Research on method to promote performance of multiple injections diesel engine

Xiaorong Wang[1]*, Chenpeng Liu, Bo Liu[2], Wenxian Tang[1], Jian Zhang[1]

[1]*Institute of mechanical engineering, JiangSu University of Science and Technology, Zhenjiang 212003, China*

[2]*Hudong Heavy Machinery Co., Ltd, Shanghai 200129, China*

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Abstract

Based on certain type of two-stroke, low-speed diesel engine for marine propulsion, we, in our research project, developed a 3-D model of in-cylinder combustion processes in a diesel engine. Thus, we were able to compare simulated in-cylinder pressure against the experimental pressure under single injection with a maximum error tolerance of 0.36%, the results of which imply that the two are basically consistent. Subsequently, based on the same injection timing, a comparison was made between the performance of a diesel engine using single injection and one using dual injection. The results indicate that the additional injection can lower NOx by58.9% and soot by 30.1%. Moreover, the piston's workload is reduced by 10.1%. Through calibrating injection quality centre, adjusting injection timing of secondary injection reasonably, we gained the method improving performance of combustion and secondary injection diesel engine. By verifying, the method can promote working ability of secondary injection diesel engine effectively. After adjusting injection timing, working ability of secondary injection is as well as it of single injection, but emissions reduce sharply, thereinto, NOx reduced 12.7%, soot reduced 41.1%.

Keywords: Marine low-speed two-stroke diesel engine; injection timing; double injection; diesel performance

1 Introduction

In recent years, the government formulated the worldwide emissions regulations, Tier II regulations had been put into force in 2011, the regulations limits the NOx emission of Marine diesel engine under 14.36 g/kw*h, it fell about 20% than Tier I, and Tier III regulations will be carried out in 2016, when the NOx emissions will be reduced to less than 3.4 g/kw*h, and it drop nearly 80% than Tier I. Diesel engine manufacturers need to look for balance from the engine performance and emissions. Fuel injection technology development makes the stringent requirements possible [1]. Mixing process of gas and air, combined effect of combustion and emission, both impact the performance of diesel engine directly [2-6].

On the basis of the high pressure common rail fuel injection system of diesel engine, AnShijie [7] and others build a common rail diesel multiple injection performance test platform, and carried out the engine test and research about influence of multiple injection on diesel engine performance, the results show that using common rail technology and multiple jet drops off diesel engine exhaust temperature 50 ℃, and noise down 15 db, carbon smoke emissions improves significantly. Zhou Lei [8] and others researched the applicability of the fuel and air mixing process on large eddy simulation model in the prediction of engine early injection. The results show that the injection time moved up is advantageous to the fuel and air homogeneous mixing, mixture distribution is more uniform. WangHu [9] and others carried out the research about repeated injection and EGR coupling control experiment on the influence of the combustion and emission characteristics of diesel engine, compared with single injection, multiple injections coupling EGR control can significantly reduce carbon emissions, and fuel consumption rate debasing. Wang Benliang [10] put forward a proposal for multiple injection coordinated control strategy, aimed at pilot injecttion, main injection and post injection, and designed the control algorithm of multiple injection coordination controller, and has carried on the experimental study, the results show that the design of multiple injection coordinated control strategy can effectively realize the coordinated control on pre-injection, main injection and post injection under different conditions. Muammer Ozkan [11] and others researched the effects of heating and power efficiency in cylinder under different injection strategies, the experimental results show that the reasonable injection timing in advance can ensure the thermal efficiency and power capability and reduce NOx emissions. Mohan, B, et al. [12] discussed all kinds of injection strategy: including different curves of injection pressure, injection curve, injection timing and injection interval Angle, the influence on engine performance and emissions, the results show that pilot injection can reduce combustion noise and NOx emission, the injection interval smaller Angle can promote the soot oxidation, the appropriate injection timing can improve engine performance. So select the reasonable injection timing, and multiple injections can improve the diesel engine performance and reduce emissions.

*** Corresponding author** e-mail:wrr31@qq.com

In this paper, we take a Marine low speed two stroke diesel engine as the research object, establish the combustion model in cylinder of diesel engine, do the combustion simulation research under the condition of single jet to the diesel engine, and compared the results with experimental data. Contrast research the diesel engine performance under the condition of single injection and secondary injection, put forward the reasonable selection method of injection timing in reducing emissions under the premise of guaranteeing the power capability, it provides references for balancing diesel engine performance and emissions.

2 Establishment of the model and meshes generation

Taking a 350 mm two-stroke low-speed Marine diesel engine as the research object, for the four whole nozzle injector, spray holes are uniformly distributed. The operational parameters of the model engine are presented in Table 1. Combustion chamber space is composed by the cylinder liner, cylinder head, valve base and piston of diesel engine, cylinder grid as shown in Figure 1. Meshing is completed by special module ES- ICE of STAR - CD, the grid diagram as shown in Figure 1, geometry model and grid of top dead centre as shown in Figure 2, the top dead centre grid number is 32415.

TABLE 1 Basic parameter of a marine diesel engine

Parameter name/unit	parameter value
Cylinder power /kw	653
Diesel engine cylinder diameter /mm	350
Stroke number	2
Compression ratio	17:1
Swirl rate	1.2
Combustion chamber	Exposure to ωtype (with BUMP ring)
Intake type	pressure intercool

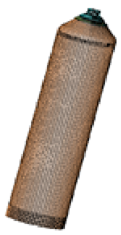


FIGURE 1 Diesel engine cylinder grid

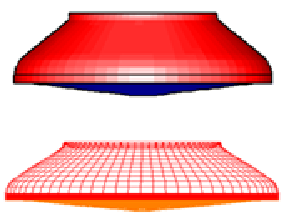


FIGURE 2 Grid of piston at top dead centre

Diesel engine cylinder gas phase flow model is based on classical hydrodynamics compressible navier-stokes equation of viscous fluid, namely according to the quality, composition, momentum and energy conservation law and the ideal gas state equation, a set of partial differential equations to describe the flow process in cylinder. The turbulence model used high Reynolds number k - Epsilon model; spray simulation adopted Huh atomized model, the Reitz - Diwakar droplets broken model and Bai bump wall model; The ignition model is compression ignition Shell model; Combustion model is laminar flow turbulence characteristic time combustion model and the EBU - LATCT model, and Zeldovich NOx generation model.

3 Initial boundary conditions

Initial conditions were given out by one dimensional simulation calculations of the machine; the initial moment pressure in cylinder is 0.485 MPa, the temperature is 363K. Boundary conditions are set according to the experience: cylinder head temperature 823K, the piston temperature 773K, and valve bottom temperature 823K. The boundary of the cylinder wall temperature is divided into three parts, the cylinder expansion direction, before one sixth is 623K, after a third of 548K, the remainder is 498K; the initial vortex ratio in cylinder is 5.5.

4 Model validations

To verify the model and algorithm, the combustion chamber combustion process was simulated under the condition of single jet; the fuel injection time is from the beginning of the 353 oCA, calculated pressure curve in cylinder is shown in Figure 3.

The Figure 3 shows that the compression pressure calculated is 13.04 MPa, explosion pressure is 16.59 MPa. And the original machine test compression pressure is 13.0 MPa; explosion pressure is 16.53 MPa, the compression stress error and the explosion pressure error were 0.31% and 0.36% respectively. The simulation result is in accordance with the test result, and it verifies the effectiveness of the algorithm.

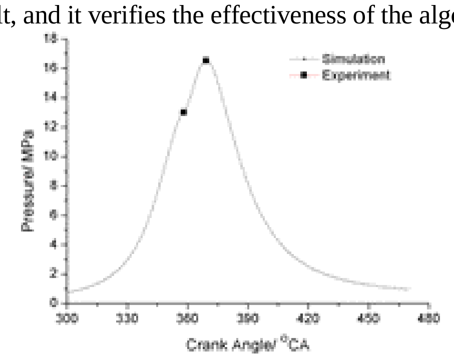


FIGURE 3 Cylinder pressure curve

5 Diesel engine performance contrastive analysis

In order to analyse the influence to diesel engine performance of different fuel injection law at the same injection current, combustion chamber combustion process was simulated under the condition of single injection and secondary injection respectively, simulation process is from exhaust valve closing time to exhaust valve open time. Injection timing of single injection and secondary injection are both 353oCA, fuel injection law is shown in Figure 4.

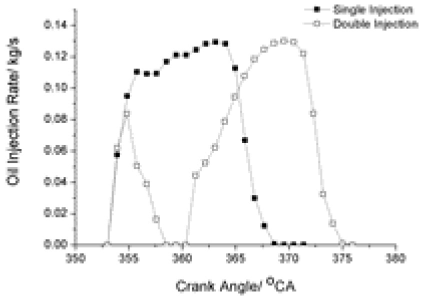


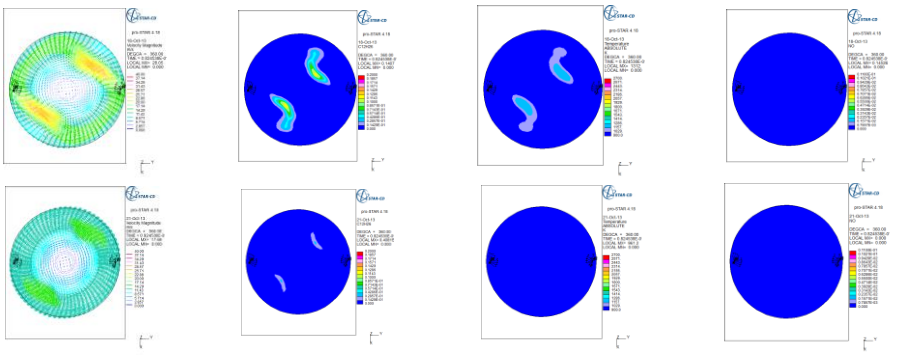
FIGURE 4 Fuel injection law

5.1 COMBUSTION SIMULATION RESULTS IN CYLINDER

Figure 5 is the distribution of oil hole in the plane (z = 27 mm) of the velocity vector diagram and fuel concentration field, temperature field and the NOx concentration field, under different fuel injection law, the piston runs to the top dead centre namely 360 oCA.

Single injection

secondary injection



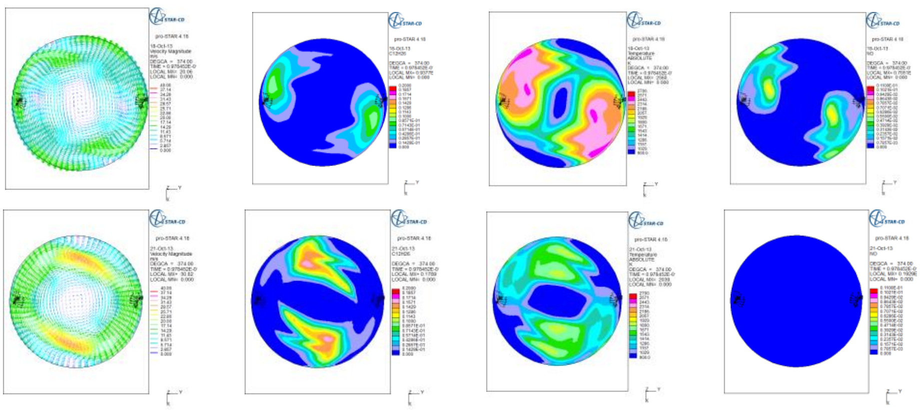
(a)Velocity field **(b) fuel concentration field** **(c) temperature field** **(c) NO_x concentration field**

FIGURE 5 Each variable field distribution in cylinder at 360ºCA

Figure 6 shows that under the condition of single jet, affectted by the eddy current in cylinder, the velocity field gradually become circular distribution, while the fuel inject-tion ended in the 368oCA, but gas has not yet been fully burning, so local high, the centre temperature of 2571K, lead to distortion near the high velocity vector field. Under the condition of secondary injection, fuel injection has just con-cluded at the moment, high-speed injection fuel in cylinder, droplet spray evaporation form two strands of strong turbu-lence, the fuel injection rate ear along the axis is as high as 40 m/s, the gas concentration is about 15.7%, because gas is not yet fully mixed with air, combustion is not sufficient, so the centre of local high temperature is 1972K only. Due to under the condition of single jet local temperature is too high, creating a large number of NOx, the centre concentration is as high as 0.63%; With less NOx formation under the con-dition of secondary injection.

Single injection

secondary injection

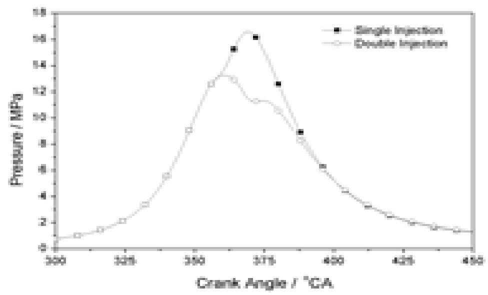


(a)Velocity field (b) fuel concentration field (c) temperature field (c) NO_x concentration field

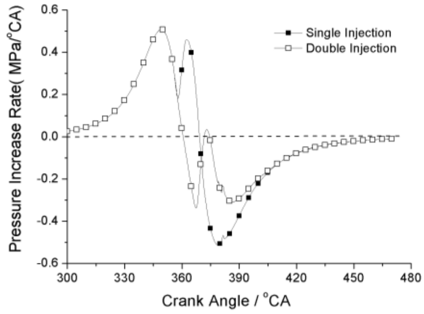
FIGURE 6 Each variable field distribution in cylinder at 374ºCA

5.2 DIESEL ENGINE PERFORMANCE ANALYSIS

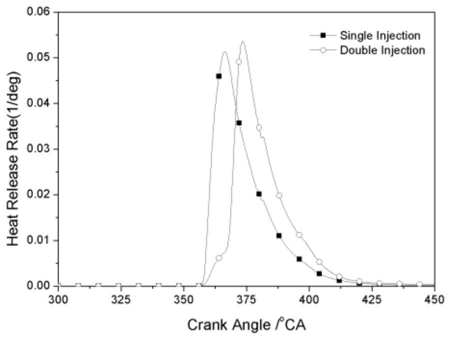
Figure 7 compares the same injection timing and different fuel injection law, combustion and emission performance curve, from top to bottom in turn is average pressure curve in cylinder, the pressure rise rate curve and heat release rate curve, the curve of average temperature in cylinder, total quality curve NOx and soot total quality and contrast figure to do work.



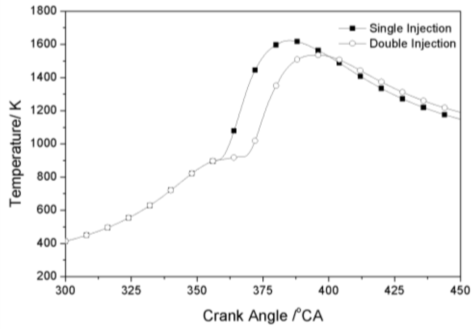
a) Average pressure curve in cylinder



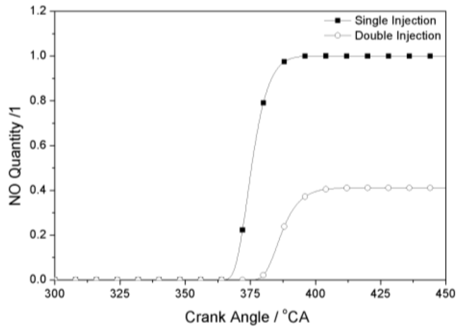
b) Pressure rise rate curve in cylinder



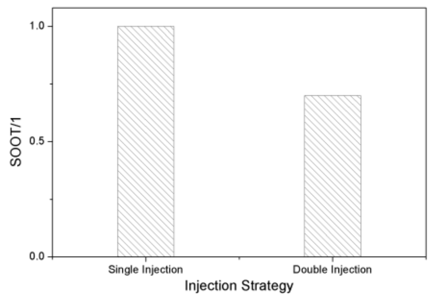
c) Heat release rate curve



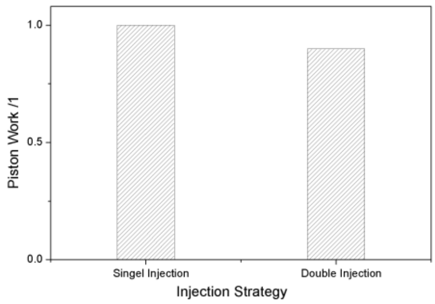
d) Average temperature curve in cylinder



e) NO_x total mass curve



f) Total quality comparison diagram of soot



g) Work contrast figure

FIGURE 7 Diesel engine performance contrast figure

The Figure 7 a) and b) shows that under the condition of single injection and secondary injection ignition delay period is short, about 1oCA, fuel injection quantity is moderate, and it has a good gas mixture; Under the condition of single jet urgent combustion period for 354 oCA - 362 oCA, most high pressure rise rate is 0.45 MPa/oCA, and under the condition of secondary jet urgent combustion period is 354 oCA -358.5 oCA (pre-injection end), due to pre-injection fuel quantity is less, pressure rise rate slowly reducing, maximum pressure is 13.2 MPa only at the moment of 360oCA. Under the condition of single jet, slow burning period is 360 oCA - 369 oCA, maximum pressure is 16.5 MPa, when the secondary injection conditions, it enters the combustion period after the top dead centre, main injection stage appeared the second peak pressure, only 11.3 MPa (374oCA), lower than the first peak pressure. In a word, main injection period of the secondary injection is in the after burning period, the fuel heats in the lower expansion ratio, and the diesel engine efficiency greatly lowered.

From figure 7 c) we know, under the condition of single injection and secondary injection, heat release starting point and end point is basic same, but the secondary injection has high peak heat release rate than single injection, the secondary injection has the superior combustion performance. From figure 7 d) average temperature curve in cylinder, the secondary injection cylinder temperature curve is always lower than that of single injection, and the temperature peak appeared late, it shows that the secondary injection power capability is less than single injection.

Figure 7 e) is NOx formation history curve, we know from the figure, compared with the single injection, under the secondary injection, the formation of NOx starting moment is later, and the total generate amount is only 41.1% of the single jet, is reduced by 58.9%, this is due to under the condition of the secondary injection the average temperature in cylinder is lower, and the peak temperature appear later.

Figure 7 f) is the soot emissions contrast figure, soot under the condition of the secondary injection is only 69.9% of the single injection, reduced by 30.1%, that under the condition of secondary injection gas and oxygen mixed fully, generated less soot. Figure 7 g) shows that the secondary injection ability of doing work is 89.9% of the single injection.

To sum up, due to injection timing of the secondary injection later, main injection in the later period, led to the decrease of the diesel engine power capability, but the secondary injection has the superior combustion performance, and the NOx and soot emissions are lower than that of single injection. If you want to improve the diesel engine work ability under the condition of secondary injection, it needs reasonable adjustment of injection timing.

6 The secondary injection results after adjustment of injection timing analysis

6.1 REASONABLE SELECTION OF INJECTION TIMING

The nature of diesel engine is to change the chemical energy of fuel into the kinetic energy of the crankshaft, the Figure 7 c) heat release rate curve shows that the secondary injecttion has the superior performance of combustion heat release than single injection, after adjusting the injection timing, the ability of doing work of the secondary injection could reach or exceed the single injection. Due to secondary injection main combustion process is located in the after combustion period, expansion ratio is larger, work performance is poor, so it should be based on the heat release rate curve, adjusting injection timing of the secondary injection reasonably, make the heating centre of gravity (that is, the heat release rate curve integral centroid)coinciding. Because the heat release rate is a process quantity, it is difficult to control, in this paper, by adjusting the cumulative injection quality centre under the condition of secondary injection (i.e., 50% of cumulative injection quantity), with a single jet overlap, such basically guarantee the both exothermic centre of gravity coincided.

Figure 8 is cumulative injection quantity curve, cumulative injection quality centre is the dotted line in the fig-ure, the accumulative fuel injection quality centre of single jet and secondary injection is 6.9oCA and 13.6oCA respectively, to make the cumulative injection quality centre coincided, it needs the injection timing of secondary injection 6.7oCA in advance

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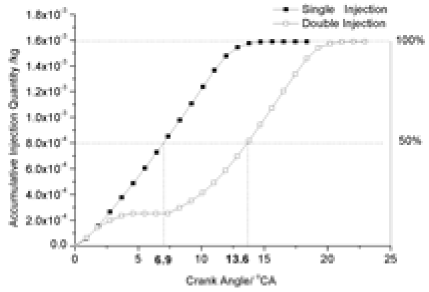


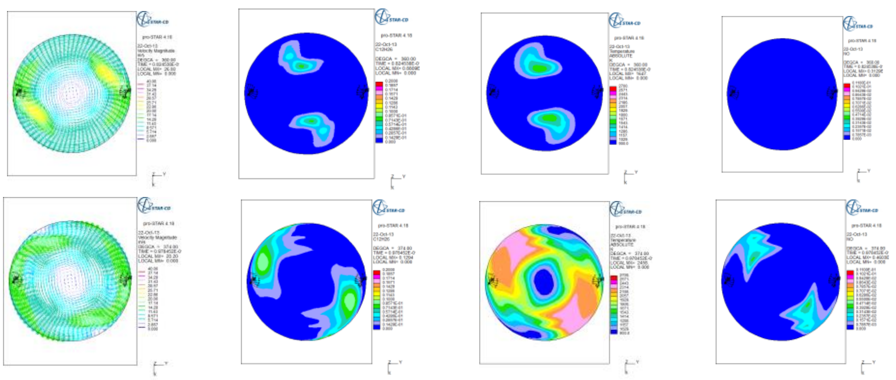
FIGURE 8 Cumulative fuel injection quantity curve

6.2 FLOW FIELD ANALYSES AFTER THE ADJUSTMENT OF INJECTION TIMING IN CYLINDER

Figure 9 for the adjustment of injection timing, under the condition of the secondary injection, 360oCA and 374oCA variables of the field.

360ºCA

374ºCA



(a) Velocity field (b) Fuel concentration field (c) Temperature field (c) NO_x concentration field

FIGURE 9 Distribution of variables in each field after injection timing adjusted

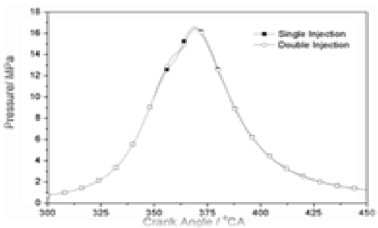
Figure 9, in the 360oCA moment, compared with the single injection, after adjusting the injection timing of secondary injection, centre speed of gas jet is 22.8 m/s, lower than that of single injection; Fuel concentration field distribution is slightly larger than single injection, the concentration of gas jet centre is about 7.9%, it shows that gas and air mixed uniformly under the condition of secondary injection. By the temperature field, the high temperature range is larger than single injection, and centre temperature is 1543K, higher than that of single injection, obviously that the secondary injection combustion performance is good, at this time there is no NOx formation.

At 374oCA, compared with single injection, the difference of velocity field between the secondary injection after adjusting and single jet is small; Range of fuel concentration field distribution is quite, and there is less difference of concentration; the distribution of temperature field is pretty, but the highest temperature is 2314K, only less than single injection, it shows that the secondary injection effectively reduces the local high temperature, temperature tends to be uniform; The NOx distribution range is small, centre concentration is only 4%, and the range is very small, that the secondary injection effectively reduced NOx formation.

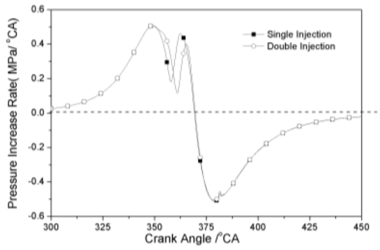
In short, after the adjustment of injection timing, oil and gas mixed more evenly, local temperature rise reduced, and it inhibits the formation of NOx.

6.3 PERFORMANCE ANALYSIS AFTER ADJUSTMENT OF INJECTION TIMING

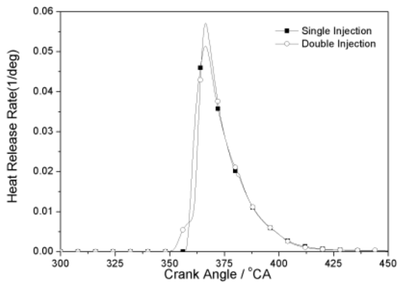
Figure 10 is after the adjustment of injection timing, the diesel engine performance comparison between the secondary injection and single injection.



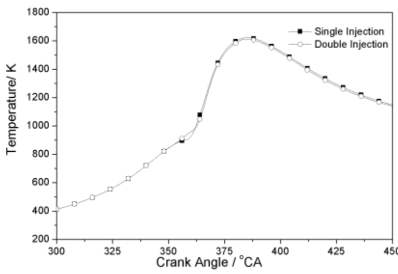
a) Average pressure curve in cylinder



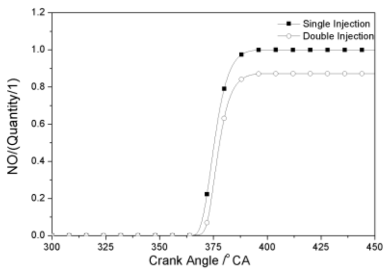
b) Pressure rise rate curve in cylinder



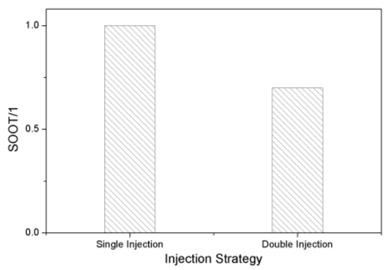
c) Heat release rate curve



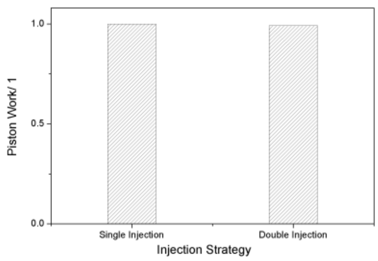
d) Average temperature curve in cylinder



e) NO_x total mass curve



f) Total quality comparison diagram of soot



g) Work contrast figure

FIGURE 10 Diesel engine performance contrast figure

The figure 10 a) and b) shows that after the adjustment of injection timing, the secondary injection ignition delay period is longer, about 8oCA, due to the fuel pre-injection quality is less, gas mixing fully, it is to lay a good foundation for the subsequent combustion; Urgent combustion period is 354oCA - 360oCA, premixed gas combust together almost at this stage, cylinder temperature rise sharply, as the main fuel injecting in cylinder, the process of fuel atomization and evaporation shorted, gas diffused and mixed combustion with oxygen, cylinder pressure rise rapidly, the high pressure rise rate is 0.4 MPa/oCA, lower than that of single injection, it shows that the secondary injection pressure change is moderate; slow-burning period is 360oCA - 365.2oCA, during this stage the peak pressure is 16.4 MPa, and was equal to that of single injection; Compared with the single injection, after combustion period of the two are basically identical.

By figure 10 c) and d), the secondary injection and single jet reach exothermic peak almost at the same time, and peak value of the secondary injection is higher than single injection, it shows that the secondary injection fuel burning more fully; the cylinder temperature curve change rule is consistent, and the secondary injection peak temperature is only 1612K, lower than that of single injection of 1623K, it shows that secondary injection combustion in cylinder is more even.

By figure10 e), NOx generation total amount of the secondary injection is 87.3% of the single jet, was reduced by 12.7%, it shows that the secondary injection high temperature area is small, NOx formation is less; By figure10 f), soot of the secondary injection is only 58.9% of single injection, down 41.1%, that shows gas of the secondary injecttion mixed fully in slow-burning period, therefore emissions reducing. By figure10 g), the secondary injection ability of doing work is 99.1% of single injection.

In conclusion, after adjusting the injection timing reasonably, the secondary injection has almost the same power capability as single injection, but NOx emissions reduce by 12.7%, soot emissions reduce by 41.1%. That shows by changing cumulative injection fuel quality to adjusting the injection timing of secondary injection, compared with single injection, it can ensure the ability of doing work and greatly reduce emissions.

7 Conclusions

1. Set up a combustion simulation model of marine low speed two stroke diesel engine, simulated and analysed the compression, spray, combustion, emission process of marine low speed diesel engine, and compared with the test data, the maximum error is less than 0.36%.

2. At the same injection timing, compares the diesel engine performance of the single injection and secondary injection, the results show that compared with single jet, the secondary injection caused the reduction of NOx by 58.9%, lower soot by 30.1%, but the ability to make the work fell by 10.1%.

3. The method of adjusting the cumulative injection quality centre to adjust the injection timing of secondary injecttion reasonably is given, it can enhance the power capability of diesel engine; And combustion simulation was done, the results show that compared with single injection, the secondary injection can ensure the ability of doing work, at the same time, reduce NOx by 12.7% and soot by 41.1%.

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Authors

Wang Xiaorong, born in 1982

Current position, grades: lecturer, Dr, master tutor
University studies: school of mechanical and engineering, Jiangsu university of science and technology,
Scientific interests: computational fluid dynamics and Marine diesel engine combustion and performance study

Chenpeng Liu, born on March 23, 1987, China

Current position, grades: graduate at Jiangsu University of Science and Technology, China.
University studies: B.S degree in machine manufacture and its automation from Henan Mechanical and Electrical Engineering College, 2009, and received the M.S degree in mechanical engineering from Jiangsu University of Science and Technology, China in 2014.
Scientific interests: include CFD analysis, engine performance and emission research.

Bo Liu, born on April 11, 1982, P. R. China

Current position, grades: senior engineer at China Shipbuilding Power Engineering Institute Co., Ltd., Shanghai, China.
University studies: B.S degree in thermal energy and power engineering from Shanghai Jiao Tong University, China in 2004, and received the Ph. D degree in power machinery and engineering from Shanghai Jiao Tong University in 2011.
Scientific interests: performance and combustion development of diesel engine.

Wenxian Tang, born on September 6, 1962, China

Current position, grades: The dean of Mechanical Engineering at Jiangsu University of Science and Technology College, China.
University studies: B.S degree in mechanical manufacturing technology and equipment from Zhenjiang Shipbuilding Institute, 1987, received the M.S degree in machinery manufacturing from Jiangsu University, China in 1994, and received the PhD in Mechanical design and theory from Shanghai University, 2004, Post-doctoral research work in mechanical engineering from Nanjing University of Science and Technology, 2004-2005.
Scientific interests: Digital development of complex products.

Chenpeng Liu, born on March 23, 1987, China

Current position, grades: graduate at Jiangsu University of Science and Technology, China.
University studies: B.S degree in machine manufacture and its automation from Henan Mechanical and Electrical Engineering College, 2009, and received the M.S degree in mechanical engineering from Jiangsu University of Science and Technology, China in 2014.
Scientific interests: include CFD analysis, engine performance and emission research.