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RESEARCH INFLUENCE OF MULTI-PULSE PILOT INJECTION ON COMBUSTION HEAT RELEASE AND COMBUSTION PROCES IN MODERN DIESEL ENGINES

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Abstract:
The publication shows an approach of optimization in case of dual pilot injection strategy in modern DI diesel engines controlled by “Common rail” fuel system. The advantages of pilot injection as a more efficient method of controlling the speed of heat release at the beginning of combustion are shown. Research in two different engine map points has been done at the same engine speed. Calculations have been made using Ricardo Wave software.

Keywords: *diesel engines, direct injection, diesel engine modeling, rate of heat release, multi-pulse pilot injection*

1. Introduction

One of the most significant disadvantages of DI diesel engines is the high level of noise as a result of fast combustion heat release immediately after the start of combustion. That high combustion speed is determined by injected fuel quantity during the longer ignition delay period in DI diesel engines [3]. The more fuel injected during the ignition delay, the stronger the initial temperature rise in the combustion chamber, and the better the boundary conditions for NOx formation. For those reasons it is important to shorten the ignition delay period [1, 6]. There are a few methods of shortening the ignition delay but the injection of small quantity of fuel shortly before the main injection is most effective. This small quantity of fuel is called pilot injection. It is easy to realize it using the modern common rail fuel systems fig.1. The pre-injected fuel mass evaporates quickly and ignition reactions start. It increases the temperature in local volume into combustion chamber therefore the ignition delay period is reduced significantly. It means that the fuel injected at begin of main injection is involved immediately in combustion process after very short ignition delay period.

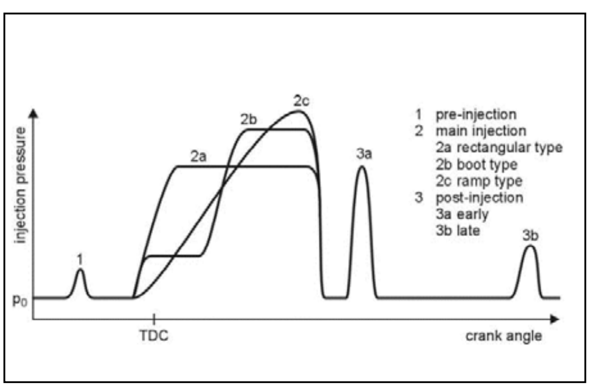

Fig. 1. Schematic diagram on multipilot injection in modern Common rail DI Diesel engines

2.Basic research.

The single pilot injection is most commonly used because it is easiest to realize. Both common rail injectors (electromagnetic and piezo controlled) can inject a small quantity of fuel before main injector [5]. The effects of this single pre-injection can be seen on fig.2 and 3 [7].

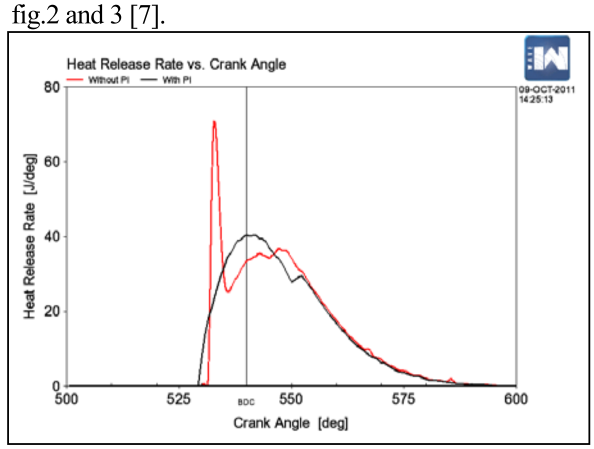

Fig.2. Difference in combustion heat release with and without pilot injection.

The results show that heat release increased much slower at the beginning of combustion and the maximum value is reduced almost twice. As a result the maximum pressure speed in the combustion cham-

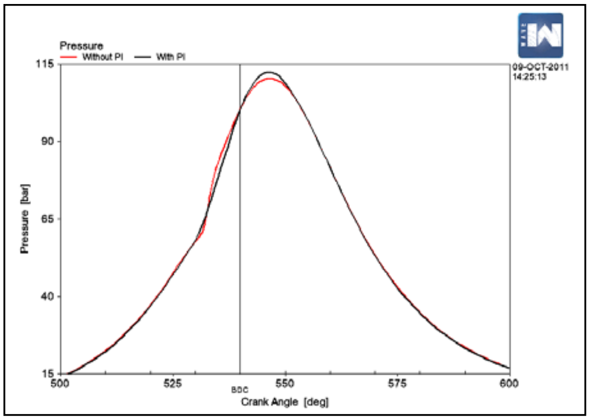

Fig.3. Difference in pressures curves during combustion with and without pre-injection.

ber decreases from 0,85MPa/deg to 0,46MPa/deg. To provide the same level of maximum pressure and BMEP it is necessary to reduce the injection advance (the moment of the start of the main injection) in case when the pre-injection is realized. It is a result of the shortest ignition delay period. The change in the injection advance is from 15deg before TDC to 10deg before TDC.

Several parameters are important for management: the mass of pre-injected fuel, the moment of pre-injection and the period between pilot and main injection. The various researches have been done in [2, 4, 7]. Based on previous results it is important to note that the quantity of pre-injected fuel should be chosen between 2% and 4% from all injected fuel. The start of pilot and main injection should be chosen in way that start of main injection coincides with the start of combustion.

The basic research shows that a single pilot injection is an efficient method of reducing the maximum speed of combustion respectively the noise produced by diesel engines. For that reason the main aim of the paper is to research the influence of multi-pulse (dual-pulse) pilot injection by combustion heat release.

3.Model of "Common Rail" DI diesel engine.

Theoretical model of modern diesel engine has been made by means of Ricardo Wave software (Fig.4). Ricardo Wave is based on 1D model of unsteady flow in intake and exhaust system and 0D model in cylinder. The software provides opportunities of modeling the injection process such as impute the geometric parameters of nozzle, spray angle, injection pressure, injection rate, shape of combustion chamber and etc. It is also possible to model the EGR system and supercharged with intercooler.

"Diesel Wiebe" [3, 8] with sub-model "Diesel jet" was chosen of combustion modeling. The diesel jet combustion sub-model is more advanced than the standard diesel combustion sub-models. It has the ability to predict the combustion heat release

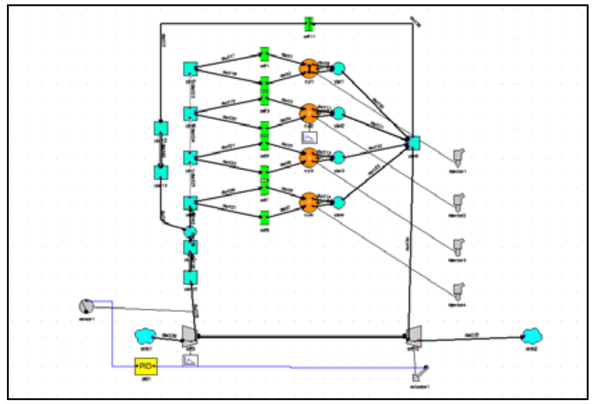

Fig.4. Ricardo Wave model of 2.0 liter "Common rail" diesel engine

heat release rate from the user-specified fuel injection rate and injector geometry. Many of the parameters available for adjustment of the jet combustion sub-model are related to the velocities, turbulence levels, and gas mixing effects in the combustion chamber. It can be assumed that, heat transfer, air entrainment, and exhaust gas re-entrainment into the combustion zone can all be expected to increase as in-cylinder velocities and turbulence levels increase. Similarly, they can be expected to decrease as the cylinder conditions approach a more quiescent state. The Diesel Jet combustion model relies on the user-defined fuel mass flow profile and nozzle diameter/number of holes, to obtain jet characteristics such as nozzle pressure drop, jet velocity, and fuel spray droplet size. It does not use the user-input injection pressure profile. The spray is divided along its length into a number of packages, each of which contains the fuel injected during one time interval [8].

Combustion in the Diesel jet model is controlled by the following factors, in order:

- ✓ Evaporation of droplets;
- ✓ Air/Fuel mixing;
- ✓ Ignition;
- ✓ Air supply;
- ✓ Quenching.

The main parameters of engine and model are given in following table:

Number of cylinders [i]	4
Bore [D]	86,5mm
Stroke [H]	85mm
Compression ratio [ε]	17
Engine speed [n]	2000 rpm
Equivalence ratio [q]	0,5and 0,28
Injection pressure [p_{rail}]	90 and 70 MPa
Number of nozzle holes	7
Diameter of nozzle holes	0,1mm
Spray angle	40 deg
Intake pressure [p]	0,15 and 0,12 MPa

The software provides different manner to impute the injector's parameters. "Multi-pulse Mg per injection" has been chosen for the model. This type of injector provides an opportunity to separate the injected fuel up to 8 injections and it is possible to control the shape of each injected rate. For the current research the injection was separated in three – the pilot injection 1, pilot injection 2 and main injection. Fig.5 shows the shape of injection rate in one point of research.

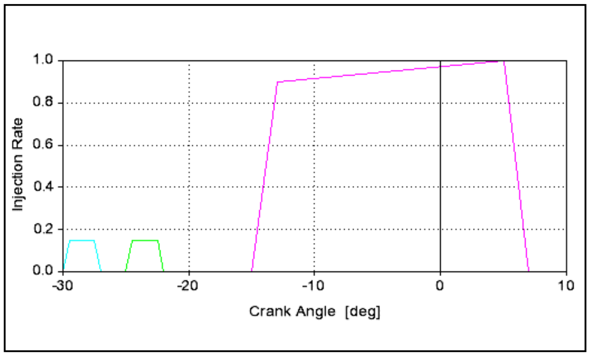

Fig.5. Typical shape of fuel injection rate in case of two separates pilot injections.

It is possible to control the beginning of each injection, rising period, plateau interval, fall period and quantity of injected fuel. Common rail injectors provide very high speed of opening and closing of nozzle needle together with almost constant injected pressure it means that the shape of each injection rate is very close to rectangular.

4.The results of research.

The research has been made in two different point of engine map. The first one is 2000rpm and equivalence ratio 0,5 the second one is 2000rpm and equivalence ratio 0,28. Research has been made in each point by changing the start of primary and secondary pilot injection.

4.1. *Research influence of the start of the pilot injections on the combustion heat release in the first map point (n=2000min^{-1}, q=0,5).*

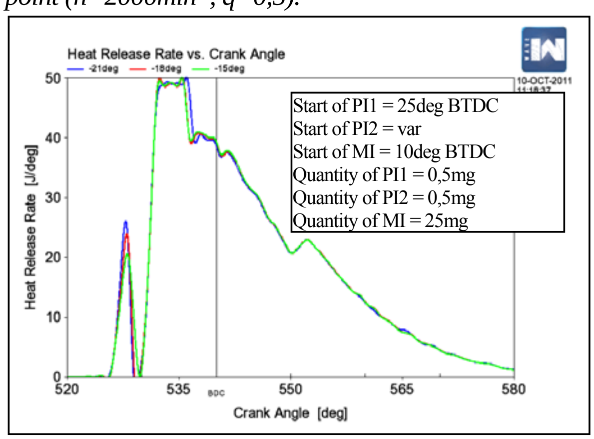

Fig. 6. Combustion heat release in different start of secondary pilot injection and fixed start of primary pilot injection on 25deg BTDC

The results are shown on fig. 6, 7 and 8. Combustion heat release can be seen on each graph in constant start of primary pilot injection and three different values on start of secondary injection. During all the calculations the start of main injection and quantity of injected fuel are constant.

The results show if the primary pilot injection is so closed and so far from the start of main injection the influence of start of secondary pilot injection is insignificant. When the start of primary pilot injection is in the middle according fig.7 it is better to start the

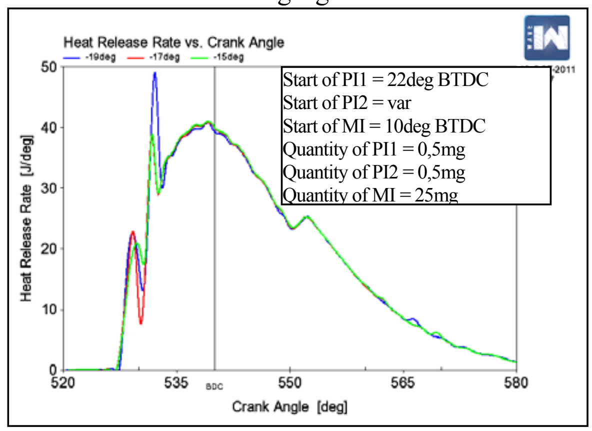

Fig. 7. Combustion heat release in different start of secondary pilot injection and fixed start of primary pilot injection on 22deg BTDC

secondary pilot injection as closer as possible to main injection. The maximum speed of combustion it can be reducing in this case. In general it is better to realize

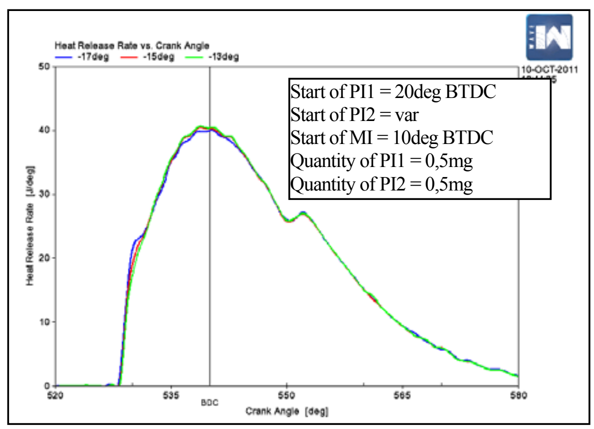

Fig. 8. Combustion heat release in different start of secondary pilot injection and fixed start of primary pilot injection on 20deg BTDC

both pilot injections as close to the main injection as possible fig.8. We could reduce the maximum speed in pressure change from 0,6MPa/deg to 0,48MPa/deg. Although the influence of secondary pilot injection is insignificant if it is possible to start it immediately after finish of primary injected fuel it can improve the shape of heat release. The limiters are fast response and accuracy on injectors. To realize the multi-pulse pilot injection it is better to use the piezo controlled injectors because it is necessary to inject a small quantity of fuel in a very short period of time.

4.2. *Research influence of the start of the pilot injections on the combustion heat release in the second map point ($n=2000min^{-1}$, $q=0,28$).*

The calculations are made in the same sequence. Graphically they are shown on fig. 9, 10 and 11.

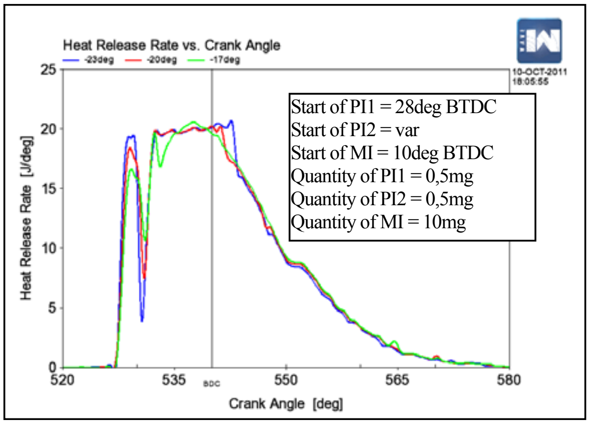

Fig. 9. Combustion heat release in different start of secondary pilot injection and fixed start of primary pilot injection on 28deg BTDC

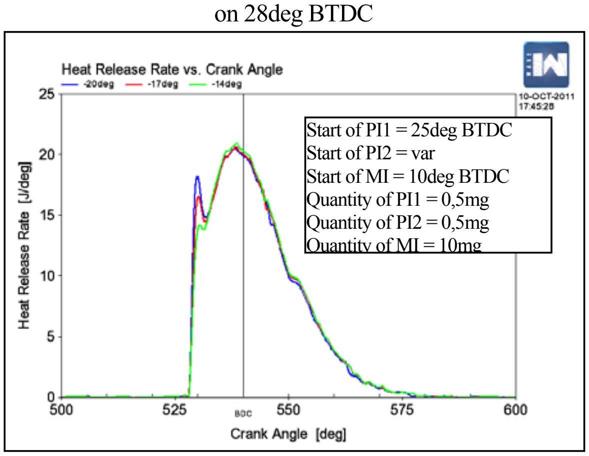

Fig. 10. Combustion heat release in different start of secondary pilot injection and fixed start of primary pilot injection on 25deg BTDC

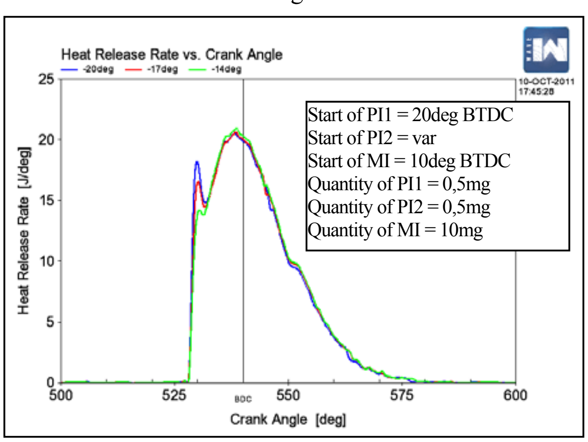

Fig. 11. Combustion heat release in different start of secondary pilot injection and fixed start of primary pilot injection on 20deg BTDC

At lower BMEP the influence of start of primary pilot injection is less. The worse condition in combustion chamber required earlier primary pilot injection to compensate a longer ignition delay period. The results show of necessary to increase pilot injection advance with minimum 8 deg then higher engine load to be able reduce slightly the maximum value on heat release fig.9. In all case the secondary injection should be as closer as possible to main injection. It is important to mention that there is no difference in engine heat release in range of 5 deg difference of primary pilot injection fig. 10 and 11. It is a positive effect because less accuracy in injector control strategy is required.

5.Conclusion

The dual step pilot injection could improve the combustion heat release by reducing the maximum combustion speed at the beginning of combustion. Based on the results in two engine map point here are some important conclusions;

✓ In case of realizing on dual pilot injection it is necessary to make optimization of moment of each injection very precisely for each engine map point;

✓ The moment of primary pilot injection is more important as it gives the main shape of combustion heat release. The secondary pilot injection can change it a little;

✓ It is better to realize the dual step pilot injection in lower BMEP when there is a long crank angle respectively time period interval to produce more separate injections.

6.References.

[1] **Baumgarten C.**, Mixture Formation in Internal Combustion Engines, Springer-Verlag Berlin Heidelberg 2006.

[2] **Chmela F.G. and Orthaber G.C.**, Rate of heat release prediction for a direct injection diesel engine based on purely mixing controlled combustion. SAE 99010186, 1999.

[3] **Heywood J.B.**, A text book on Internal Combustion engine fundamentals. McGraw-Hill International edition, 1988.

[4] **Lakshminarayanan P.A and Aghav Y.V.**, Modelling diesel combustion, Springer, 2010.

[5] **Merker, G., Schwarz, C., Stiesch, G., Otto, F.**, Simulating Combustion, Springer-Verlag Berlin Heidelberg 2006.

[6] **Mollenhauer, K., Tschöke, H.**, Handbook of Diesel Engines, Springer-Verlag Berlin Heidelberg 2010;

[7] **Punov, P.**, Research influence of injection rate on the combustion heat release in “common rail” internal combustion engine, 19th international scientific and technical conference on transport, road-building, agricultural, hoisting & hauling and military techniques and technologies, Varna, Bulgaria, 2011.

[8] **Ricardo**, Wave 8.0 help system.