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Genetic algorithm optimization applied to the fuel supply parameters of diesel engines working at plateau ☆

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HIGHLIGHTS

- We proposed a novel parameter to measure the surge trend of operating points.
- We put forward the method to determine the plenty parameters' values of GA.
- The power and efficiency @4500 m is improved by 22.7% and 6.4% via GA optimization.

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ABSTRACT

In order to enhance the power performance for the diesel engines working at plateau, the method to adjust fuel injecting parameters had been adopted. However, the diesel engine is considered as a complicated nonlinear multiple-inputs and multi-boundary system. Hence, it is difficult to find out the appropriate value for fuel injecting parameters for all conditions, this is the reason why we study the Genetic Algorithm method for optimization. Firstly, the numerical model of a turbocharged diesel engine with the predictable combustion model was established and then verified by experimental data. Base on the engine model, the relation between injecting parameters and performance was studied. Secondly, the optimization model is constructed, including the objective and the boundary conditions with a novel parameter introduced, measuring the surge margin of the operating points. Then, the Fitness function is proposed employing penalty functions to express constraints. Based on the impact of injecting parameters on constraint conditions, the method was put forward about how to choose the penalty parameter values, named "Fitness Equal to Zero at the Worst Point". In order to explain this method, 4500 m rated operation point was illustrated and four schemes with different plenty values were compared. After the comparison of the population distributions and the optimizing processes, the Scheme II is proofed to be accurate and efficient, which adopted the plenty value chosen method (Fitness (w) = 0). Finally, this GA model was used for the fuel supply parameters optimization of full-load operation at 4500 m altitude. The result demonstrates that the rated engine power is enhanced by 22.7% and the fuel consumption reduces by 6.4%.

1. Introduction

At the plateau environment, the diesel engine performances deteriorate in the aspects of power, economy and emission. What is worse, the trend of surge, over-speed and overheating will reduce the reliability of the turbocharger. Reference [1] pointed out that appropriately earlier injection timing can improve the efficiency and to reduce the T_T (turbine inlet temperature), while adjusting the injected fuel amount could partly recovery the power. However, too early injection leads to a too high p_{max} (peak pressure in-cylinder) and power loss at compression stroke, while the too much injected fuel would result in over-speed or overheat for turbines. And other researchers got the similar conclusions through experiments [2] or simulations [3].With many restrictions,

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Nomenclature

0-D	zero dimensional	K	penalty parameter
BTDC	before dead center	NN	neural network
CA	crank angle	n_T	speed of turbocharger
EUP	electric unit pump	p_{max}	peak in-cylinder pressure
GA	genetic algorithms	RoHR	rate of heat release
h	degree of violation against constraint	T_T	turbine inlet temperature
HRL	heat release law	Ts	trend of surge

it took huge work to find out the best values for injection parameters at different operating conditions [4].

As the engine model is considered to be complicated, nonlinear and discontinuous, the traditional methods are not capable for the optimization of fuel supply parameters [6]. As a common optimization method, GA (genetic algorithm) has a widely use in engineering. Based on the idea of natural selection, it features the "survival of fittest" strategy to search for the optimal solution [7]. At the aspects of ICEs (internal combustion engine), the GA method has been applied in modeling, structure design, and calibration for operation parameters.

At the aspects of GA applications for modeling, Alonso et al. [8] has employed the GA and ANN (artificial neural networks) for prediction of engine emissions, while Togun and Sedat [9] has established a GA model to predict the toque and BSFC for a gasoline engine based on experimental data. In Ref. [10], a GA based method has been developed to estimate the instantaneous pressure in cylinders. Some parameters associated with a pressure curve are optimized from two validated sub-models which reproduce the engine behavior via GA.

At the aspects of GA applications for design, Donateo et al. [11] has studied the design method to take use of empirical based models and CFD (computational fluid dynamics) simulations together. The structure parameters of the chamber in database differ for shape of the bowl, compression ratio, the offset of the bowl and the size. It is impossible to simulation all the possible combinations of geometric and control parameters in a feasible computational time, so GA is chosen for its robustness and multi-objective optimization capability. Fang et al. [12] has investigated the design parameters and the performance variable interactions for a VGS (variable geometry spray) fuel injector by CFD software. Based on the results, multi-objective genetic algorithm was taken to find out the best combination of actuator stroke and spray angle.

At the aspects of GA applications for calibration, Dempsey and Reitz [13] studied the effects of swirl ratio, injection parameters and EGR rate on the combustion for a heavy-duty diesel engine. After that, with the help of GA, they found out the best parameters values for mid and high loads operation. Li et al. [6] had taken the GA method to optimize the SOI (start of injection timing) and EGR (exhaust gas recirculation) rate of a RCCI (reactivity controlled compression ignition) engine. Ref. [14] had applied penalty functions to GA optimization for an Atkinson engine, which is considered as a practical method to express the constraints. In such a GA model, the optimization results greatly rely on the selection of penalty parameters values: Inappropriate penalty values will reduce the efficiency, or even worse, cause the failure of optimization.

In this paper, the simulation model for diesel engine had been established and validated, based on which the influence of fuel supply parameters was discussed. Then, the boundaries, the fitness and the penalty functions of the GA model were defined. In the GA model, a novel parameter was proposed to measure the operation surge trend, and the principle to choose the values for penalty parameters was put forward. Finally, the GA model and the engine simulation model were combined for optimizing the fuel supply parameters at 4500 m altitude environment.

2. Simulation model and parameters study

Firstly, a numerical model for diesel engine performance was established and then verified by experimental data, and these processes were explained by a previous published paper in detail [5]. Some key points are briefly introduced as follow.

2.1. Numerical models establishment

This study selected the turbocharged intercooled BF6M1015 diesel engine for investigation, which is manufactured by DEUTZ AG with 6 cylinders in V type and a mechanical diesel pump. Some specifications of the engine are shown in Table 1.

As the combustion prediction is complicated and important in the engine simulation, we adopted the 0-D Predictive combustion model based on NN (neural network) and three Wiebe functions, which was proposed by Galindo, Serrano et al. in Ref. [15–17].

The main procedures to establish the 0-D Predictable combustion model are shown in Fig. 1. Step1, the RoHR (rate of heat release) was obtained via thermodynamic calculation from in-cylinder pressure. Step2, The Three-Wiebe function model [18] was adopted to describe the RoHR and the values of model parameters were obtained via Levenberg–Marquardt [19] fitting. Step 3, NN is trained by experimental data to find out the relations between operating conditions and parameters of combustion model [20]. As this model was established for injecting parameters optimization, five factors had been chosen for NN training after the study of the influence of operation factors on the combustion process, which are the outlet air temperature of intercooler, the outlet air pressure of intercooler, the injection mass, the injection timing and engine speed. In the investigation, the experimental data of different operating conditions were taken to training the NN, covering the range of 820–2100 r/min, 10–100% load, several injection

Table 1
Specifications of the V6 engine.

Parameter	Value
Number of cylinders	6
Displaced volume	11.9 L
Bore	132 mm
Stroke	145 mm
Compression ratio	17:1
Rating power at plain	330 kW @2100 r/min
Maximum torque	1980@1300 r/min
Maximum allowable p_{max}	160 bar
Maximum allowable T_T	750 °C

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