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Optimization of Diesel Engine Parameters using Genetic Algorithm

Magesh Kannan V[1]* and Amirthagadeshwaran KS[2]

[1]*Department of Automobile Engineering, PSG College of Technology, Coimbatore, Tamil Nadu, India*

2Department of Mechanical Engineering, Government College of Technology, Tamil Nadu, Coimbatore, India

***Corresponding author:** Kannan MV, Assistant professor, Department of Automobile Engineering, PSG College of Technology, Coimbatore, Tamil Nadu, India, E-mail: vmk.auto@psgtech.ac.in

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Abstract

This work involves in selection of parameters for a compression ignition engine which influence fuel economy and harmful emissions such as carbon monoxide and oxides of nitrogen. Experiments are conducted for performance and emission by varying the operating parameters within the operating range. Full factorial experimentation is done and this large data is analyzed by non-traditional soft computing techniques namely Genetic Algorithm (GA). Mathematical models are formed using MINITAB software and the same are used for optimization of settings using GA. A single layer Levenberg-Marquardt back propagation network has been trained using the experimental data. By using the trained network the output for the optimum set of parameters obtained from GA is predicted. The outputs from experiments, GA are compared and the outcome is discussed. This optimized set of parameters, when applied in the engine, reduces the harmful emissions of the engine and increases its performance, thus conserving fuel and promoting a cleaner environment.

Keywords: Full factorial; Genetic algorithm; Artificial neural network; Back propagation; Optimum

Introduction

Conventionally all immobile engines are designed for a general optimal set up, but almost all engines are run at specific load which is constant in most of the cases. Hence it is highly required to optimize the engine parameters at different loads. This optimal set is likely to have comparatively lower emission and higher efficiency. To achieve this Genetic Algorithms (GA) technique is used and the results were verified by experiments.

GA was introduced in United States in 1970s with the motive of improving the performance/price of computational systems by John Holland, University of Michigan. Considering the workability of GA in continuous and discrete, combinatorial and multi-parameter optimization problems the usage GA in optimization enhanced exponentially. The key advantage of GA is that they do not get stuck at local optima like gradient search method. Owing to the levels of optimization required in engines and considering the advantages of GA, the same is used as an optimization tool in this work.

Litrature Survey

Based on the need for performance improvement and reduction of emission the details of works/studies conducted earlier are collected and are discussed in this section. Lembit Salasoo et al. [1] has stated that, the particulate matter emissions were strongly dependent on the variation in the number of holes in the nozzle up to four. In the range tested the number of holes in the nozzle had a strong influence on particulate matter emissions when compared to injection pressure. On the other hand specific fuel consumption was strongly influenced by injection pressure when compared to number of holes in the nozzle. Interestingly the influence of numbers of holes in the nozzle on particulate matter was fundamentally different, as it was distinct. Rosli et al. [2] have affirmed that within the speed range 1500 to 2500 rpm more number of holes in nozzle will increase the efficiency of the engine. When the number of holes is increased to seven, the engine was at its best performance, due to finer atomization, higher dispersion of fuel and better mixing rate, however increasing the number of holes in the nozzle is not widely undertaken as it involves manufacturing complications. Rosli et al. [3] have concluded by numerical analysis that increasing the number of nozzles increases the performance of IC engines, in terms of efficiency. From the above it is clear that the increase in number of nozzles increases the combustion phenomenon with the stroke volume as a constraint.

Rosli et al. [3] in another study, has affirmed that, increase in injection pressure is in-line with increase in power. This conclusion was made after experimenting the consumption of fuel for different loads with different speeds by varying either load or speed at a time. This study also inferred that an increase in injection pressure leads to increase in both emissions and consumption of fuel in diesel engines [4]. Kannan et al. [5] asserted that an improvement in brake thermal efficiency and reduction in brake specific fuel consumption was evident above 150 bar injection pressure. However, only the peak enhancement in performance was about 1% only, but while considering the running hours of the engine this could lead to phenomenal saving in fuel. From the above it is clear that the increase in injection pressure increases the performance of the engine.

Adelman et al. [6] and Atkinson et al. [7] stated that at elevated temperatures, the use of reducing catalysts will reduce oxides of nitrogen to atmospheric nitrogen. Chen's et al. [8] investigations affirm the conversion of carbon dioxide from hydrocarbons when catalyzed. The above studies show appropriateness of catalytic conversions in diesel engine exhaust.

The details of the experimental setup and the conduct of experiment are discussed in the next section.

Engine setup

The 5.968 kW kirloskar engine investigated, has a 0.242 m wide brake drum, a three hole nozzle, piston head clearance of 1.4 mm and an injection pressure of 170 bar [9-14].

Based on the literature surveyed six parameters are chosen and the variations of these parameters are shown in Table 1. The variation of parameters was done in accordance to the operating range of the engine, cost and their availability. The reactivity of the catalyst depends on its molecular weight hence this numerical value is used for analysis and representation.

Parameters	Level 1	Level 2	Level 3
Number of nozzle holes	3	4	3 and 4
Piston head clearance(mm)	1.2	1.4	1.6
Injection pressure(bar)	160	170	180
Load(kg)	3	6	9
Direct oxidization catalyst	MgO	CH3COOH	CuO
Molecular weight (g)	40.3	60.05	79.55
Selective reduction catalyst	V2O5	WO3	W2O3
Molecular weight (g)	181.88	231.85	415.7

Table 1: Variation of the selected parameters.

The combinations that can be obtained by varying these parameters are 486(2 × 35).

Experimentation

The output such as oxides of nitrogen, hydrocarbons, carbon dioxide, carbon mono-oxide and brake thermal efficiency were obtained experimentally for all 486 combinations.

Model generation technique used, using the experimentally obtained data is discussed in the following section.

Optimization

Model generation using MINITAB 14

Mathematical models were generated using MINITAB 14 the same are shown below in equations 1 to 5. Since the number of variations in the parameter number of nozzles is two, only linear models can be generated (i.e. NOH*NOH cannot be obtained) where as a quadratic models are generated for all other parameters.

NOx=+25489.2 –972.826 *NOH –30243.8 *PHC +6.04599 *IP +8.24669 *LOAD –0.01185 *SCR –0.01151 *DOC –0.24172 *FC +9075.55 *PHC *PHC –0.00122 *IP *IP –0.8353 *LOAD *LOAD +1.74E –07 *SCR *SCR +1.85E –06 *DOC *DOC –6.19E –06 *FC *FC +409.342 *NOH *PHC +0.175607 *NOH *IP –5.90069 *NOH *LOAD +6.27E –05 *NOH *SCR +0.005154 *NOH *DOC –0.00557 *NOH *FC –2.98637 *PHC *IP +3.72013 *PHC *LOAD –1.28E –04 *PHC *SCR –0.01611 *PHC *DOC +0.119764 *PHC *FC +0.061613 *IP *LOAD –1.11E –06 *IP *SCR +3.10E –05 *IP *DOC +0.000162 *IP *FC +1.58E –05 *LOAD *SCR –6.55E –04 *LOAD *DOC –0.00399 *LOAD *FC +1.51E –08 *SCR *DOC +6.14E –08 *SCR *FC –2.71E –06 *DOC *FC (1).

HC=–57.6508 +8.77475 *NOH –197.312 *PHC +0.043036 *IP +7.35443 *LOAD +0.002631 *SCR +0.029866 *DOC +0.007783 *FC +118.573 *PHC *PHC +0.000214 *IP *IP –8.88E –04 *LOAD *LOAD –3.89E –08 *SCR *SCR –1.03E –05 *DOC *DOC +5.08E –07 *FC *FC +15.2647 *NOH *PHC –0.02969 *NOH *IP +0.196934 *NOH *LOAD +1.32E –05 *NOH *SCR –0.00149 *NOH *DOC +0.001084 *NOH *FC –0.21581 *PHC *IP –0.51028 *PHC *LOAD +0.00014 *PHC *SCR +0.008923 *PHC *DOC +0.004582 *PHC *FC –0.004 *IP *LOAD –1.13E –07 *IP *SCR +4.07E –05 *IP *DOC –1.89E –05 *IP *FC –1.77E –06 *LOAD *SCR –0.00181 *LOAD *DOC +0.000302 *LOAD *FC +1.97E –08 *SCR *DOC +2.38E –10 *SCR *FC –3.64E –06 *DOC *FC (2).

CO=+1.44933 –2.27E –01 *NOH –8.04E –01 *PHC +1.96E –03 *IP –0.05105 *LOAD –1.21E –06 *SCR –8.43E –04 *DOC –1.33E –04 *FC +4.53E –01 *PHC *PHC +2.71E –07 *IP *IP +2.43E –03 *LOAD *LOAD +2.29E –11 *SCR *SCR –9.77E –08 *DOC *DOC +8.04E –09 *FC *FC +1.71E –02 *NOH *PHC –7.19E –05 *NOH *IP +1.04E –03 *NOH *LOAD –1.11E –07 *NOH *SCR +1.91E –04 *NOH *DOC +5.35E –06 *NOH *FC –3.00E –05 *PHC *IP –2.23E –02 *PHC *LOAD –2.78E –07 *PHC *SCR +7.86E –05 *PHC *DOC –2.92E –05 *PHC *FC –6.66E –05 *IP *LOAD +2.58E –10 *IP *SCR +3.18E –07 *IP *DOC –1.16E –07 *IP *FC +1.52E –08 *LOAD *SCR –1.33E –05 *LOAD *DOC +9.22E –06 *LOAD *FC –1.28E –10 *SCR *DOC +8.30E –12 *SCR *FC –2.81E –08 *DOC *FC (3).

CO2=+976.597 +5.74711 *NOH –1120.89 *PHC –0.06138 *IP –1.19812 *LOAD +0.000137 *SCR –7.77E –04 *DOC +0.000257 *FC +325.048 *PHC *PHC +2.28E –05 *IP *IP +9.09E –04 *LOAD *LOAD –1.28E –09 *SCR *SCR –8.63E –08 *DOC *DOC +5.31E –08 *FC *FC –2.03247 *NOH *PHC –0.00191 *NOH *IP –0.01551 *NOH *LOAD +1.21E –06 *NOH *SCR +8.52E –05 *NOH *DOC +5.74E –05 *NOH *FC +0.015539 *PHC *IP +0.972406 *PHC *LOAD –2.68E –05 *PHC *SCR +0.000301 *PHC *DOC +0.000677 *PHC *FC –2.42E –04 *IP *LOAD –8.97E –09 *IP *SCR –1.79E –06 *IP *DOC –1.96E –06 *IP *FC –2.32E –08 *LOAD *SCR +6.84E –05 *LOAD *DOC +1.75E –05 *LOAD *FC –7.26E –10 *SCR *DOC +3.52E –10 *SCR *FC +1.48E –07 *DOC *FC (4).

BTE=+0.14946 –6.16E –08 *NOH +3.06E –07 *PHC –5.58E –10 *IP –0.02491 *LOAD +3.46E –13 *SCR +1.17E –11 *DOC –8.12E –04 *FC –1.18E –07 *PHC *PHC –2.14E –13 *IP *IP +6.77E –11 *LOAD *LOAD +2.28E –19 *SCR *SCR +7.44E –16 *DOC *DOC –1.38E –15 *FC *FC +9.00E –09 *NOH *PHC +6.83E –11 *NOH *IP –1.13E –09 *NOH *LOAD –7.69E –14 *NOH *SCR –7.56E –13 *NOH *DOC –3.78E –12 *NOH *FC +2.54E –11 *PHC *IP –5.89E –11 *PHC *LOAD +7.02E –14 *PHC *SCR –4.09E –12 *PHC *DOC +1.79E –15 *PHC *FC +1.22E –11 *IP *LOAD –4.65E –16 *IP *SCR –1.73E –15 *IP *DOC +5.31E –14 *IP *FC +1.24E –14 *LOAD *SCR –1.24E –14 *LOAD *DOC +0.000135 *LOAD *FC (5).

These equations were used as functions in MATLAB editor to be accessed by the optimization tool of MATLAB and the same is discussed in the following section.

Optimization using genetic algorithm

Optimization was done using optimization tool of MATLAB, optimization technique in genetic algorithm was used for this purpose. The optimum sets of parameters is obtained separately for the standalone engine

Regression coefficients obtained from optimization tool of MATLAB are tabulated in Table 2.

Properties	R-Sq %	R-Sq (adj) %
BTE	100	100
CO2	99.8	99.8
CO	92.9	90.1
HC	99.1	99.1
NOX	99.2	99.2

Table 2: Regression coefficients obtained from minitab 14.

Since the regression coefficients are above 90% the equations formed are acceptable, hence used as mathematical models in genetic algorithm. The optimum values in number of nozzle holes, piston head clearance, injection pressure, load, direct oxidization catalyst and selective reduction catalyst are obtained for the stand alone engine and the same are shown in Table 3.

Parameters	Optimum set for standalone engine
Number of nozzle holes	4
Piston head clearance (mm)	1.59
Injection pressure (bar)	170.01
Load (kg)	7.99
Direct oxidization catalyst (molecular weight (g))	40.236
Selective reduction catalyst (molecular weight (g))	181.8

Table 3: Optimum set of parameters for standalone engine.

From the above results a four holed nozzle proved to be more effective than a three holed nozzle. Piston head clearance and injection pressure increases with load. Direct oxidization catalyst magnesium oxide was efficient whereas anhydrous acetic acid and cupric oxide are not suitable for the selected loads. Selective reduction catalyst vanadium pentoxide is more efficient than the oxides of tungsten for the selected loads.

Performance and Emission for Optimum Sets

The experimentally investigated performance and emission values for optimum sets when imposed on the engine are given in Table 4.

Properties	Optimum Standalone load
NOX	541
HC	33
CO	0.01
CO2	9.1
FC 50	162
BTE	37.85

Table 4: Experimentally investigated values of the optimum set.

The performance and emission values predicted by GA for optimum sets when imposed on the engine are given in Table 5.

Properties	Optimum set for Standalone engine
NOX	549.46
HC	37.21
CO	0.0185
CO2	9.58
BTE	36.12

Table 5: Performance and emission for optimum sets predicted by GA.

It is apparent that the values forecasted by GA show close relationship with the experimental results hence GA can be used as a tool for predicting the operating parameters of an engine.

The performance and emission for the load applications selected at factory settings (three whole nozzle, piston head clearance of 1.4 mm and an injection pressure of 170 bar) are shown in Table 6.

Properties	Optimum Standalone load
NOX	586
HC	36
CO	0.02
CO2	8.9
BTE	37.15

Table 6: Performance and emission at factory settings.

The above results show 7.68% decrease in NOX, 8.33% decrease in HC, 50% decrease in CO, 2.25% increase in CO2 and 0.7% increase in brake thermal efficiency.

Hence changing the engine settings has enhanced combustion which led to the increase in in efficiency and carbon dioxide, while catalytic reaction reduced carbon mono oxide and oxides of nitrogen.

Conclusion

This study deals with the conduct of experiment on a typical engine by varying a set of parameters and assessing the engine with regard to power and emission.

Using the data, Genetic Algorithm in MINITAB and MATLAB software, the optimum settings for minimum emission and maximum efficiency is instituted.

As a result of implementing the optimum settings the harmful emissions (Carbon monoxide and Oxides of Nitrogen) of the engine are reduced.

Carbon monoxide is reduced remarkably, hydrocarbons are brought down significantly and oxides of Nitrogen are condensed notably. This largely reduces the environmental effect caused by the engine.

Apart from emission reduction the implementation of optimum parameters also induces a marginal increase in efficiency due to complete and enhanced combustion, which has been verified through experiments.

Additionally the optimal settings will provide economic benefits to users due to increased efficiency. More parameters like type of combustion including pre–chamber type, retardation in injection timing, number of injectors, induction swirl, shape of combustion chamber, etc., can be chosen and better parameter settings, reducing emissions and improving performance may be obtained.

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