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Research Paper

Application of DoE evaluation to introduce the optimum injection strategy-chamber geometry of diesel engine using surrogate epsilon-SVR

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HIGHLIGHTS

- DoE method incorporation with Sobol sequence to determine desirable diesel engine design points.
- Lower injection angle and smaller bowl volume is the optimum engine design.
- The best case has reduced bowl volume, more encircled shape compared to baseline configuration.
- Simultaneous NO_x and droplet diameter reduction through the proposed modification.

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ABSTRACT

With the advance of computational fluid dynamic methods for simulation of diesel engines, the requirement is felt to find the optimal operational design by scanning through various design points. In this sense, a design of experiment technique was applied to a baseline 1.8 L Ford diesel engine by defining a multi-objective function that is consisted of sub-objectives of NO_x emission and spray droplet diameter. The success of the optimization procedure is contingent upon reduction of emission and enhancement of the spraying characteristics.

It is determined that the effect of adjustment in injection strategy is more important than that of the engine modification. A slight reduction of inner bowl diameter and bowl radius should be concomitant with decrement of spray cone angle and injection angle with respect to the baseline engine. The best design configuration is achieved at Run ID 22 (R4/Di/injection angle/spray cone angle = 5.77 mm/43.7 mm/121.9 deg/4.11 deg). DoE method using Sobol sequence is used incorporating with the support vector regression to predict output parameters with acceptable accuracy in this research project.

1. Introduction

Energy crisis owing to the political turmoil of crude oil providers and atmospheric pollution are of the most substantial challenges of the globe. The pollutants have direct and indirect dangers on the health of human, jeopardizing national security, and various destructive results on nature and biology. The existing environmental contamination to great extents stems from the emission of pollutants such as NO_x, CO, and soot [1].

The share of diesel engines in the total pollution is considerable and a lot of research work has been dedicated on the experiments, closed-form equations, and simulations to take a drastic measure in the emissions reduction. The methods to investigate reducing the emissions of DI engines include the experimental tests that are available in the literature [2–5], analytic works [6] and numerical simulation [7,8]. DI diesel engines have been widely used around the world owing to the durability and fuel economy [9]. It is extremely urgent to introduce an effective optimization method of diesel engine combustion system that is focused on the simultaneous reduction of soot and NO_x while maintaining a reasonable power performance [10].

The adoption of new artificial intelligence (AI) techniques gives a better way to achieve a robust solution to solve the problems in the domain of IC engine performance and emissions [11–14]. This might be attributable to the inherent nature of AI methods to deal with nonlinear problems satisfactorily. AI tools in this regard have been applied for the purpose of modeling and optimization. Each of

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these techniques can be implemented through numerous techniques of ANN (artificial neural networks), fuzzy logic, ANFIS (adaptive neuro-fuzzy inference system), SVM (support vector machine) for prediction and GA (genetic algorithm) and meta-heuristics such as ICA (imperialist competitive algorithm), PSO (particle swarm optimization) for optimization. In the area of the soft computing, support vector regression has gained much interest in industrial scale, especially in the field of optical lens system [15,16], sensor data fusion [17], and evaluation of gas turbine behavior [18]. In the case that one intends to adopt a modeling approach, it should be considered that ANNs often converge on local minima rather than global minima and that they often overfit if training continues for a long run. However, SVM can be an outperforming method over ANN and ANFIS for the prediction of engine performance and emission.

As seen, previous literature review corroborates that little study is devoted on practical "engine design – injection system" optimization based on DoE method with integration of the epsilon-SVR predictability. The current study unlike other investigations, which take objectives separately, incorporates sub-objectives into final objective function and optimize them at the same time. This is the first that the objective function is set to enhance the spray quality and yet to reduce the NO_x emission through a comprehensive modeling-optimization approach. The main objective in this study is to minimize both defined sub-objectives and the aggregate sum values as the final objective function. The objective function is of significance since the trade-off between producing small SMD (soot) and NO_x is obviated. Therefore, reducing both parameters simultaneously can be accomplished by modification in injection system and design structure.

2. CFD numerical simulation

In this study, ESE (Engine Simulation Environment) module of the AVL FIRE commercial software was used for the simulation of the base diesel engine and Design Explorer from DVI tool was taken for DoE evaluation. As to save in time and reduce the computational cost, a quarter of the combustion chamber was taken into account for meshing. The geometrical domain is composed of 23,623 cells, which assures consistency of the results irrespective

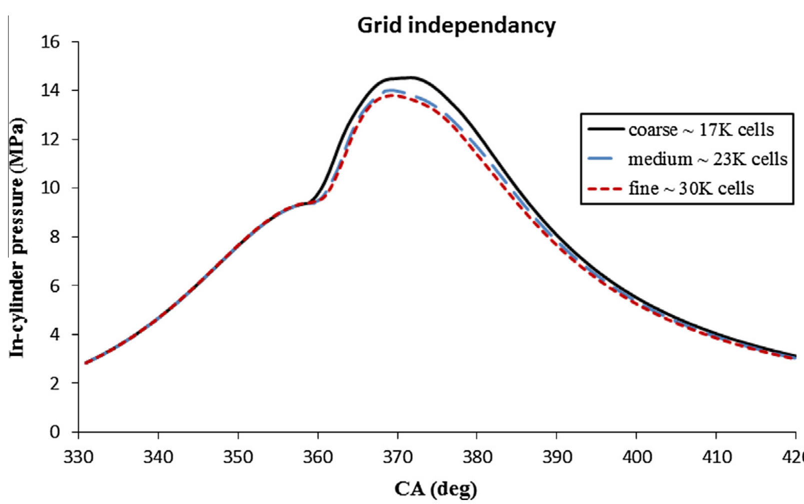

Fig. 1. Grid independency for three mesh densities.

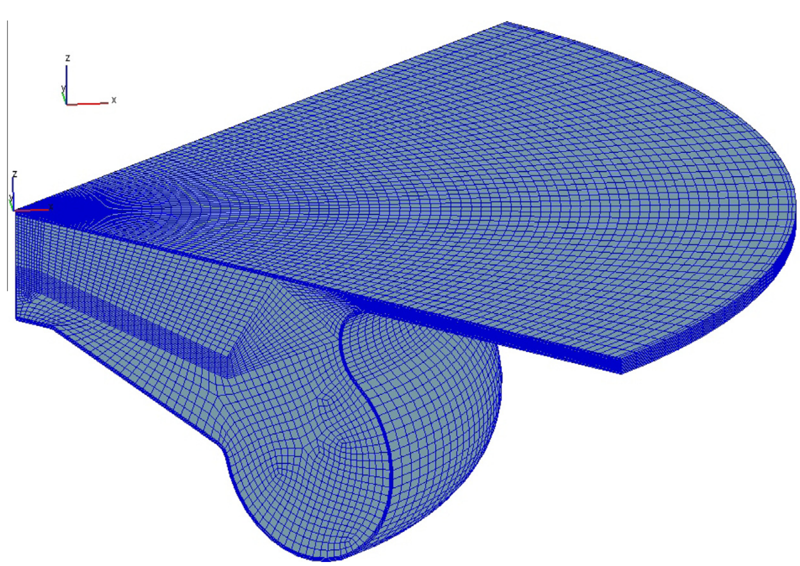

Fig. 2. Computational domain of the model at TDC.