller particle mass compared to larger particle mass have higher surface area per unit mass and more hazardous for human health because it provides large surface area for absorption of toxin.

ii. Effect of engine load on diesel soot particle

To identify the effect of load on diesel soot particle **Virtanel et al [8].** performed experiments on a passenger car vehicle consuming both EGR and oxidation catalyst and on a city bus vehicle consuming only oxidation catalyst (1). As a general discussion load increases the amount of fuel injected increases resulting in increase in temperature providing sufficient environment for initial soot formation. Fractal dimension was used to define the agglomerate structure as well as particle mass, as a function of mobility size [1,2]. It was concluded that for both passenger and city bus vehicles the fractal dimension of particle decreases and width of soot distribution increases with increase in load. The particle size value lies between2.6 to2.8 depending on engine load.

iii. Impact of nitrogen oxide (NO, NO_2, N_20) on formation of soot

Nitrogen oxide can affect the soot emission when it presents in recalculating mixture. To investigate this phenomena **Maria et al[9]** performed pyrolysis experiments of C2H4(ethylene) which present at 30000 ppm and concentration of different nitrogen oxide are 0, 500, 1000, 5000 & 12000 ppm and reported that at concentration 12000 ppm of NO_2 soot emission is lower than the soot emission at without nitrogen oxide and when concentration of N_2O is less than 5000 ppm than it provided favorable condition for more soot emission but at 12000 ppm it decreased the emission of soot. They also concluded that at low concentration of NO oxidation and reburn reaction took place, due to this reaction amount of CO and HCN increased.

Conclusion

Following establishments are made after this exhaustive study:

i. Injection timing was retarded 6° (from 27° to 21°) CA BTDC), at 15 Nm load and 1800 rpm, the unburned HC increased by 51.2%

ii. Increasing manifold pressure increased from 0.1 bar to 0.23 bar, soot emission rate decreases due high intake air temperature.

iii. With introduction of synthetic fuel consumption decreased by 11.9% whereas thermal efficiency increased by 6.4%.

iv. At 0% EGR cylinder pressure decreases with increase the injection timing and low ignition create high soot and emission of NO decreases with decreases the injection timing.

v. Both passenger and city bus vehicles the fractal dimension of particle decreases and width of soot distribution increases with increase in load

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