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Performance Evaluation of Diesel engine by feature selection of Exhaust using Machine Learning Algorithm

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Abstract: *In Diesel Engines, it has always been a field of interest, the control of Air-Fuel Ratio (AFR) in its transient operating conditions. Exhaust gas related to emission of CO2, NOx, PM, CO and unburned HC, together with the consumption of fossil fuels, gives a lot of interest at Global level. Thus in this work an attempt is made to evaluate the Performance of Diesel Engine by considering parameters like CO2, NOx, PM, CO and unburned HC for better efficiency using Machine Learning algorithm like Genetic Algorithm.*
Keywords*- Diesel Engine, Exhaust gas, Feature Selection, Genetic Algorithm*

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I. Introduction

In Direct Injection engines, injectors inject fuel directly into the main combustion chamber, which is a gap between cylinder and piston, where it pierce into the hot mass of compressed air. Indirect Injection (IDI) has mainly two designs are used viz. pre- combustion chamber and air cell. Pre-Combustion Chamber: In this, total fuel is injected into pre-combustion chamber and initial combustion take place here only. Due to the combustion, pressure in the pre-combustion chamber increases because of which fuel present in this chamber comes out at a high velocity through a wee orifice into the main combustion chamber. This high velocity of fuel helps the fuel atomize automatically and mix with air present in main combustion chamber and the combustion take place here. Air Cell: A small chamber provided inside the piston in some design is called Air cell. The piston compresses the air during compression stroke and pushes it into this air cell. As the piston retracts the pressure in the cylinder falls down resulting in the flow of hot air from the cell into the combustion chamber. These actions provide turbulence which mix the air and the fuel furthermore and complete the combustion.

II. Literature Survey

1) Data Analysis to Predictive Modeling of Marine Engine Performance using Machine Learning: In this paper, predictive analysis of the marine engine performance is analyzed and subjected to multiple machine learning and clustering algorithms. Variables analyzed are shaft power, shaft rpm and shaft torque. Neural network performed as a good model predictor here.
2) Improving Performance of Evolutionary Engine Calibration Algorithms with Principal Component Analysis: This paper put forth an idea to improve the speed and the performance of engine. Challenge includes expensive engine evaluation and time consumption. Method implemented in this paper is a PCA based optimization algorithm, resulted in minimizing fuel consumption & gas and particle emission in a Jaguar XF.
3) An identification method of characteristic parameters for single-cylinder engine fuel film based on genetic algorithm to find the Air-Fuel Ratio of single cylinder engine. Method of perturbation is performed in this test. Genetic algorithm used as to the performed to analyze.
4) Simulation study of optimization of genetic algorithm for vehicle power train: To improve performance of the car, work mainly focuses the use of Genetic Algorithm for the best match of automotive power train parameters. Computer simulation is used for the automotive power system parameters optimization.
5) Combining neural networks and GA to predict and reduce diesel engine emissions: Objective of the paper is to find best way to set the engine as the emission rate is reduced and the reduced rate of fuel consumption. The experimental analysis is performed with the help of a large database. Artificial Neural Network as the simulation tool receives readings from the engine operating parameters and results in controlled emission and fuel consumption.
6) Fault diagnosis in internal combustion engines using Extension Neural Networks: Effective and automated technique to find fault of ICE by emitting sound signal of ICE is the main objective. Data gathering from the sound emitted and relies only on emitted sound of ICE at idle position. Emitted sound wavelets are

decomposed as the extraction tool. Extension Neural Network is used as the fault classification from the extracted data.

7) Robustness evaluation of real-time fuzzy logic control of VGT and EGR on diesel engine: A robust evaluation of fuzzy logic controller is done in this work. Evaluation in-cludes a sudden air leak test and a mechanical efficiency deterioration test. Sudden air leak test: to test whether Fuzzy logic controller can make necessary adjustments for inlet pressure and flow loss by air leak. Deterioration test: to find whether the fuzzy logic controller can adapt to change of turbo mechanical efficiency. Result: Fuzzy logic controller can make adjustments in both the tests. AVL-BOOST is simulation tool with advanced models for accurately predicting engine performance.

III. Phases Of Diesel Engine Combustion

Four phases in Combustion are:
Ignition Delay Phase: Ignition delay period is the time interval from the point of beginning of the injection to the point of the ignition of fuel.

Pre-mixed Burning Phase: The heat transfer to the adjacent area increases rapidly, when the ignition of fuel starts. It results in rapid combustion of majority of the injected fuel. This phase is the typical characteristic of a diesel engine combustion process and is the prominent phase in direct-injection type engines.
Diffusion Controlled Burning Phase: The pre-mixed burning phase changes the AFR. Hence the amount of air available for combustion is mainly governed by this diffusion controlled burning phase. And the process of mixing air & fuel (AFR) is controlled by swirl and turbulence. This phase may also include the burning of fuel deposited on the wall, which is drawn off by subsequent air movement.

Combustion Tail Phase: As a continuation of the diffusion controlled burning phase the heat release will continue at a lower rate and finally reduces to zero somewhere in the expansion stroke. Because of the decrease in pressure & temperature in the expansion stroke, chemical reaction slows down in this phase, which results in reduce the heat release.

IV. Genetic Algorithm

Genetic algorithm (GA) is usually used to produce a reliably best quality solution to optimization and search problems. GA is meta heuristic, which is developed by the process of natural selection. It is one among the best ways to find a problem solution for which limited information is known. Using the techniques such as inheritance, mutation, selection and crossover, genetic algorithm generates solution for optimization problems. It works well in any search space since its a very general algorithm.

V. Methodology & Design

As a new level of optimization and as a technique of finding an effective and efficient way for running a diesel engine, certain factors viz. NOx, PM, AFR, EGR and PIP are observed and analyzed. The analyzed factors are observed under the transient condition of diesel engine. The observed values are tabled against the pre-decided values on the x axis. These tabled values are used to find the Lagranges interpolation equation using an online Lagrange's interpolation polynomial calculator. As a result, a polynomial is generated and this polynomial is used in the Genetic Algorithm for optimization. Genetic Algorithm is performed using the tool RStudio and the optimized values are generated for the tabular values. These optimized values are the key of the research study here and further analysis is made according to that.

The work is extended to a data base which constitutes various features like NOx, PM, AFR, EGR and PIP. Of these features it is observed that NOx form the core feature which helps in identifying the Exhaust gas performance. Next to the NOx, it is the Peak pressure and EGR maintained influences the exhaust rates. Thus the Model is designed to consider NOx as one important parameter, followed with summation of PM, EGR and PIP as one more parameter. The features like NOx, PM, EGR and PIP are considered by certain weight value based on Empirical analysis which is added to the NOx to make a Wt. These two features like PM and Wt are taken as input to Genetic Algorithm in identifying the possible best combination of Exhaust gas who is likely to be associated with the Diesel Engine. The values are generated by properly considering different probabilities for Mutation and Cross over which forms the basis for Genetic Algorithm. Once the best possible Exhaust Gas parameters are obtained, the data may be used to measure the best performance of Diesel engine. A sample data is considered for evaluation.

DI		IDI	
AFR	NOx	AFR	NOx
0.1	80	0.1	200
0.15	100	0.15	220
0.2	200	0.2	250

0.25	350	0.25	300

PM-N O_x (2-valve engine)

PM	NOx
0.1	22.4
0.15	18.4
0.2	15.6
0.25	12.6
0.3	10.4
0.35	8.2
0.4	7,

PM-N O_x (4-valve engine)

PM	NOx
0.03	21.6
0.04	18
0.05	15
0.052	12.6
0.053	10.6
0.055	8.6
0.058	7.8
.1	7

PM-PIP (4-valve engine)

PM	PIP
0.1	1675
0.2	1500
0.3	1275
0.4	1075
0.5	900
0.6	675
0.7	475

EGR-NOx (4-valve engine)

EGR	NOx
0	3
10	1.5
20	.7
30	.3
40	.05
50	.05
60	0

VI. Fitting Function In GA Using Lagranges Equation

To identify the optimal AFR for the maximum NOx emission in exhaust gas, fitting function for the DI engine has to be calculated. The process will be repeated for different data sets to get an optimal value in each of the Data sets.

To calculate the Fitting function, a Lagrange fitting function polynomial is used. In this work the data sets referring to PM-NOx with reference to 2 & 4 valve engines are considered for proof of concept.

PM-N O_x (2-valve engine)

PM	NO_x1	NO_x2	NO_x3	NO_x4
0.1	22.4	22.6	22.8	22
0.15	18.4	18	18.2	17
0.2	15.6	14.5	15.9	10
0.25	12.6	7.8	14.2	25
0.3	10.4	8.2	10.8	21
0.35	8.2	8	10.4	2
0.4	7.2	7.6	10.3	23
0.45	6.2	7.4	9.9	13
0.5	5.5	7.2	9.6	11
0.55	5.4	6.9	8.8	16

PM-N O_x (4-valve engine)

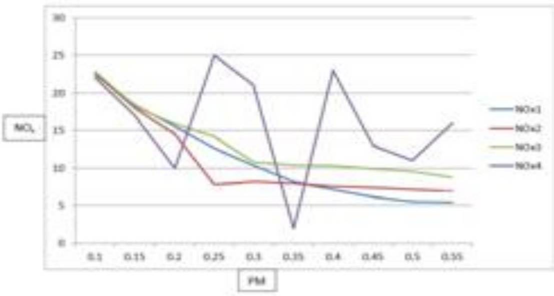
PM	NO_x1	NO_x2	NO_x3	NO_x4
0.03	21.6	21.9	20.5	23
0.04	18	21.5	17.6	12
0.05	15	20.1	14.6	7

0.052	12.6	15.6	11.3	9
0.053	10.6	10.2	9.6	16
0.055	8.6	7.6	7	20
0.058	7.8	7.4	6.5	17
0.1	7	7.2	5.1	25
0.15	6	6.6	5.5	3
0.2	5	6.2	5.6	5

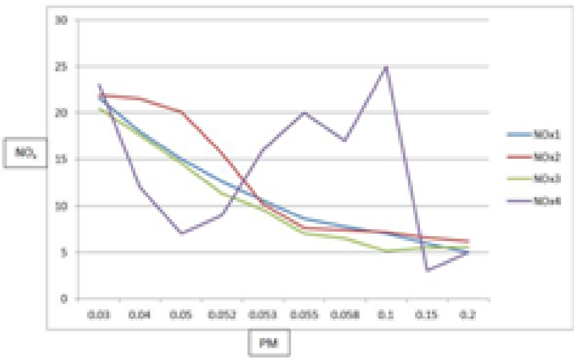
VII. Graphical Analysis

PM-NO_x (2-valve engine) Fitting function = equation

```
f(x)=-2.57496*10^8*x^9+7.80698*10^8*x^8-
1.02658*10^9*x^7+7.66427*10^8*x^6-
3.5692*10^8*x^5+1.07124*10^8*x^4-
2.06318*10^7*x^3+2.44695*10^6*x^2-161410*x+4511.4
```



PM-NO_x(4-valve engine)



Best fit by Feature selection

To identify the best possible values in combinations of PM and NOx, the work is extended to consider a data set in terms of PM, Peak pressure obtained, NOX and EGR values of Diesel Exhaust. The Peak pressure obtained, NOX and EGR values are represented in form of weight(Based on Literature Study), using GA for feature selection, maximum best fit combination of Wt. is calculate to generate the best feature set for optimal performance of Diesel engine.

PM	Peak	NOx	EGR	Wt
0.01	3000	0.05	40	3.45
0.01	2300	0.3	30	2.9
0.02	2050	0.7	20	2.95
0.03	1950	1.5	10	3.45
0.05	1800	3	0	2.1
0.1	1675	5	0	2.1
0.2	1500	6	0	2.1
0.3	1275	7.4	0	2.01
0.4	1075	8.6	0	1.93
0.5	900	10.6	0	1.96
0.6	675	12	0	1.875
0.7	500	14.8	0	1.98

An object representing generation 1 in a genetic algorithm.
Population size: 12
Mutation probability: 0.001
Crossover probability: 0.75
Fitness distribution:

Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
14.85	16.14	16.47	16.55	17.38	17.80

An object representing generation 100 in a genetic algorithm
Population size: 12
Mutation probability: 0.001
Crossover probability: 0.75
Fitness distribution:

Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
14.95	16.57	16.84	16.78	17.59	17.87

Thus the best fit is 17.89 ie the values (Wt) whose sum is equal to 17.87 in the exhaust will give a better performance of the Diesel engine.

VIII. Conclusion

It has always been a keen focus in the research of experts, the control of Air-Fuel Ratio (AFR) in transient operating conditions of engine. As an extension of the work, by considering the other factors in emission gas viz. Nitrogen Oxide (NOx), Particulate Matters (PM) and the standard factors like Peak Injection Pressure (PIP), Exhaust Gas Recirculation (EGR) also paves a new conclusion for the better efficient engine.

For a standard value of PM, 0.1000219 g/kWh NOx is the safest amount in emission in 2-valve engine, where as in 4-valve engine the NOx slightly increases to 0.1374515 g/kWh. Likewise for a unit value of PM, 0.1056914 bars of peak injection pressure is evaluated as the safest amount in emission using Genetic Algorithm as well as for the standard value of EGR, 0.176577 g/kWh NOx is the safest amount in emission. Furthermore the most possible weightage of each factors together in the emission gas is also tried using GA for Feature selection.

IX. Future Work

To work on various interpolation techniques like cubic spline and other techniques and to identify the suitability of the fitting function with respect to technique used. To work on different parameters like combustion chamber design, injection system in improving the performance of Diesel engine. The relevance of Neural Networks in improving the performance of Diesel engine may also be studied.

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