# Multi-Objective Optimization of Diesel Engine Emissions and Fuel Economy Using SPEA2+

Tomoyuki Hiroyasu
Doshisha University
tomo@is.doshisha.ac.jp

Mitsunori Miki
Doshisha University
mmiki@mail.doshisha.ac.jp

Seiichi Nakayama
Doshisha University

Yoshiko Hanada
Doshisha University

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## 1. INTRODUCTION

The diesel engine has excellent fuel economy and is widely used especially in commercial vehicles. However, there are ever increasing concerns with regard to environmental problems, drawing attention to air pollution caused by the NOx and Soot exhaust from diesel engines. In this paper, diesel engines that have the small amounts of NOx and SOOT with the high fuel economy are tried to design. To design such diesel engines, one of multi-objective genetic algorithms, SPEA2+[3], is applied. SPEA2+ is an enhancement of SPEA2 and has not only the high searching ability but also the mechanism of maintain the diversity in the design variable space. Through the numerical examples, the effectiveness of SPEA2+ was examined by applying SPEA2+, SPEA2[1], and NSGA-II[2] to the fuel emission scheduling problem. Our results indicated that multi-objective optimization is effective for designing diesel engines.

## 2. SPEA2+ AND HIDECS

### 2.1 SPEA2+

SPEA2+ is a new model of a multi-objective genetic algorithm that improves the search performance of SPEA2 by considering these problems. SPEA2+ is SPEA2 with the addition of the following mechanisms:

1. Neighborhood crossover to allow crossing over individuals located close to each other in objective space
2. Mating selection that reflects all good solutions preserved in the archive
3. Application of two archives to maintain diverse solutions in the objective space and the design variable space


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### 2.2 HIDECS

The simulation of diesel engine is very complicated. In this study, HIDECS was used as an analyzer to determine the target function values in optimization. HIDECS is one of phenomenological spray-combustion models and has shown great potential as a predictive tool for both performance and emissions in a wide range of direct injection diesel engines[4, 5].

## 3. DIESEL ENGINE FUEL EMISSION SCHEDULING PROBLEM

### 3.1 Outline of the diesel engine fuel emission scheduling problem

In this study, a diesel engine was designed to minimize the amounts of SFC, NOx and Soot. SFC is an index that when minimized the fuel economy is maximized. There are many design parameters for the diesel engine. In this study, we didn't target shape parameters, such as bore diameter and stroke length, we targeted parameters that can be controlled electronically, such as EGR, swirl rate, and fuel injection ratio. Target shape parameter was related to physical size are pre-determined by the specification, and the degree of design freedom is low. On the other hand, the parameters that can be controlled electronically are controllable or are new technologies that are becoming controllable, and will be used for engines in the near future. By targeting parameters that can be controlled electronically, the designed engine will not have one fixed solution but will have a dynamic design that can be adapted according to requirements. This is a so-called, flexible system, and will also be one of the forms of future engine design.

The Specification of targeting diesel engine is shown in Table 1.

In this study, the amounts of SFC, NOx, and Soot were used as the objective function, and we tried to minimize them simultaneously. The injection shape of the fuel is two-step injection where the fuel is injected in two pulses. Moreover, the fuel injection duration angles of the first and second pulses are the same, and the amount of total fuel is constant. To achieve two-step injection in this study, the percentage of fuel in the first pulse, dwell between injections,

**Table 1: Specification of the target diesel engine**

| | |
|---|---|
| Bore (m) | 0.1329 |
| Stroke (m) | 0.0825 |
| Connected Rod (m) | 0.26 |
| Compress Ratio | 14.7 |
| Nozzle Diameter (m) | 0.00029 |
| Nozzle Number | 8 |
| Engine Speed (rpm) | 2200 |

and duration angle are necessary. Therefore, two-step injection was achieved by handling these as design variables in this study. Moreover, start angle, exhaust gas recirculation (EGR), boost pressure, and swirl ratio are also handled as design variables in addition to those described above. These parameters can be controlled electronically. The constraint conditions of each design variable are shown in Table 2.

**Table 2: Range of design variables**

| item | Min | Max | bit for GA |
|---|---|---|---|
| Percentage of first pulse | 50 | 84 | 7 |
| Dwell between injections (CA) | 3.0 | 15.0 | 7 |
| Start Angle (ATDC) | -10.0 | 10.0 | 8 |
| Duration Angle (CA) | 25.0 | 40.0 | 5 |
| Boost Pressure (kg/cm2) | 3.45 | 3.65 | 5 |
| EGR rate | 0.0 | 0.30 | 5 |
| Swirl Ratio | 0.0 | 6.0 | 5 |

The GA parameters used in this experiment are shown in Table 3.

**Table 3: GA Parameter**

| | |
|---|---|
| Population Size | 200 |
| Terminal Generation | 100 |
| Crossover Rate | 1.0 |
| Mutation Rate | 1/42 |
| Runs | 5 |

## 3.2 Comparison between SPEA2+, SPEA2 and NSGA-II

Figures 1 and 2 show the solution sets obtained by SPEA2+, SPEA2, and NSGA-II.

¿From these results, it can be said that NSGA-II was slightly inferior to those of SPEA2 and SPEA2+. In addition, SPEA2+ and SPEA2 showed almost equivalent proximity and breadth of the obtained solution sets.

Figures 3 show the relations between NOx and start angles from the solution sets obtained by SPEA2+, SPEA2, and NSGA-II.

As shown Fig. 3, the design variable archive of SPEA2+ was the most diverse design variable values.

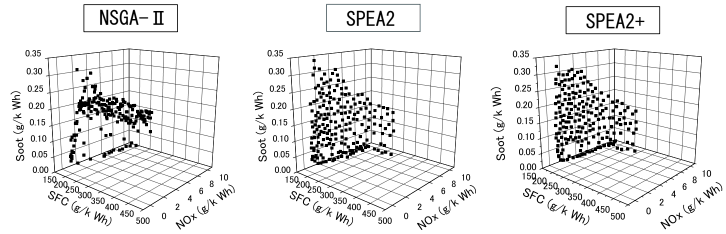


**Figure 1: Pareto Optimum Solutions (SFC, NOx, Soot)**

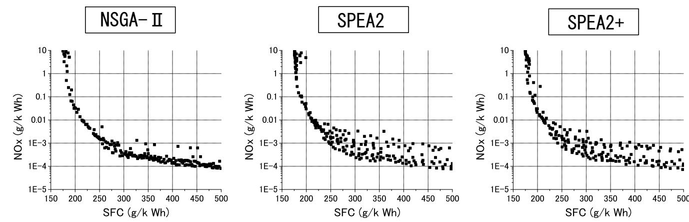


**Figure 2: Pareto Optimum Solutions (SFC, NOx)**

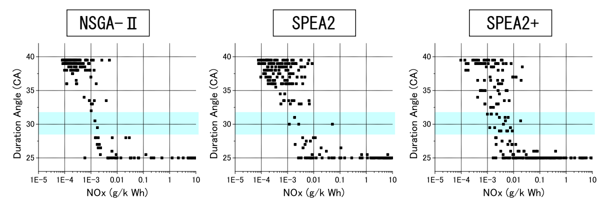


**Figure 3: Relation of NOx and Duration Angle**

## 4. REFERENCES


[1] E. Zitzler and M. Laumanns and L. Thiele, "SPEA2: Improving the Performance of the Strength Pareto Evolutionary Algorithm", Technical Report 103, Computer Engineering and Communication Networks Lab (TLK) , Swiss Federal Institute of Technology (ETH) Zurich (2001)

[2] Kalyanmoy Deb, Samir Agrawal, Amrit Pratab, and T. Meyarivan, "A Fast Elitist Non-Dominated Sorting Genetic Algorithm for Multi-Objective Optimization: NSGA-II", KanGAL report 200001, Indian Institute of Technology, Kanpur, India (2000)

[3] M. Kim, T. Hiroyasu, M. Miki, "SPEA2+: Improving the Performance of the Strength Pareto Evolutionary Algorithm2", Parallel Problem Solving from Nature - PPSN VIII, 742-751, 2004

[4] Imanishi, H. Yoshizaki, T and Hiroyasu, H., "Simulation Study of Effects of Injection Rate Profile and Air Entrainment Characteristics on D.I.Diesel Engine", SAE Paper 962059, 1996.

[5] Long, Y. S., Gakumazawa, H. and Hiroyasu, H., "The Simulation of the Distribution of Temprature and Mass of Liquid and Vapor Fuels, and the Wall Impinging Spray Pattern in a Diesel Combustion Chamber", SAE Paper 2000-01-1887, 2000.