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EXPERIMENTAL INVESTIGATION OF TURBOCHARGER MAPPED BY DATALOGGER IN I.C. ENGINE

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ABSTRACT

This research article focused a new representation of the compressor performance mapping oriented for turbocharger characterization with the help of simulation and the data logger. The ultimate aim of this mapping methodology is to facilitate to the engine simulation models and to interpolate data from turbocharger with test bench comfortably. The data-logger used to search for adapting the best choice of matching turbo charger for the speculative requirements with the expected performance. The data observed from the data logger used for real time data for the turbocharger matching the compressor, which superimposed with the engine operating point on compressor maps in terms of pressure ratio and mass flow for the different road conditions. A conjectural, simulated result compared with the test bed results and adopting turbo charger based on matching the performance. The parameters such as mass flow rate, engine speed, operating pressure ratio considered for the best matching of the turbo charger for the respective engine. The compressor map is also used to depict the matching the performances.

Keywords: turbocharger, turbo matching, data logger, mass flow rate, compressor, sensors, pressure ratio.

Nomenclature

AFR = Air Fuel Ratio

BMEP = Brake Mean Effective Pressure

BSFC = Brake Specific Fuel Consumption

CFD = Computational Fluid Dynamics

C_p = Specific heat at constant pressure (kJ/kg.K)

C_p = Specific heat at constant pressure (kJ/kg.K)

Cot = Compressor outlet Temperature

Cop = Compressor outlet Pressure

D = Swept volume (m^3)

Imt = Intake Manifold Temperature

IMD = Intake Manifold Density

m = Mass flow (g/s)

m_a = Mass of the air (kg/s)

m_g = Mass flow of gas (kg/s)

NEDC = New European Driving Cycle

N = Engine speed in (rev/sec.)

Nrpc= Number of Revs Per Cycle (2 in the case of 4 stroke engine)

P_1 = Compressor inlet pressure.

P_3 = Turbine inlet pressure

Pco = Compressor outlet pressure

P_{ref} = Reference pressure (Pascal's)

P_{cin} = Compressor pressure inlet

PR = Pressure Ratio

TIT = Turbine inlet Temperature

R = Gas constant for air (0.287 J/g.K)

T_1 = Air inlet Temperature

T_2 = Compressor outlet Temperature before intercooler

T_{ref} = Reference temperature (Kelvin)

TIT = Turbine inlet Temperature

η_{TC} = Turbocharger efficiency

η_{vol} = Volumetric efficiency

1. INTRODUCTION

The recent trend of researchers focused on optimum utilization of the energy with the environment cognizant. Especially most of the researchers are focusing on maximizing the engine power and minimizing the pollution by improving the performance of the turbocharger. The turbo charging offers to improve the engine performance in terms of fuel consumption and reduce the pollutant of hydrocarbon emissions. The development of a turbocharger is the experience and concerned with to the improvement of engine performance as well as environmental consciousness.

Therefore, the many researchers focus of their research based on the turbocharger. The Turbocharger has castigated as a boon of providing additional power to the I.C. engines by downsizing of the engine, thereby increasing the overall performance of the engine. Turbocharger driven by the engine exhaust, both the compressor and Turbine is turbo machines running on a common shaft and bearing system. A turbocharger has an advantage of a diesel engine in that partial altitude

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compensation arises naturally during operation. Which is compared to a naturally aspirated engine the benefits of a turbo engine effective in terms of increase the power, lower fuel consumption and emission reduction [1] based on present Euro Norms. With increasingly severe environmental and energy requirement problem faced in the past and in present days. The turbocharger matching methods and study of different technology is more and more important.

It became a stringent to find a better strategy and procedural method to meet the perfect matching technique which can meet the overall requirement of the engine operating point. The compressor map plotting based in terms of surge and choke limit of the compressor pressure ratio and the mass flow rate of the engine in real time road condition. Many researches focused research based on matching a turbo to meet the requirement of the engine in terms of flow requirement and pressure ratio on the operating zone of compressor map is proposed, but there is need of perfect technique and methodology that can give much higher level of accuracy for matching is in great need. Today, downsizing an engine to make compact vehicle is an urge among all the customers, fleet owners, researchers, and turbo manufacture. Therefore, the need for finding a procedure of superimposing the realistic data as well as simulation results combining on the same map to find the best and perfect accurate match.

The Turbo matching technique includes clusters of method that includes simulation software. However, there some drawbacks exist, in terms of assumptions made in simulation. The matching increases the shifting of operating points from the maximum efficiency zone to even choke and surge region of the compressor map. The researchers are focus to take a long time to selecting a proper map for fitting the engine operating point and in comparison made against the engine test bed. It founds that there is exist a mismatch between simulated results and the test bed results. Therefore, finding a procedure from real time data captured from the data logged on the turbocharger by proper instrumentation and fitting of sensor, it gives a high level of accuracy and confidence among researchers and turbocharger manufacturer for better and best matching of the turbocharger. So finding a procedure of superimposing the realistic data as well as simulation results combining on the same compressor map to find the best and perfect accurate match is must.

2. LITERATURE SURVEY

Turbocharger matching method is a keen area of many researchers in the internal combustion engine; it is a more gorgeous area for the past two decades for many researchers. By adding a turbo charger is a technology to increase the engine efficiency and performances. In this context, numerous studies have focused on the improvement of turbocharger control strategies. Its main objective is to find a matching for turbo-machinery. Some of the following research papers are [1]. Eriksson Lars *et al.* (2010) proposed a Turbo-mapping method that has formulated on Gas Stand to measure speed lines from choke to surge region on compressor map. A setup has been investigated and analyzed and it proposed that some amount of extra throttle has to be given to meet the reachable region of the turbocharger map and not to exceed choke and surge limit.With gas stand the results were not achieved so three corrected speed lines were proposed [2].

YANG Ming Yang *et al*., (2010) designed a compressor of high P.R and analysis of data is carried out for superimposing on the results of mass flow and pressure ratio on the compressor map to have matching of the results. A new Compressor designed and evaluated thus the results show better P.R and Mass flow for new proposed compressor. The proposed compressor seems to give more power density of 40% [3]. Jean-Christophe Schmitt *et al*., (2010) proposed two stage Diesel Turbocharger Engine matching method to meet Euro 6 norms. A 0D simulation for two the turbochargers considered by the manufacturer and simulated at part load. The load was analyzed on NEDC Emission norms to meet the required norms were also checked for higher efficiency. In this, a new detailed concept for the turbocharger considered as a part load [4]. F. Bouffaud *et al*. (2014) has done a detailed study of the behaviour of shaft motion of the turbocharger by proper instrumentation of small the turbo charger for automotive application of infrared sensors. It can measure shaft motion to a higher level of accuracy far away from the shaft.

The advantages lie to get high-level accuracy with greater resolution of the data having better accuracy, although it can give better results for destructive testing. With this sensor, system lies a disadvantage of mounting a bigger diameter nuts for holding the sensor to avoid scattering of lights and it doesn't give direct observation [6]. T.C. Zannis *et al*., (2013) have done electrical turbo compounding system for a heavy diesel engine by using component charts for the turbocharger. The focus also given to the operational behaviour of the truck engine by electrical equipment's on a theoretical basis. A simulation model for diesel engine also developed using operating charts for turbocharger and power turbines. A method for using operating charts on the engine model proposed. A detailed study for improvement in bsfc of diesel engine with electric turbo compounding discussed. Overall, it was also proposed that installation of a power turbine downsize of the turbocharger is an effective mean to improve the bsfc of heavy duty truck engines and such technologies include installation of Rankine Cycle System. In addition to that, it was also proposed that by turbo compounding on engine air supply, the bsfc also be improved by the difference between charge pressure and exhaust backpressure [7].

Bernd Becker *et al*., (2015) gives a detailed analysis by using CFD on Compressor map computation.

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They gave a procedure to compute for compressor maps for engine based on 3D CFD. Corresponding constant speed lines on compressor map was determined. The process developed and applied to 4.5 stage axial compressor to check the feasibility of the strategy. A coding developed which can be automatically computed the compressor map on 3D CFD. An optimized problem solved for efficient search of the surge and choke by proper optimization of the corresponding meshes by solving problems. It's also a better convergence checker used to detect convergence and divergence at the earliest as possible. The application made for calculating speed lines from 65% to 100% of the design speed. Further, in the investigation for matching between CFD solver and the experimental data [8].

Giorgio Zamboni *et al.*, (2013) have done a performance check pulsating flow on turbocharger compressor for automotive application. In this paper, an experimental investigation carried out in a small size turbocharger compressor matched to a downsized gasoline engine. Testing conducted at the University of Genoa, which gives a detailed study of steady and unsteady flow condition. After this testing, it fitted to the automotive engine intake system and pulsating flow generated by motor driven cylinder head fitted with variable valve actuator system. Different level of rotating speed and different level of valve opening strategies also studied. Different parameters like inlet and outlet static pressure, mass flow and rotational speed of the turbocharger evaluated. The obtained results in the unsteady flow of a small compressor for downsize automotive engine have been presented and discussed in detail. The matching of the different operating zone of surge and choke was also investigated [9]. Magnus Hellring *et al*, (2009) gives a methodology for real world logged Truck Data and knowledge extraction for real road condition. In this paper a procedure for extraction of data by proper fitments of instruments were done on two different trucks and a method for evaluation duty cycle is proposed and applied to extract knowledge from three different large real world data sets measured on long haulage truck Engine.

3. EXPERIMENTAL SETUP

The defective turbocharger is the consequence of some other primary engine defect, which cannot be cured, but it can be replacing the turbocharger. However, with the diagnostic tool you can determine the true nature and extent of the trouble without any problems. Then we can repair your vehicle more quickly and at less expense so an engine failure will not cost you any more time or money than necessary. The turbo matching serves as an opportunity for all the manufacturers, fleet owners, customers, researchers find the behaviour of the turbo charger installed in their engine. So it becomes inevitable to know their best way of matching the turbocharger. It matching includes different ways of representation and formulating in matching of turbocharger and collects the data on the map. The Figure-1 shows the experimental setup of the Engine test bed of SAJ type used for validation of this truck engine data.

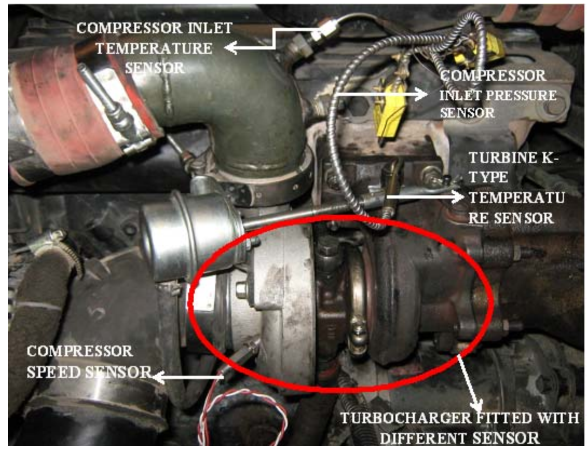

Figure-1. Engine fitted with a turbocharger in the vehicle.

3.1 Engine details

Engine Make /Model: TATA 497 TCIC -BS III (Turbocharged intercooler)

a. Fuel Injection Pump : Electronic rotary type
b. Engine Rating : 92 KW (125 PS)@2400 rpm
c. Torque: 400 Nm @1300-1500rpm
d. No. of Cylinders : 4 Cylinders inline water cooled, DI Diesel Engine.
e. Fuel used : Diesel
f. Road Condition : Traffic, Highway, Ghats, Overrunning, etc.
g. Engine speed : 2400 rpm (Max power), 1400 rpm (Max Torque).
h. Engine Bore / Engine Stroke: 97 mm/128mm.

3.2 Simulation

Match-Bot is an internet based interactive turbo matching program, which provides an optimal engine target of the appropriate engine. In each stage, it provides various options of the engine data to enter it through the pop-up menu. The parameters such as BSFC, VE, and exhaust gas temperature are often difficult for the user to estimate, but helpful suggestions offered at each step of the way. The turbocharger matching defined in terms of logical science of combining engine and turbocharger characteristics to optimize the performance of the combination over the required operating spectrum. The MatchBot software used to simulate the engine condition and get the performance of the appropriate engine for matching the correct turbocharger to a diesel engine. It is very important and which is most successful operation of

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the turbocharger diesel engine. Some of the simulation tools are CFD, GT Power, Turbo-Genius TM Simulation Tool, Cavalli Turbo, Mini-match Turbo, Turbo calc, MatchBot available with the manufacturer.

This matching makes use of boot match to find, the better-optimized point on compressor map and a turbine drive the compressor point. The simulation tools developed from the turbocharger matching calculations by balancing the energy between the compressor and turbine to provide an approximate turbocharger match for a given four-stroke diesel engine. The program contains a simple algorithm for the calculation of different point. Matching is carried at full load, full speed. The program then matches under different loads, speeds or ambient conditions It will not calculate transient performance or the action of pulses in the exhaust or inlet Manifolds. The Figure-2 shows that the turbo Simulation approach block diagram stage by stage.

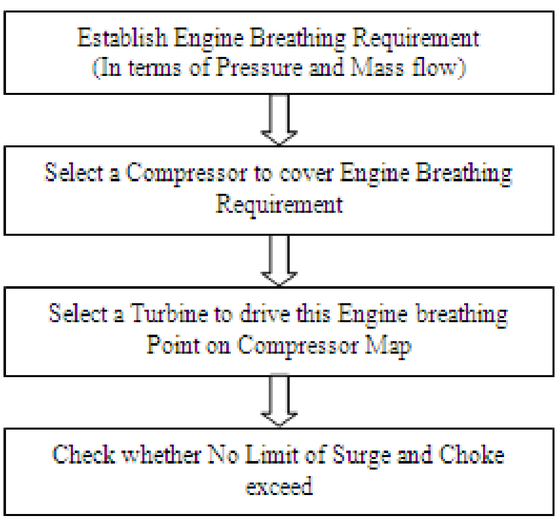

Figure-2. Simulation Turbo Matching block diagram.

For establishing engine-breathing point the following steps of calculation are as follows:

$$PR = \frac{N_{rpc} \times m \times R \times I_{mt}}{N \times \eta_{vol} \times D \times P_{ci}} \tag{1}$$

PR is plotted on the Y-Axis.

$$PR = \frac{\eta_{vol} \times D \times N \times P_{ref}}{N_{rpc} \times R \times I_{mt}} \tag{2}$$

'*m*' is mass flow plotted on the X-Axis in terms of Mass flow parameters:

$$\text{Mfp} = 1000 \times m \times \frac{\sqrt{T_{cin}}}{\sqrt{P_{cin}}} \tag{3}$$

$$\text{Mfp} = \text{Air mass flow} \times m \times \frac{\sqrt{T_{cin}}}{p} \tag{4}$$

In terms of corrected PR:

$$PR = \frac{Mfp \times N_{rpc} \times I_{mt} \times R}{1000 \times N \times D \times \eta_{vol} \times \sqrt{T_{cin}}} \tag{5}$$

The mass flow is in X-Axis and the PR on the Y-Axis, is plotted on the compressor map for the matching process of the turbocharger.

3.3 Data logger

Data logger or data recorder is a real time of field data gathering instrument, they were based on a digital processor or a computer. The data logger is an electronic device that records data a period of time or in relation to location either with a built in instrument or sensor or via external instruments and sensors increasing slightly, but not entirely. It is always finding its application on scientific research and experiments. Data logger monitor processes by making use of sensors and sophisticated instruments are connected to the computer systems and electrical system channels are connected to collect data to a system. Instrumentation of vehicle to captures the data's, in this research work the Graph-Tech type of Data logger is used for capturing and recording the real time data which is stored in the field of on road vehicle testing. The methodology for data logger discussed in the Figure-3, systematically in the block diagram.

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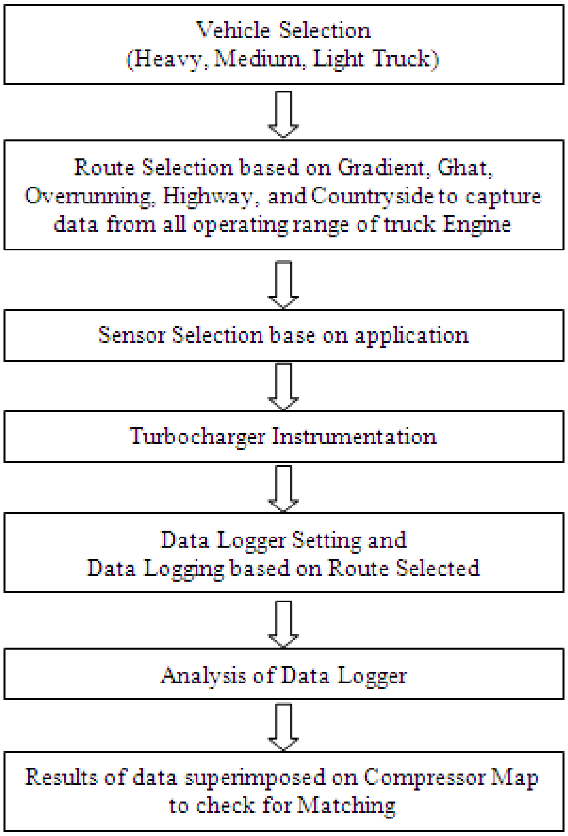

Figure-3. Data logging for Turbo Matching block diagram.

4. RESULT AND DISCUSSIONS

The theoretical results were calculated under the aforementioned parametric investigation, are provided. An investigation is conducted to find the optimal compressor map movement that will maintain the various turbo shaft speeds as possible during rapid throttle transients. The engine speed was varied range from 1000 rpm to 2400 rpm and the corresponding results tabulated in the Table-1. The results show that the compressor should follow a path of least consumed torque, which coincides with the surge line. Thus, all the predictions of the appropriate speed derived for the operational parameters from the turbocharger. As for the above plot, it can be stated that there exist less deviation of the mass flow parameter and pressure ratio (PR) and SFC in Data Logging method. Therefore, the deviation of the Simulation values is more due to certain assumption made in calculating mass flow, PR and SFC, during the simulation process. Therefore, by data logging the data captures seems to deviate less because it is the real data and sensor seems to give better accuracy. It evidenced that the above graph there is an increase in the mass flow in turbocharger to increase of the engine speed.

The simulation results for mass flow parameter seems to deviate away too much from the datalogger and test bed results because there are assumed for air flow, power consumption etc. but the data-logging and test bed results seems to match each other almost showing similar characteristics for mass flow. The results of 2000rpm shows a deviation for data logging and test bed because the operation of vehicle in real road condition demands different rate of acceleration and mass flow requirement due to driver driving behaviour and the hence the deviation occurs. It can be seen from the above plot that the PR increases with an increase in the Engine speed, the pattern of pressure increase in all the three methods almost same, the variation of PR for simulation is showing a little deviation from the Data logging and Test Bed. It shows that the Data-Logging method lies in the average of all the two methods.

The observed data was tabulated in the Table-1. From that, the patterns for SFC in all the three methods are almost same up to 1800 rpm. The speed of 1800 rpm the SFC show a greater deviation from each result, SFC for simulation is showing greater value due to assumptions made in calculation , the test bed data for SFC shows an increase in fuel consumption as compared to data-logging. It can also be seen clearly from the above plot that the SFC values for Data logging is less, that's means the amount of fuel consumption is comparably less in data-logging in real road condition than all the three methods. Therefore, it gives better match. The subsequently upon the research work for turbocharger matching the results of the simulation and data-logger were plotted on the compressor map to analyze the engine operating line on the compressor map and the results obtained from Data Logging seems to be correct with maximum efficiency.

The Compresser map plotting in shown in Figure-4 were plotted by superimposing the multiple Engine operating points on the compressor map, the blue circle operating points show the engine operating point line for simulation at different rpm of the engine and the indigo blue square shows an engine operating point line for Data logging and orange squares shows engine operating points for Test bed. It was also observed that the simulation results when plotted for wrong compressor having trim size than 68, the operating point was shifted towards the surge for PR of below 1.8 and hence shows the instability of working and the life span of turbo also will be less if matched wrongly.

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Table-1. Comparison of data's for simulation, datalogger and testbed for turbocharger.

S. No	Engine speed	Simulation			Data logging			Test bed			
		Mass flow	Pressure ratio	SFC	Mass flow	Pressure ratio	SFC	Mass flow	Pressure ratio	SFC	Power
	rpm	Kg/Sec.rtK/ MPa		g/kW.hr	Kg/Sec.rtK/ MPa		g/kW.hr	Kg/Sec.rtK/ MPa		g/kW.hr	KW
1	2400	26.48	2.4	316.3	28.48	2.5	249.27	28.3	2.49	255.31	84.32
2	2250	25.28	2.4	311.44	27.28	2.4	251.75	27.22	2.4	259.64	80.74
3	2000	22.97	2.3	288.06	26.97	2.35	246.79	26.49	2.31	245.84	78.57
4	1900	22.06	2.3	278.97	26.06	2.33	236.24	25.49	2.27	242.52	75.96
5	1800	22.98	2.3	262.81	23.92	2.3	249.39	23.76	2.29	248.42	74.21
6	1500	18.9	2.3	259.64	21.27	2.3	218.14	21.11	2.25	224.56	69.42
7	1400	12.37	1.9	254.56	16.27	2	213.64	15.93	1.95	219.77	62.88
8	1300	11	1.7	249.48	14.28	1.8	199.17	13.76	1.72	205.21	55.29
9	1200	10	1.6	242.39	10.29	1.5	201.28	9.76	1.39	207.26	51.57
10	1000	7.29	1.4	304.14	8.21	1.4	239.16	7.91	1.31	245.16	46.64

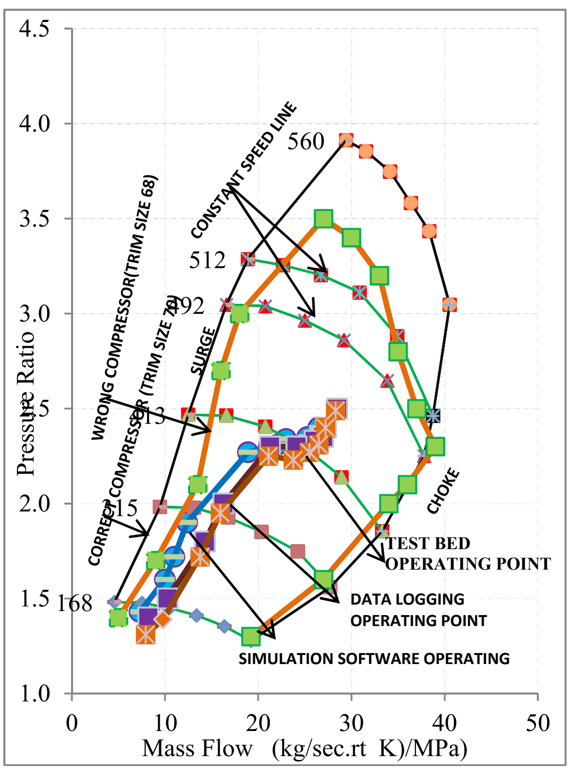

Figure-4. Comparison of results of the three methids of the compressor map.

So a new compressor was proposed and when plotted against correct compressor having trim size 70, its shows better matching at the heart of the compressor map having maximum efficiency. It can also be stated that there exist deviation between simulation and data logging data, but data logging method results seems to be more bitter than the simulation because in simulation method assumption of the data were made for calculating mass flow requirement of the engine and pressure ratio. So the data logging data show better and more reliable data and hence more accuracy. On plotting the obtained operating point for all the test results on compressor map, it was obtained that the simulation results show a lesser value for PR and mass flow as compared with the Data loggervalues.

The reason lies in the facts that during matching using simulation, assumptions were made in the calculation but when the real data were captured its shows higher values of mass flow and the PR and when the data are validated with test bed results shows better accuracy of data loggers with simulation data. So the data logger gives the best results of matching turbocharger with an engine having less SFC, better mass flow parameter and PR when compared with simulation software and test bed results and hence better accuracy.

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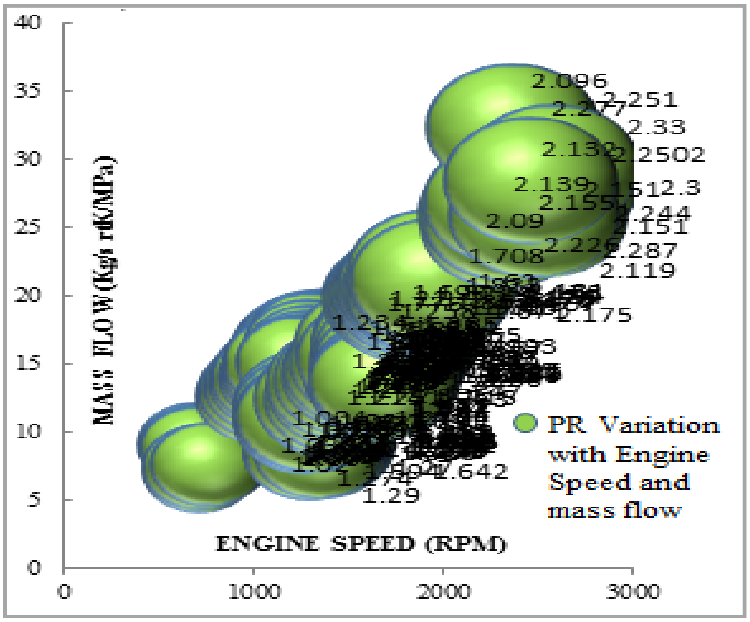

Figure-5. Pressure variation with engine speed and mass flow of the engine.

The plotting in Figure-5 states that the maximum operating zone of the truck engine when it was run at the real road condition. It was also observed from the plot that, truck engine operates maximum of its life span from 1400 to 2000 rpm., so the engine needs to be matched accordingly. As the truck real operating zone includes ghats, overrunning, city drive, Highway drive, Countryside so the behavior of the operation of the Engine and the Turbocharger is a must.

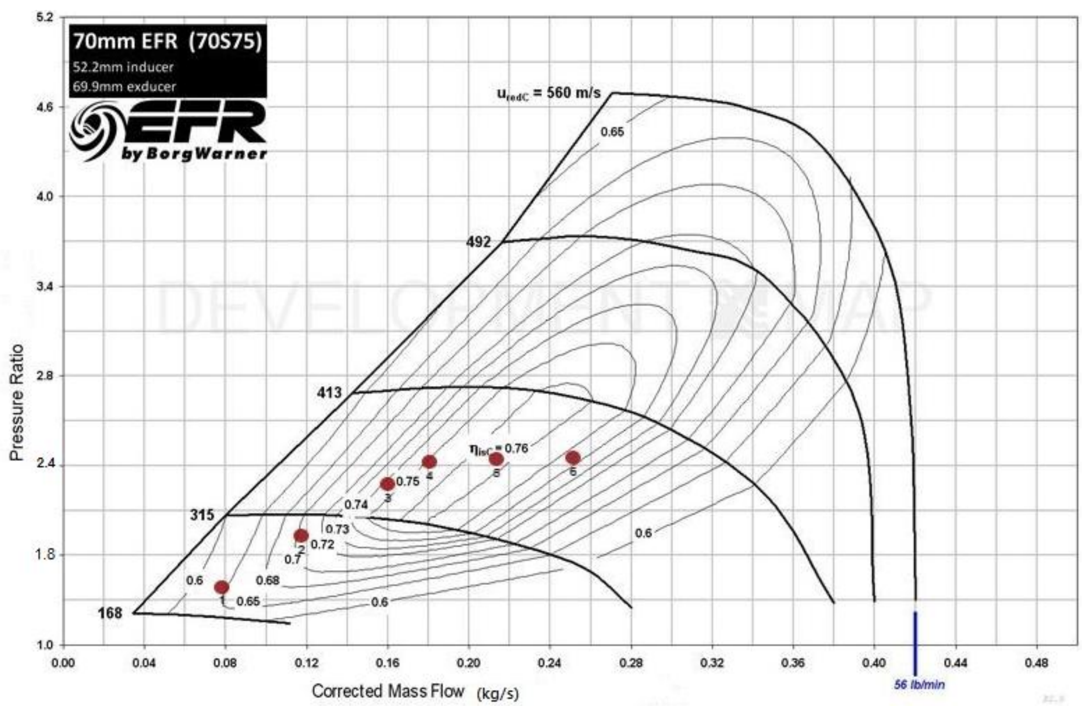

Figure-6. Experimental performance comparison and operation characteristic with IC engine.

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It was observe d from the above plot that the simulation results when plotted for wrong compressor having trim size 68, the operating point was shifted towards the surge of pressure is below about 1.8 and hence shows the instability of working and the life span of turbo also will be less if matched wrongly. So a new compressor was proposed and when plotted against correct compressor having trim size 70, its shows better matching at the heart of the compressor map having a better compressor efficiency. So the new compressor map is used for data-logging and test bed testing.

So this above plot gives the better differentiation between the software matching and Data logging and test bed. As an operating point for simulation lies away from surge and choke region with a correct compressor map having trim size 70 which makes the compressor operation of turbocharger for better matching with an Engine. By data-logging the operating point lies in the middle of the compressor map which gives best match. As the operating point of data logging shift more in the middle of the map, far away from choke and surge region of operation of turbocharger having more compressor efficiency. So data logging gives the best results of matching turbocharger with an engine having less SFC, better mass flow parameter and PR when compared with simulation software and test bed results and hence better accuracy.

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So the behavior of the operation of the Engine and the Turbocharger is a must.

The Turbocharger performance characteristic specified in terms of mass flow rate, Pressure ratio and isentropic efficiency for varying the compressor speed on a steady flow rig. The selection of proper trim size to accommodate the engine operating point is necessary.

The test results obtained and which is plotted in the Figure-6 based on the case of variable turbine geometry, various trim size of the compressor and the inlet blade position.

5. CONCLUSIONS

In this work an experimental study of the turbocharger, test bench and engine simulation environments were included. In this test the Matchbot software is employed for the test of the truck turbo compressor of an automotive engine. The turbine characteristics were accurately fitted with quadratic polynomial functions which was continuously differentiable and without discontinuities. Three different methodologies were adopted for turbocharger matching to find the best operating condition. The data logger extends the best matching up to the operating parameters of engine speed 1800 rpm, mass flow rate 23 (Kg/Sec.rtK)/MPa and the pressure ratio 2.45. After that the operating point of data logger shift more in the right side of the map and deviate away from the left side of the surge region of operation of the turbocharger.

In case the Engine operating points shifted away from the heart region (1800 rpm) or the center of the compressor map, the instability of Engine performances was observed. So the turbo charger function was not satisfied, and the fuel efficiency also reduced. Hence this method is applicable to mach turbocharger for other engines also. The limitation of the datalogger method is; sometimes the sensor gives wrong readings due to loose connection because of Engine vibrations, worn out etc. The periodical maintenance is required. This method can be used by manufacturer, customer or fleet owners in knowing the warranty period of turbocharger fitted to their vehicle. This realistic method may be used to know the duty cycle and behavior of truck turbochargers at different road conditions.

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