

A study on Optimization of Combustion Chamber Geometry in Heavy Duty Diesel Engines by Using CFD and Machine Learning

Ryo Matsumae¹⁾ Tomohiro Matsuda¹⁾ Jin Kusaka¹⁾

*1) Waseda University, Graduate School of Creative Science and Engineering, Department of Modern Mechanical Engineering
Postal Code 169-8555, Room 226, Building 58, 3-4-1 Okubo, Shinjuku-ku, Tokyo, Japan*

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To achieve carbon neutrality by 2050, further improvements in thermal efficiency and reductions in harmful emissions are required for large diesel engines. However, thermal efficiency and emissions generally involve trade-offs, and optimization of combustion chamber geometry is therefore important. In conventional design processes, three-dimensional CFD is widely used, but extensive parameter searches require a large computational cost. In this study, we developed an efficient optimization method for diesel engine combustion chamber geometry by combining an Artificial Neural Network, or ANN, with Particle Swarm Optimization, or PSO.

Three combustion chamber parameters were considered: lip diameter, lip depth, and reentrant angle. Three levels were selected for each parameter, resulting in 27 combustion chamber geometries. Three-dimensional CFD calculations were performed for these geometries under a medium-load condition at an engine speed of 1080 rpm using diesel fuel. The ANN was trained using these CFD results. As shown in Figure 1, the three geometry parameters were used as inputs, while indicated thermal efficiency, soot emissions, and NOx emissions were used as outputs. The ANN therefore provided a response surface that could estimate engine performance without performing CFD for every candidate geometry. Next, PSO was applied to this ANN response surface. Each particle represented a combination of the three design parameters, and the particles searched for the geometry that minimized an objective function consisting of normalized thermal efficiency, soot, and NOx. The weighting factors for thermal efficiency, soot, and NOx were set to 0.5, 0.3, and 0.2, respectively, with greater emphasis placed on thermal efficiency under the assumption that NOx emissions would be treated by a DeNOx aftertreatment system.

Figure 2 shows the convergence process of PSO. At the beginning of the optimization, the particles were widely distributed in the design space. As the number of iterations increased, the particles gradually converged toward a common region, and after 50 iterations, they converged around the optimal solution. This indicates that PSO can stably identify an optimal candidate from the ANN response surface. For the optimized geometry, indicated thermal efficiency increased from 53.42 to 56.51 percent, corresponding to an improvement of 3.09 percentage points. Soot emissions decreased from 3.124 to 0.543 grams per kilogram of fuel, corresponding to a reduction of 82.6 percent. On the other hand, NOx emissions increased slightly from 1.745 to 1.827 grams per kilogram of fuel, corresponding to an increase of 4.7 percent. These results demonstrate that the proposed optimization method can identify a combustion chamber geometry that substantially improves thermal efficiency while reducing soot emissions, although a slight increase in NOx emissions was observed.

In conclusion, an optimization method combining 3D-CFD, ANN, and PSO was developed. PSO successfully searched the ANN response surface and obtained an optimal combustion chamber geometry. In addition, changing the weighting factors of thermal efficiency, soot, and NOx enabled the intended performance priority to be reflected in the optimized geometry. This method can therefore provide an efficient approach for multi-objective optimization of diesel engine combustion chamber geometry.

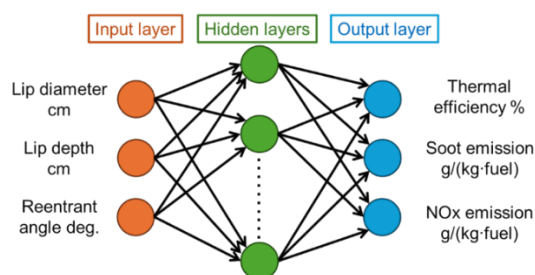


Fig.1 Schematic of ANN model

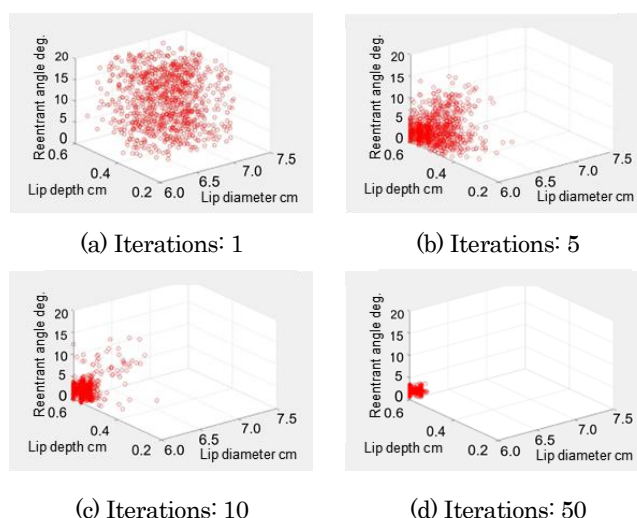


Fig.2 3D output results of PSO model