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Full Length Article

An unprecedented multi attribute decision making using graph theory matrix approach

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ABSTRACT

A frame work for investigating the best combination of functioning parameters on a variable compression ratio diesel engine is proposed in the present study using a multi attribute optimization methodology, Graph Theory Matrix Approach. The functioning parameters, attributes, sub attributes and functioning variables of sub attributes are chosen based on expert's opinion and literature review. The directed graphs are developed for attributes and sub attributes. The 'Parameter Index' was calculated for all trials to choose the best trial. The experimental results are verified with the theoretical data. Functioning parameters with combination of compression ratio of 17, fuel injection pressure of 20 N/mm^2 and fuel injection pressure of 21°bTDC was found to be best. The proposed method allows the decision maker to systematically and logically find the best combination of functioning parameters.

1. Introduction

The engine functioning parameters like compression ratio, fuel injection pressure, fuel injection timing, load etc., play a vital role in the performance of the engine to increase the efficiency and reduce exhaust gas emissions. With the stringent norms laid by the pollution regulatory bodies around the world in reducing the admissible limits on exhaust emissions, the optimization of on-board engine management has become a difficult task to comply with emission regulations and fuel economy.

Multi-attribute optimization has been applied in many fields of science and technology where optimal decisions need to be taken with trade-offs between two or more conflicting objectives. Most of the tribulations in engineering are multi attribute optimizations. Furthermore, minimizing or maximizing all attributes simultaneously is very complicated when there is trade-off relationship between objective functions. A multi-attribute optimization problems can be defined in a general sense as given in Eq. (1), [11]

$$\min(\bar{f})(\bar{x}) = \{f_1(\vec{x}), f_2(\vec{x}), \ldots f_x(\vec{x})\}^T x \in X = \{\bar{x} \in R^n / g_i(\bar{x}) \leqslant 0(i = 1,2,3,\ldots m\} f_i(\vec{x}) = f_i(x_1, x_2, \ldots x_n), i = 1,2,3,\ldots k g_j(\vec{x}) = g_j(x_1, x_2, \ldots x_n), j = 1,2,3,\ldots m \quad (1)$$

where, χ is the vector design variables that maximize or minimize 'k' objective functions with 'm' constraints and, on an engine, maximizing the performance, minimizing the fuel consumption and exhaust emissions is the objective. Bose et al. [3] adapted multi attribute optimization on a timed injection system with 31.74% enhancement in brake thermal efficiency and the predicted optimum combination improved volumetric efficiency by 24.04%. Karnwal et al. [15] adapted Taguchi based grey relational analysis method to optimize the performance parameters of a diesel engine. The optimum factor level and optimum multiple performance characteristics were determined by considering four factors at three levels. An L9 orthogonal array was used for collecting data from responses. The grey relational analysis resulted that the combination of 30% biodiesel, 14 compression ratio, 250 bar injection pressure and 20 degree injection timing produces the maximum performance with minimum emissions from the engine.

Yuvarajan et al. [31] applied the L9 orthogonal array based on Taguchi method and conducted experiments adapting design of experiments. Three parameters like oxygen content of additives, blends and injection timing were considered and grey relational analysis was carried out with three levels and three factors. It was found that the blend of 10% Diglyme-diesel, 21 degree injection timing was the optimum combination for simultaneous reduction of NOx and smoke. Deb et al. [5] used Pareto based genetic algorithm to optimize the performance parameters where in, to find the optimum load condition on a diesel engine. Rajesh kumar et al. [18] considered exhaust gas recirculation, fuel injection timing and fuel blends as factors to measure the responses like

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Nomenclature

AF	air fuel ratio	GTMA	graph theory matrix approach
AFM	air fuel mixing	HC	hydro carbon
AO	amount of oxygen	IP	injection pressure
bTDC	before top dead centre	IT	injection timing
BTE	brake thermal efficiency	L	load
BSFC	brake specific fuel consumption	MAF	mixing of air fuel
CO	carbon monoxide	MF	mass of fuel
CR	compression ratio	ON	oxidation of nitrogen
CT	combustion temperature	ppm	parts per million
FP	fuel properties	ON	oxidation of nitrogen
FS	flame speed	S	speed

NOx, HC, CO, BTE using Response surface methodology. Desirability approach with an objective to minimize NOx, smoke and BSFC with maximum BTE was used. The results indicated 99% confidence level with 5% error in prediction. The combination of 25 degree fuel injection timing at 30% exhaust gas recirculation was found to be optimum for that engine, Premkarthik [17]. Dhingra et al. [7] developed mathematical models to optimize functioning parameters on a diesel engine fueled with jatropha biodiesel using genetic non-dominated sorting algorithm-II. Central composite design was used to design the experiments. Regression equations were predicted from analysis of variance and the genetic algorithm was developed in MATLAB. The study concluded that there was significant change in values of performance parameter by genetic algorithm in comparison to response surface methodology. Sivaramakrishnan and Ravikumar [27] investigated the effect of varying compression ratio and blends of biodiesel on a diesel engine and optimized the functioning parameters using desirability approach of response surface methodology for better performance and lower emissions. Furthermore, the significant parameters which influence the performance characteristics were also found. The combination of 17.9 compression ratio and B10 diesel blend was found to be optimum and a high desirability of 0.97 was obtained, Sarma et al. [25]. Saravanan et al. [24] and Teah et al. [28] adapted multi response optimization in controlling NOx emission on a diesel engine with fuel injection timing, percentage in EGR and fuel injection pressure as levels and NOx, smoke concentration and brake fuel conversion efficiency were taken as response variables. Multi response signal to noise ratio was employed to get the optimum combination. It was found from ANOVA results that fuel injection pressure has more contribution in reducing NOx. Roy et al. [22] studied the challenges in optimization of BSFC-NOx-PM on a common rail direct injection diesel engine. L16 orthogonal array using Taguchi method was employed for experimental design and Grey-Fuzzy Grade with S-N ratio was taken as performance index. An algorithm with the combination of grey relational analysis and fuzzy logic was proposed for optimization of performance and emission characteristics. The most influencing factor was exhaust gas recirculation and the combination of 4 kg load, 700 bar fuel injection pressure at 20% exhaust gas recirculation was optimum.

Jadhav and Tandale [12] conducted experimental study on a diesel engine using Mangifera indica biodiesel as fuel. Taguchi grey relational analysis was adapted to optimize performance parameters. L25 orthogonal array was applied for experimental design for six input parameters, seven output variables and five levels. Signal to noise ratio and grey relational grade was generated to obtain the optimum combination of functioning parameters. Gul et al. [10] aimed to optimize parameters on a turbo charged diesel engine using Grey-taguchi method. The input parameters considered in their study were fuel blends, speed and load. L9 orthogonal array was used for design of experiments. The optimization technique was adapted to maximize engine torque, brake power and heat release with minimization of brake specific fuel consumption. Furthermore, confirmatory test was performed to validate the results using artificial neural network in MATLAB.

Etghani et al. [8] adapted artificial neural network model for optimizing performance parameters like biodiesel blend and speed. Dawody and Bhatti [4] investigated experimentally and theoretically the combustion, performance and emission parameters using soybean methyl ester blends at various loads and compression ratios. Rosenbrok method was adapted for multi-parametric optimization of functioning parameters.

From the above literature survey, engine performance parameter optimization studies have often unraveled multiple attributes that need to be addressed simultaneously. The multiple attributes are often contradictory where in, efforts to optimize one attribute would lead to a compromise of the other desired objectives. Thus, a multi-attribute decision making problem provide a challenge to establish a set of solutions that would be acceptable from view point of the contradictory objectives.

In this paper, Graph theory matrix approach (GTMA) is adapted to find the best combination of functioning parameters (Compression ratio, fuel injection timing and fuel injection pressure) on a single cylinder variable compression ratio diesel engine to attain better performance and reduced exhaust gas emissions. The compression ratios of 17, 18 and 19, fuel injection pressures of 20 N/mm^2, 22 N/mm^2 and 24 N/mm^2 and fuel injection timings of 21°bTDC, 23°bTDC and 25°bTDC are considered in this study. Section 2 of this paper describes the experimental materials and methods. The best combination of functioning parameters found using the experimental results is compared with the theoretical data obtained from the expert's opinion. To the knowledge of the authors, this represents the first attempt in the literature to apply GTMA to solve a multi attribute decision making problem for selection of best combination of functioning parameters on a diesel engine.

2. Experimental materials and methods

2.1. Experimental setup

The test rig consists of a single cylinder four stroke variable compression ratio diesel engine. The specifications of the engine are shown in Table 1. An eddy current dynamometer is coupled to the engine to apply load, which is measured by a strain gauge type load cell. Different sensors and instruments are coordinated with data acquisition system for online data collection of air and