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An Experimental Investigation on Single Cylinder Piston Type Compressed Air Engine using Taguchi Technique

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Abstract: This study presents the investigation on piston type compressed air engine for different loading condition on a test bench. A conventional 100CC four stroke internal combustion engine was modified to a two stroke compressed air engine and engine speed and mass flow rate has been examined with different loading condition by use of design of experiments. For design of experiments L_9taguchi method is used for experimentation and parametric analysis.
Keywords: Compressed air engine, piston type, Design of experiment, different loading condition

I. INTRODUCTION

A wide variety of renewable source technologies are needed to meet the challenges of sustainable energy development[1].The air pollution has become a severe problem that influences the survival and development of humankind [2]. The burning of fossil fuels has been recognized as the main cause of serious environmental issues, including the greenhouse effect, ozone layer depletion and acid rain [3]. Renewable fuels, such as wind, solar, compressed air, etc., are used as obvious solutions [4]. With respect to environmental protection, Shafiee and Topal believe that oil and gas reserves may be diminished in 2042; this enhances the competition in the field of renewable energy vehicles [5].

Because transportation accounts for a major share of global primary energy demand[6] and exhaust from internal combustion (IC) engines contributes largely to carbon emissions,[7] it is an urgent need to find alternative energy sources for engines with clean and environmentally friendly energy carrier. Some kinds of zero emission vehicles have been explored extensively. The battery electric vehicles offer high energy efficiency, allow energy diversification, enable load equalization of the power system, and operate quietly;[8] however, the heavy metal pollution, high initial cost, limited battery life, and long charging time have limited their development and application [9].

The superiority of hydrogen energy carrier is of high energy density; nevertheless, the lack of safety, energy efficient, and storage difficulties currently prevent the development of hydrogen-powered fuel cell vehicles [10]. Compressed air is a potential clean and environmental-friendly energy carrier. When the pressure and temperature of the compressed air are 30MPa and 300 K, respectively, the energy density is close to that of the lithium battery[11] Furthermore, the air tank can be completely refilled in a much less time than batteries,[12] and the price of compressed air engine (CAE) is relatively cheaper [13]. The feasibility of compressed air as a vehicular energy source has been researched. CY Huang et al.[14] created CAE by modified conventional IC engines. Motor Development International (MDI)[15] have developed airpod for transportation vehicle. A small air turbine with vaned-type rotor has been developed by BR Singh and O Singh.[16] A single screw expander working with compressed air was developed by W He et al.[17] And the influence of intake pressure on the performance was obtained. L Liu and X Yu[18] analyzed the feasibility and outlook of compressed air vehicles by thermodynamic analysis and experiment data. H Ibrahim et al.[19] introduced different energy storage techniques and their field of application. The energy stored in compressed air could be divided into transmission energy and expansion energy.

The higher the air pressure, the larger the ratio of expansion energy.[20] The temperature of the compressed air decreases when the compressed air energy converts into mechanical work through CAE.This study focuses on the experimental investigation of a compressed air engine to be installed in vehicles as a main power system. These results can be used to evaluate practical applications of compressed air engines and possible solutions in improving the efficiency and extending the duration time. Selecting piston type engine for compressed air operation has the advantages of easy adapting to conventional Internal Combustion (IC) Engines in the consideration of further use of vehicles with zero pollution.

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II. EXPERIMENTAL METHOD

4-stroke internal combustion engine in not suitable for CAV because CAV completes its cycle in 2-stroke so modification is required to 4-S to 2-S engine, for present study, focused on change in valve timing mechanism .Cam profiling represents basic idea of converting the four strokes engine to the two strokes engine, here Fig. 1 and 2, shows Pictorial view of the Conventional cam and modified cam. Fig. 3 and 4 shows the Valve timing diagram for conventional cam and modified cam and Fig.5and 6 de-scribes the dimension and Actual view of cam. For replacing the original cylinder head, a new set two flank cams has been designed for operating the inlet and exhaust valves of the modified engine. Both the exhaust and inlet cams are symmetric about the center line of the cam shaft. The cams are made of mild steels. The cam shaft originally had two cams with one lobe each which were mutually perpendicular to each other. The crank rotates due to the movement of the piston; the camshaft is attached with the crankshaft by a timing chain or a timing belt. And as the crank rotates the camshaft also rotates and hence the timing of the valves is managed. In the traditional camshaft the inlet and exhaust valve both functions[21]. Table (1) lists the specification of the 4-stroke IC engine, which was modified in the current study as a single cylinder piston type compressed air engine.

Table 1: Engine Specifications for 4-stroke engine

Parameter	Honda Sleek
Engine displacement	97.2 cc
Engine type	air cooled ,4 stroke
Number of cylinder	1
Valves per cylinder	2
Max power	7.0 ps @8000 rpm
Max torque	7.5 nm
Bore*Stroke	50 mm*49.5 mm
Fuel type	petrol
Starter	kick
Number of speed gear	4

Fig.1 Pictorial view of the Conventional cam

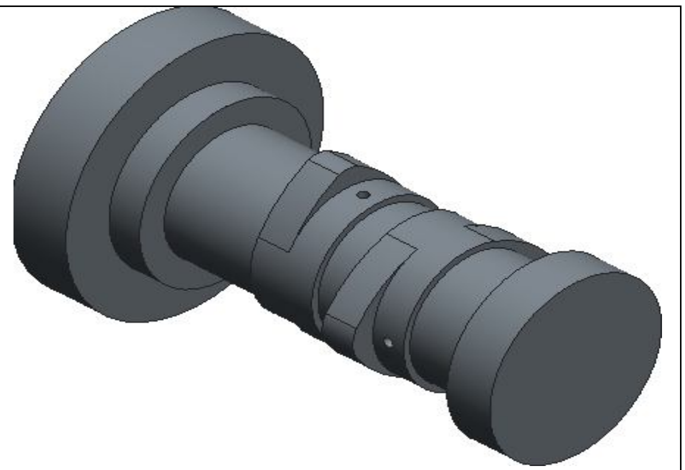

Fig.2 Pictorial view of the Modified cam

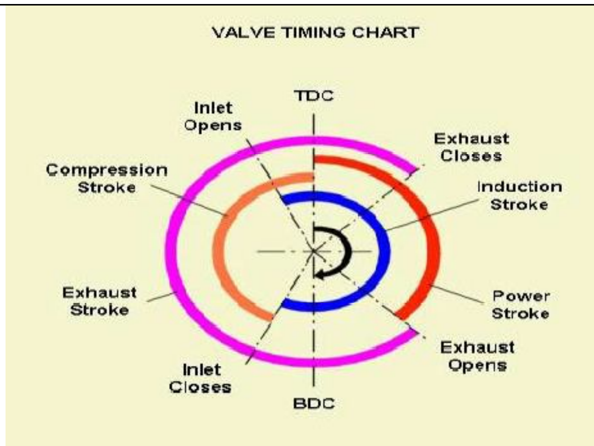

Fig.3 Valve timing diagram of the Conventional cam

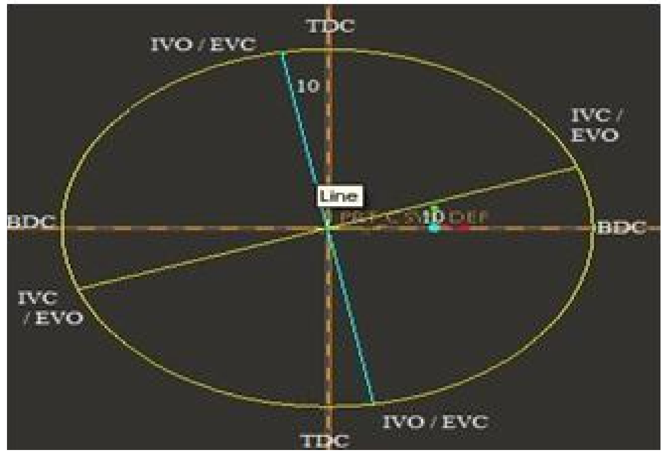

Fig.4 Valve timing diagram of the Modified cam

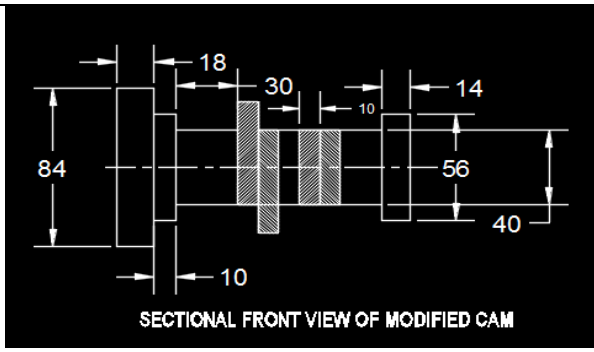

Fig.5 Sectional front view of Modified cam

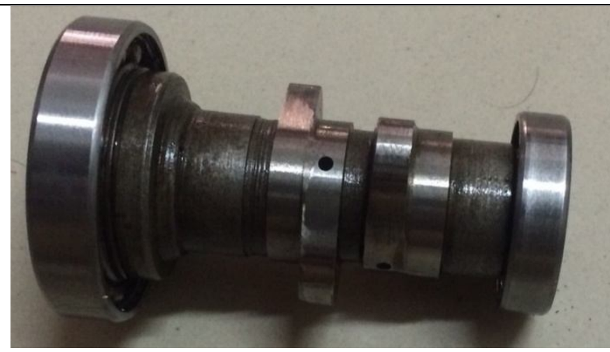

Fig.6 Actual view of the Modified cam

Fig.7 Experimental set up for single cylinder piston type air engine

Before the experiments, the 97.2 cc Internal Combustion engine was modified and connected to a compressed air tank. The cam profile was modified to be conjugate to change the engine from 4-stroke to 2-stroke operation. After the engine was installed, the intake and exhaust valves were examined for possible leakage under high-air-pressure operation. The leakage of the intake valve was thus close to the flow rate in the experiments, and it seriously affected the performance of the compressed air engine. The exhaust valve leakage was examined when the engine was locked in the intake process, and no leakage was observed. The experimental set up for 4 stroke single cylinder air engine is shown in Fig.7.

III. EXPERIMENTAL DESIGN

The objective of Design of experiment is to determine the variables in a process that are the critical parameters and their target values [22]. On the basis of selected parameters, experimental design is carried out. The Taguchi experimental design is done for L_9 OA for two parameters which are air pressure and different load condition.

A. *Process parameters*

Process parameters are one of the most important factors for any experimental work. The process parameters in present case are selected based on various literature reviews. The different levels for process parameters are shown in table 2below.

Table 2 Levels for process parameters

Factor	Symbol	Unit	-1	0	+1
AIR PRESSURE	p	kg/cm^2	4	5	6
LOAD	L	KG	1.5	2	2.5

B. *Output Process Parameters*

In present study parameters taken as a response are Speed and Mass flow rate.

IV. RESULT AND DISCUSSION

For load testing of air engine, it is connected with the rope break dynamometer with brake drum, spring balance, belt and holding frame. During testing, the rotational speed and mass flow rate were measured to determine effective parameters of air pressure with loading condition by using taguchi design of experiments L_9

A. *Taguchi Analysis of rotational speed of air engine versus pressure, load*

The response tables 4 and 5 show the average of the selected characteristic for each level of the factors. The response tables include ranks based on Delta statistics, which compare the relative magnitude of effects. The Delta statistic is the highest average for each factor minus the lowest average for each factor. Ranks are assigned based on Delta values; rank 1 is assigned to the highest Delta value, rank 2 to the second highest Delta value, and so on. The main effects plot provides a graph of the averages in the response table.

Table 3 Experimental Readings For Taguchi L_9 Orthogonal Array (Rotational Speed)

Pressure	Load	Speed 1	Speed 2	SNRA1	MEAN1
4	1.5	487	490	53.7772	488.5
4	2.0	475	475	53.5339	475.0
4	2.5	460	462	53.2740	461.0
5	1.5	506	510	54.1171	508.0
5	2.0	490	495	53.8478	492.5
5	2.5	482	480	53.6428	481.0
6	1.5	546	545	54.7359	545.5
6	2.0	510	512	54.1684	511.0
6	2.5	456	460	53.2171	458.0

Table 4 Response Table for Signal to Noise Ratios (Larger is better)

Level	pressure	load
1	53.53	54.21
2	53.87	53.85
3	54.04	53.38
Delta	0.51	0.83
Rank	2	1

Table 5 Response Table for Means

Level	pressure	load
1	474.8	514.0
2	493.8	492.8
3	504.8	466.7
Delta	30.0	47.3
Rank	2	1

Look at the response tables and main effects plots for the signal-to-noise (S/N) ratios to see which factors have the greatest effect on S/N ratio, which in this parameter for larger-is-best.as per the above table ,the factor with the biggest impact on the S/N ratio is load (delta = 0.83,Rank =1),and also it can be seen that at the response table and main effect plots for S/N ratio , for 2 kg and 2.5 kg of load have almost the same average S/N ratio (53.85 and 53.38)

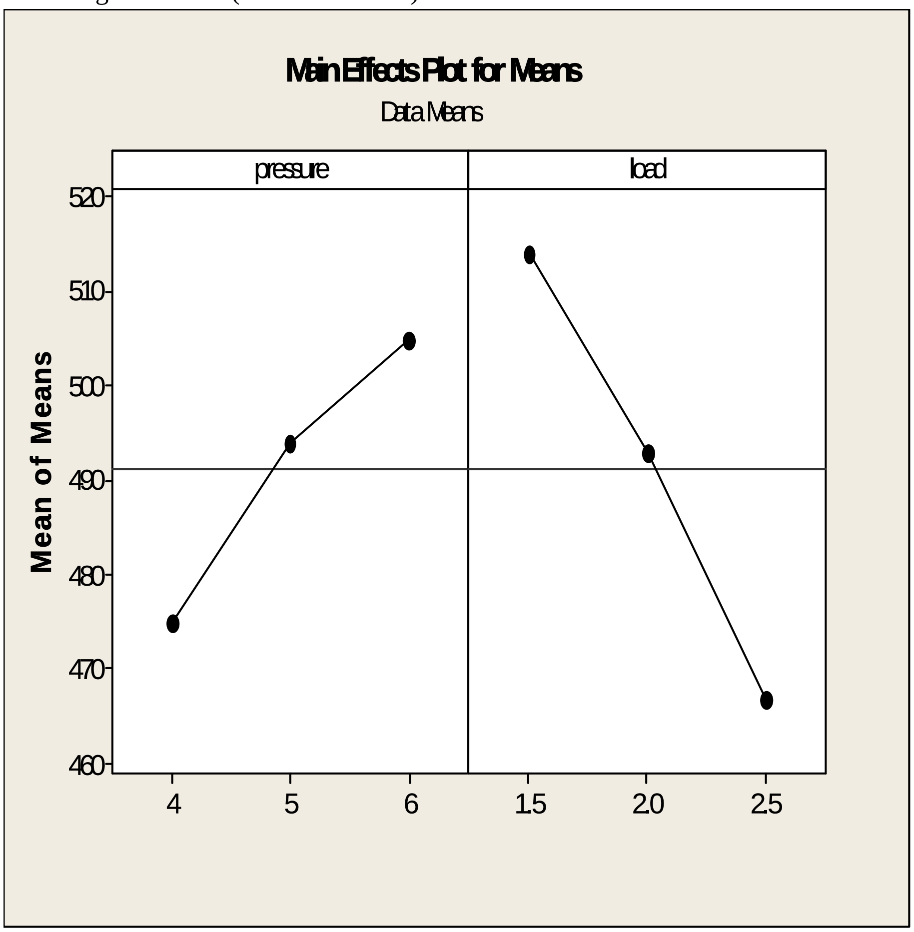

Fig.8 Main Effect Plot for Means (Speed)

Main effects plots are obtained by using trial version on MINITAB 16.0 software of design and analysis. By importing all the data in software response diagrams can be developed. From the response diagram in fig. 8and main effects plot S/N ratio fig.10**,** it can be seen that at 6 bar pressure achieved maximum means of speed and it can be also seen that at lower value of load i.e 1.5 kg load got maximum means of speed.

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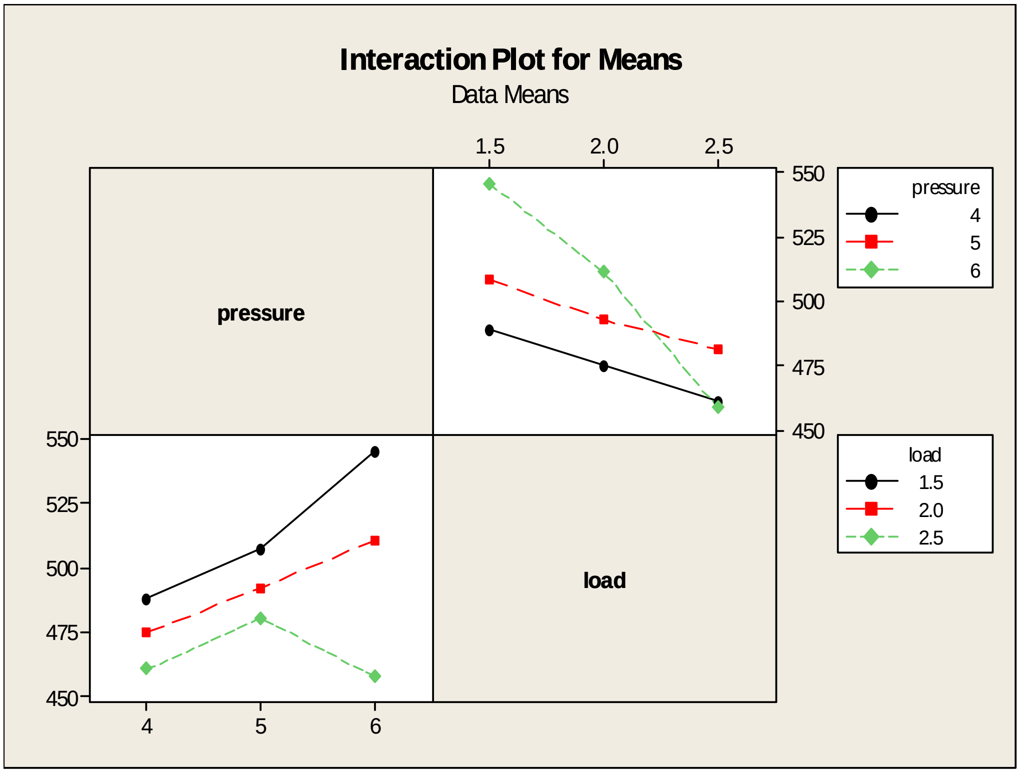

Fig.9 Interaction plot for Means (Speed)

As shown Fig.9 and Fig.11 ,this interaction plot the lines are not parallel. this interaction effect indicates that the relationship between load and speed depends on the value of the pressure. for example, as per the plot at 1.5kg load and 6 bar pressure this combination is associated with the highest mean speed.

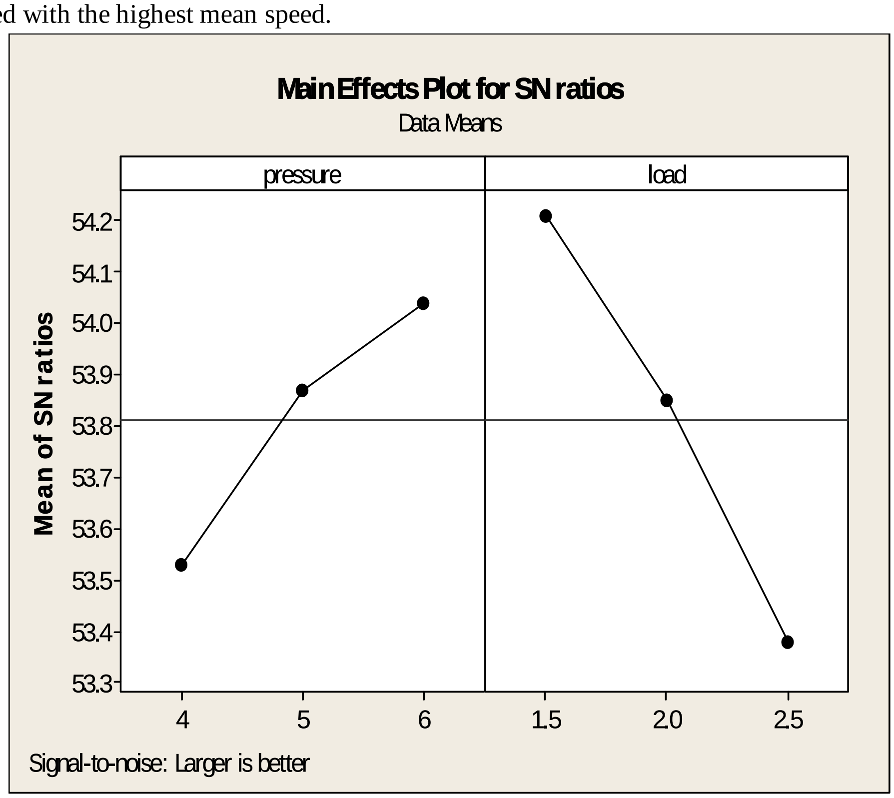

Fig.10 Main Effect plot for SN ratio (Speed)

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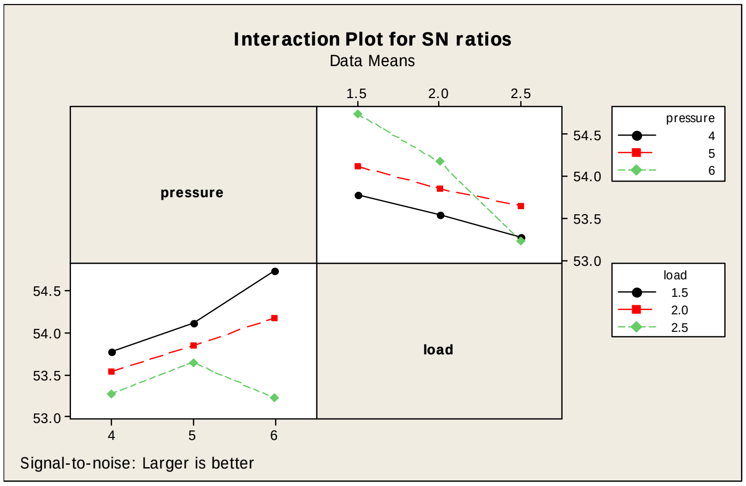

Fig.11 Interaction plot for SN ratio (Speed)

B. Taguchi Analysis of Mass flow rate of air engine versus pressure, load

Table 6.Response Table for Signal to Noise Ratios (Smaller is better)

Level	pressure	load
1	8.536	10.282
2	8.867	8.837
3	9.347	7.632
Delta	0.810	2.650
Rank	2	1

Table 7. Response Table for Means

Level	pressure	load
1	0.3750	0.3067
2	0.3633	0.3617
3	0.3450	0.4150
Delta	0.0300	0.1083
Rank	2	1

Table 8,shows the experimental readings for Mass flow rate based on the analysis, from above two tables as per table no 6 and 7 it can be seen that for mass flow rate ,the factor with the biggest impact on S/N ratio is load (delta = 2.650,Rank =1) so load is given more impact for both the parameters i.e for speed and mass flow rate.

Table 8 Experimental Readings For Taguchi L_9 Orthogonal Array (Mass Flow Rate)

pressure	load	mfr 1	mfr 2	SNRA2	MEAN2
4	1.5	0.35	0.32	9.4904	0.335
4	2.0	0.40	0.37	8.2842	0.385
4	2.5	0.38	0.43	7.8344	0.405
5	1.5	0.32	0.29	10.3035	0.305
5	2.0	0.37	0.35	8.8706	0.360
5	2.5	0.41	0.44	7.4268	0.425
6	1.5	0.29	0.27	11.0513	0.280
6	2.0	0.36	0.32	9.3554	0.340
6	2.5	0.43	0.40	7.6334	0.415

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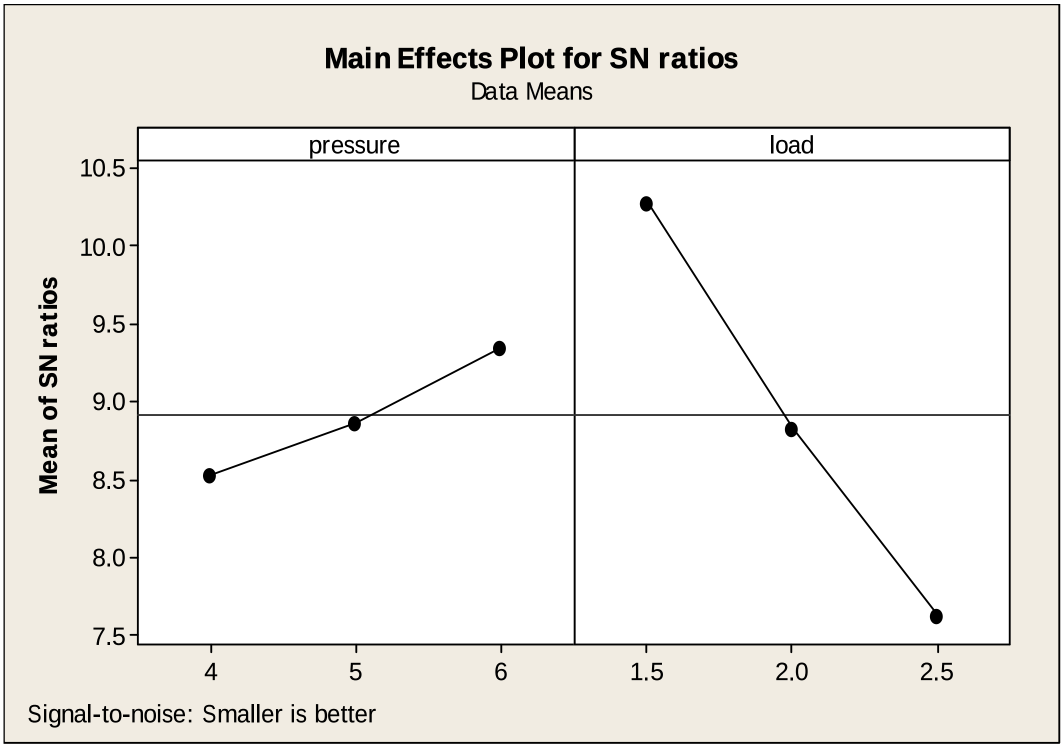

Fig.12 Main Effect plot for SN ratio (Mass Flow rate)

From the Figure 12 and figure 14,It can be seen that at 4 bar pressure achieved minimum means of mass flow rate and it can be also seen that at lower value of means of S/N ratio for minimum mass flow rate i.e below 7.5 is also less as compared with pressure means of S/N ratio.

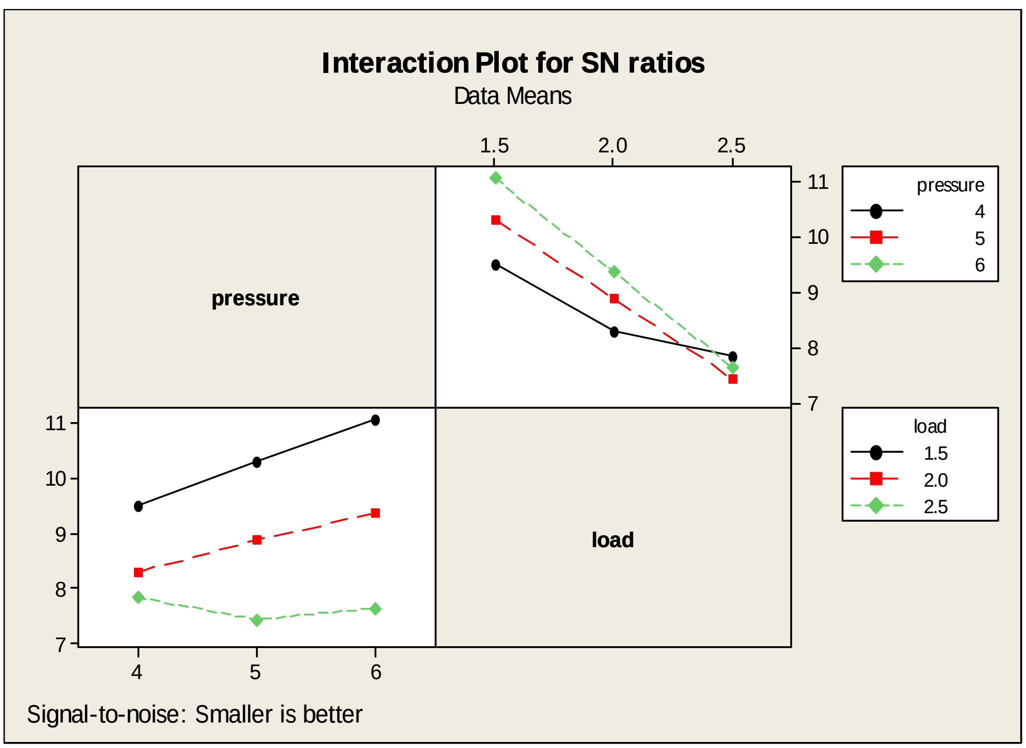

Fig.13Interaction plot for SN ratio (Mass Flow rate)

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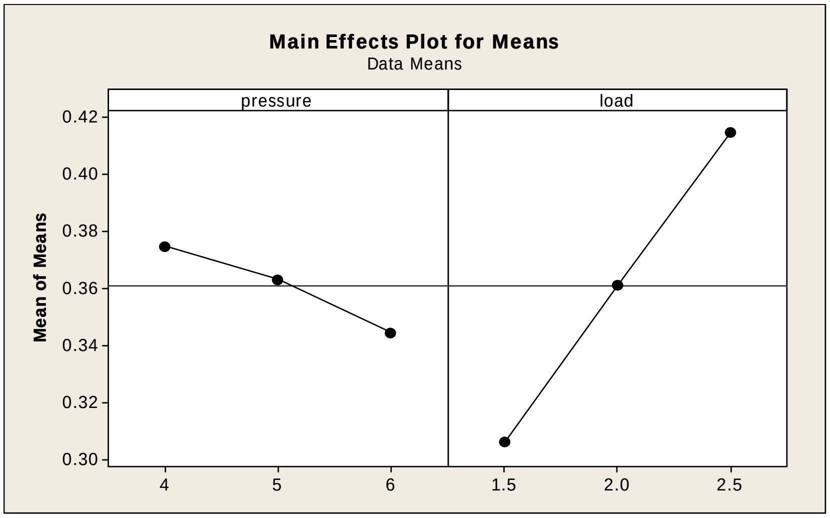

Fig.14 Main Effect of plot for means (Mass Flow rate)

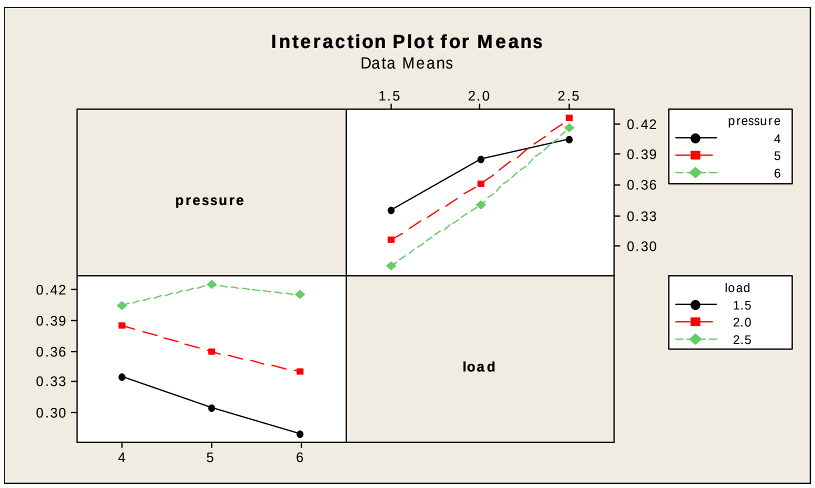

Fig.15 Interaction plot for Means (Mass Flow rate)

Fig.13 and fig.15, shows that interaction effect between load and mass flow rate depends on the value of the pressure. for example, as per the plot at 2.5kg load and 5 bar pressure this combination is associated with the lowest mean mass flow rate.

C. Contour Plot Analysis

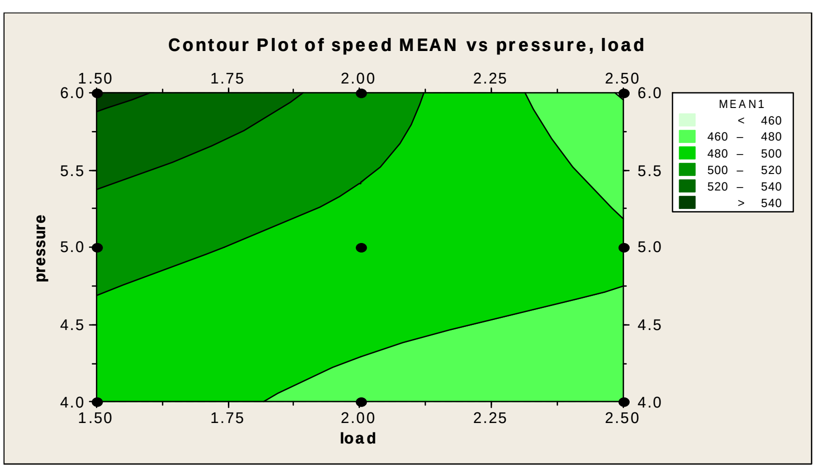

Fig.16Contour plot of Speed Mean vs Pressure & load

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Fig.16 shows how pressure (y) and load (x) affect the contours of a speed. The darker regions indicate higher speed. The contour levels reveal a peak in the vicinity of 1.5 kg load and 6 bar pressure. Quality scores in this peak region are greater than 540 rpm.

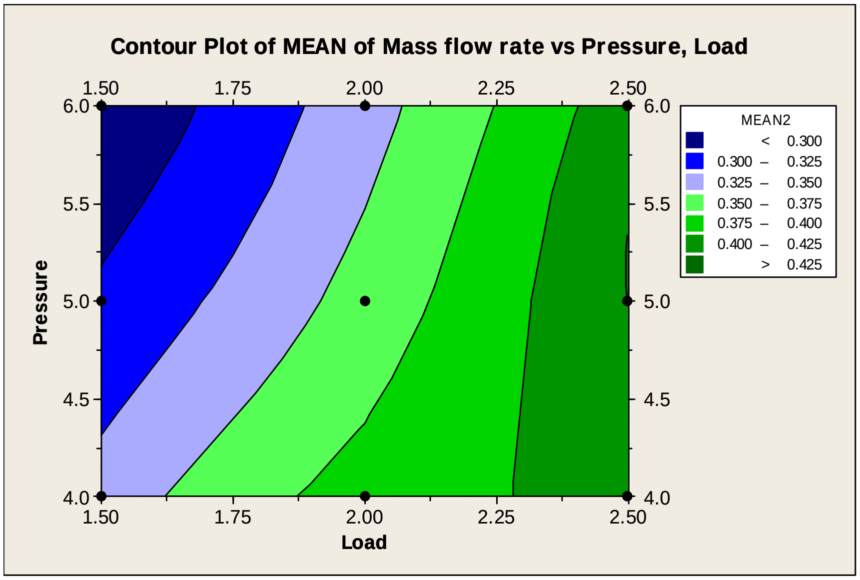

Fig.17Contour plot of Mass Flow rate Mean vs Pressure & load

Fig.17 shows how pressure (y) and load (x) affect the contours of a mass flow rate. Figure depicts at 6 bar pressure with load 1.5 kg ,mass flow rate is less than 0.3 kg/min. so this combination of the parameters gives minimum mass flow rate. as load increases beyond 2.25 mass flow rate shoots up based on green darken region.

V.CONCLUSIONS

Present work based on DOE L_9 three different values of pressure viz; 4bar ,5bar and 6 bar and three different values of load i.e 1.5 kg ,2kg and 2.5kg are experimentally investigated on air engine test rig i.e modified from the existing 4 stroke internal combustion engine. based on experimental observation, graphs are plotted and results are critically discussed for the different responses.. From the results that for make different relations with responses, following conclusions have been observed:

Load is given more impact for both the parameters i.e for speed and mass flow rate as compare to pressure. At 1.5kg load and 6 bar pressure this combination is associated with the highest mean speed. At 2.5kg load and 5 bar pressure this combination is associated with the lowest mean mass flow rate.

The contour levels reveal a peak in the vicinity of 1.5 kg load and 6 bar pressure. Quality scores in this peak region are greater than 540 rpm.At 6 bar pressure with load 1.5 kg ,mass flow rate is less than 0.3 kg/min. So this combination of the parameters gives minimum mass flow rate. As load increases beyond 2.25 mass flow rate shoots up based on green darken region.

In this study, the taguchi method gives effective methodology in order to find out the effective performance output for any machines.

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