

Experimental study on Turbo-matching of Turbo-Charger B60J68 for Commercial Vehicle Engine

Badal Dev Roy¹, Dr.R.Saravanan²
¹ Research Scholar, Department of Mechanical Engineering, School of Engineering, Vels Institute of Science Technology & Advanced Studies (VISTAS), Vels University, Chennai, TN, India.

² Research Supervisor, Professor (Mechanical) & Principal, Ellenki Institute of Engineering and Technology, Jawaharlal Nehru Technological University, Hyderabad, TS, India.

Abstract — Turbocharger is a charge booster for IC engines especially at higher load. This Commercial vehicles and heavy vehicles require boosting of charge specifically at higher load. The turbocharger is such charge booster for automobile engines. Selection and matching are need more attention and care. Because the mismatch of turbo charger for the desired engine may leads to disadvantages like surge and choke at engine air flow, bearing oil leakage. Test based matching is adopted in this research. The initial matching performance is identified by the simulation method. The data-logger type matching method is used for confirming or validating the performance of matching. The objective of this research is to find the appropriateness of matching of B60J68, Turbo Charger for the TATA 497 TCIC -BS III engine. The compressor map is used for evaluating the solutions yielded both methods. The appropriateness was evaluated at various route conditions and presented.

Keywords- Trim, Turbo matching, Data-logger, choke, surge, Compressor map, simulation.

I. INTRODUCTION

Turbo charger is an accessory in the IC engines to boost pressure, especially at higher loads. Turbo charger also helps to reduce specific fuel consumption (SFC), downsizing the engine, reduce CO₂ emission, etc.[1]-[5]. Due to the character of centrifugal compressor, the turbocharged engine yields lesser torque than naturally aspirated engine at lower speeds [6],[7]. Comparatively in diesel engine these problems very worse than petrol engine. Some of the system designs were made to manage this problem. They are: adopting the sequential system [8], incorporate the limiting fuel system, reducing the inertia, improvements in bearing, modification on aerodynamics [9], establishing electrically supported turbocharger [10], the use of positive displacement charger i.e., secondary charging system and use of either electric compressor or positive displacement charger with turbocharger [10],[11] facilitating the geometrical variation on the compressor and turbine [12], adopting the twin turbo system [13], and dual stage system [14]. It is noticed that the transient condition is always worst with the engine which adopted single stage turbo charger. The variable geometry turbine was introduced for reducing the turbo lag in petrol as well as diesel engines. But that system is not accurate match for petrol engines [15]. Even though many researches were done on this case still the problem is exist. [12],[15]-[18]. Though the advancements in system design like variable geometry turbine, common rail injection system, and multiple injections, the problem is still persist due to the limiting parameter say supply of air. [19] discussed in detail about the benefits, limitations of turbo charger in single stage, parallel and series arrangements. According to the literature the turbocharger matching is a monotonous job and demands enormous skill. The turbo matching can be defined as a task of selection of turbine and compressor for the specific brand of engine to meet its boosting requirements. That is, their combination to be optimized at full load. The trial and error method cannot be adopted in this case because the matching is directly affecting the engine performance [5],[20],[21]. So it is a difficult task and to be worked out preciously. If one chooses the trial and error or non precious method, it will certainly lead to lower power output at low speeds for partly loaded engines for the case of two stage turbo charger. It is because of the availability of a very low pressure ratio after every stage than single stage [21]. Some cases the turbocharger characteristics are not readily available, and in some cases, not reliable or influenced by the engine which is to be matched [19]. Nowadays the Simulator is used for matching the turbocharger to the desired engine. The simulator was used to examine the performance at constant speed of 2000 rpm of two stage and single stage turbo chargers, the aim of the study was to optimize the high load limit in the Homogeneous charge compression ignition engine. For increasing the accuracy of matching the test bench method is evolved. Test bench was developed and turbo mapping constructed for various speeds to match the turbocharger for the IC engine by Leufven and Eriksson, but it is a drawn out process [21]. The on road test type investigation is called Data Logger based Matching method is adopted in this research. [22] discussed the data-logger turbocharger matching method in detail and compared with the result of test best method and simulator based matching method. And proved the data logger method outputs are reliable. By use of the data logger method the performance match can be evaluated with respect to various speeds as well as various road conditions. The core objective of this research is investigating the matching performance of the turbocharger with trim 68 (B60J68) to the TATA 497 TCIC -BS III Engine by simulator method. The validation of the same by Data Logger based Matching method.

II. MATERIALS AND METHODS

A logical science of combine the quality of turbocharger and engine and which is used to optimize the performance in specific operating range is called as turbo-matching. The Simulator method, data-logger method and Test Bed method is identified for this matching. Apart from the above three this research used the Simulator method and data-logger method for evaluating the performance of turbo matching. The trim size is a parameter, which can be obtained from the manufacture data directly or by simple calculation. That is the trim size is a ratio of diameters of the inducer to exducer in percentage. This parameter is closely related to the turbo matching. Various trim sizes are available but in this study the trim size 68 is used for investigation.

A. Simulator Based Matching:

Various kinds of simulation software are being used for turbo matching. In this research the minimatch V10.5 software employed for turbo-matching by simulation. The manufacturer data of engine and turbocharger are enough to find the matching performance. The manufacturer data are like turbo configuration, displacement, engine speed, boost pressure, inter cooler pressure drop and effectiveness, turbine and compressor efficiency, turbine expansion ratio etc. The software simulates and gives operating pressure, mass flow rate and SFC, required power etc., at various speeds. These values are marked in the compressor map that is the plot of pressure ratio vs. mass flow rate. This plot is used for matching the engine and turbo charger with better compressor efficiency by the position of engine operating points and engine operating curve line. Based on the position of points and curve join those points the performance of matching will be decided.

B. Data Logger based Matching

This type of data collection and matching is like on road test of vehicle. This setup is available in the vehicle with the provision of placing engine with turbocharger and connecting sensors. It is a real time field data gathering instrument called as Data-logger. It is a computer aided digital data recorder which records operating condition of engine and turbo during the road test. The inputs are gathered from sensors at various parts of engine and turbo charger. The Graphtec make data logger is employed in this work. It is a computerized monitoring of the various process parameters by means of sensors and sophisticated instruments. The captured data are stored in the system and plot the operating points on the plot of pressure ratio versus mass flow rate. The figure 1 depicts the setup for the data-logger testing in which the turbocharger is highlighted with a red circular mark.

C. Decision Making

The decision making process is based on the position of the operating points in the turbo map. The Turbo map is plot of pressure ratio versus the mass flow rate plot. The plot has a curved region like hairpin bend road, in which the left extreme region is called as surge region. The operating points falls on the curve or its left side, is said to be occurrence of surge. That means the mass flow rate limit below the compressor limit. This causes a risk of flow reversal. The right extreme region curve is called as Choke region. The points fall on the curve and beyond its right side is denoted as occurrence of choke. In the choke region the upper mass flow limit above compressor capacity which causes the quick fall of compressor efficiency, Chances for compressor end oil leakage and insufficient air supply. The all operating points fall in between those extreme regions i.e, the heart region holds good, thereby having maximum compressor efficiency. It must be ensured at all level of operation of the engine holds good with the turbo charger. The manufacturer of Turbocharger provides the compressor map for each turbo charger based on its specifications.

D. Engine Specifications

The TATA 497 TCIC -BS III engine is a common rail type diesel engine. It is commonly used for medium type commercial vehicle like Tata Ultra 912 & Tata Ultra 812 trucks. The engine develops 123.29 BHP at 2,400 rpm and also develops the peak torque of 400 Nm between 1,300 and 1,800 rpm. The other specifications can be found in Table 1.

Table I. Specification of Engine

S.No	Description	Specifications
1	Fuel Injection Pump	Electronic rotary type
2	Engine Rating	92 KW (125 PS)@2400 rpm
3	Torque	400 Nm @1300-1500rpm
4	No. of Cylinders	4 Cylinders in-line water cooled
5	engine type	DI Diesel Engine
6	Engine Bore / Engine Stroke	97 mm/128mm.
7	Engine speed	2400 rpm (Max power), 1400 rpm (Max Torque)

E. Turbocharger Specifications

The TATA Short Haulage Truck bearing HE221W-4045 series turbocharger (B60J68) is considered for examine the performance of matching for TATA 497 TCIC -BS III engine. Here B60 is design code and J68 meant that the Trim Size of the turbo charger in percentage. The other Specification furnished in Table 2.

Table II. Specification of Turbo Charger B60J68

S.No	Description	Specifications
1	Turbo maximum Speed	200000 rpm
2	Turbo make	HOLSET
3	Turbo Type	WGT-IC (Waste gated Type with Intercooler)
4	Trim Size(%)	68
5	Inducer Diameter	46.9mm
6	Exducer Diameter	68.9 mm

III. EXPERIMENTAL OBSERVATIONS

The simulation and data-logger methods are adopted to analyze the turbo-matching of the Turbocharger B60J68 to TATA 497 TCIC -BS III engine. The matching performance can be obtained by simulation by using the data from the manufacturer catalogue. The desired combination is simulated at various speeds (1000, 1400, 1800 and 2400 rpm) to obtain the predicted operating conditions for this combination. The pressure ratio and mass flow rates are important parameters to know the turbo matching performance. The simulated observations presented in the Table III. In data-logger method the turbocharger is connected to the TATA 497 TCIC -BS III Engine of TATA 1109 TRUCK with sensors. The vehicle loaded to rated capacity 7.4 tones of net weight. The grass weight of vehicle is 11 tones. The experimental setup for Data logger type matching is shown in Fig. I. The operating conditions collected while driving at a specific speed in the selected route. For the same set of engine speeds the operating conditions were observed while vehicle driving in the routes like Rough Road, Highway, City Drive, Slope up and Slope down. The observations were recorded in the data-logger automatically through sensors and other sophisticated equipments. Those observations were tabulated road condition wise from Table IV to Table VIII.

Table III. Simulator based Turbo Charger matching results.

Sl.No	Engine Speed (rpm)	Mass Flow Rate (Kg/sec.sqrt K/Mpa)	Pressure Ratio
1	1000	11.449	1.856
2	1400	22.56	3.051
3	1800	29.451	3.556
4	2400	36.872	3.817

Table IV. Road Test Results for Match Performance at Rough Road

Sl.No	Engine Speed (rpm)	Mass Flow Rate (Kg/sec.sqrt K/Mpa)	Pressure Ratio
1	1000	07.37	1.35
2	1400	15.41	1.95
3	1800	21.73	2.33
4	2400	27.43	2.55

Table V. Road Test Results for Match Performance at Highway

Sl.No	Engine Speed (rpm)	Mass Flow Rate (Kg/sec.sqrt K/Mpa)	Pressure Ratio
1	1000	08.12	1.35
2	1400	15.92	1.95
3	1800	21.87	2.33
4	2400	27.87	2.56

Table VI. Road Test Results for Match Performance at City Drive

Sl.No	Engine Speed (rpm)	Mass Flow Rate (Kg/sec.sqrt K/Mpa)	Pressure Ratio
1	1000	07.41	1.36
2	1400	15.52	1.95
3	1800	21.68	2.35
4	2400	27.39	2.59

Table VII. Road Test Results for Match Performance at slope up

Sl.No	Engine Speed (rpm)	Mass Flow Rate (Kg/sec.sqrt K/Mpa)	Pressure Ratio
1	1000	08.02	1.38
2	1400	15.81	2.00
3	1800	21.94	2.39
4	2400	27.97	2.62

Table VIII. Road Test Results for Match Performance at slope down

Sl.No	Engine Speed (rpm)	Mass Flow Rate (Kg/sec.sqrt K/Mpa)	Pressure Ratio
1	1000	07.97	1.35
2	1400	15.79	1.95
3	1800	21.76	2.33
4	2400	27.41	2.60

IV. RESULTS AND DISCUSSIONS

The appropriateness of turbo matching can be found by plotting the observations in the compressor map. So the data logger and simulated observations plotted on common compressor map for easy comparison for each selected route. The Fig. II illustrates the comparison of data logger matching at Rough Road route and simulated matching performance of B60J68 turbocharger for TATA 497 TCIC -BS III engine. Similarly for the Fig. III for Highway (HW) route, Fig. IV for the City Drive (CD) route, Fig. V for the slope up (SU) route and Fig. VI for the slope down (SD) route. The plots show that the pattern of variation of operating performance with respect to speed is almost similar irrespective of routes. The simulated solution results implied that this combination provides surge occurs at lower speed (1000 rpm). But the operating performance higher speeds found satisfactory. But the safe operating performance was observed at all routes through data logger method (Refer Fig. II to Fig. VI).



Figure 1 Experimental setup for Data-logger Method
 Rough Road

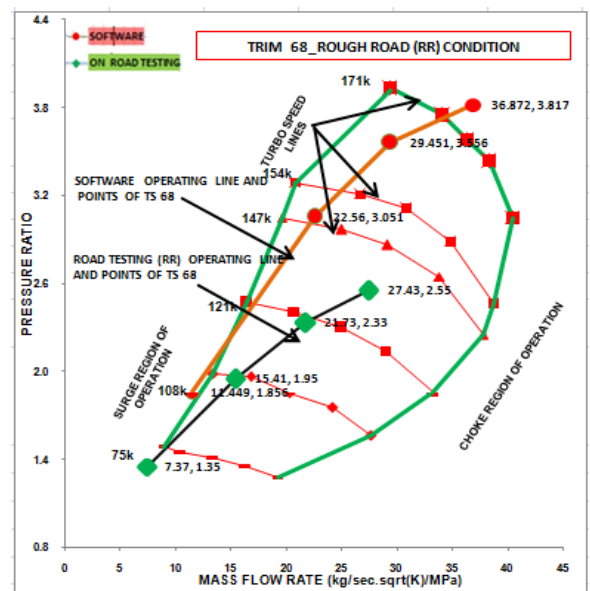


Figure 2 Turbo-matching at simulation and on-road testing

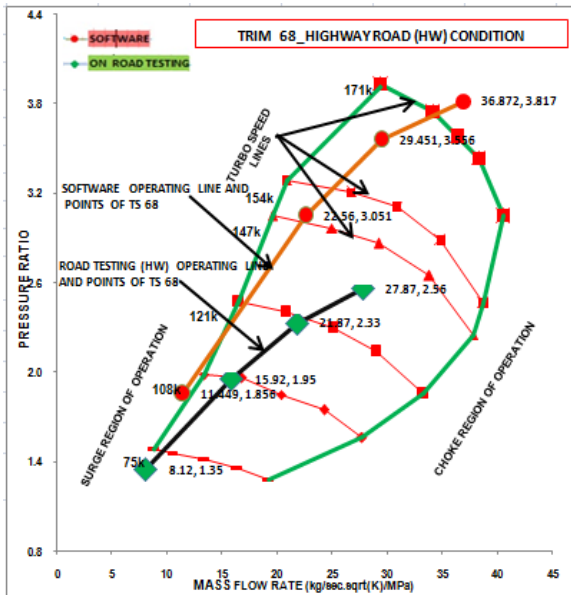


Figure 3 Turbo-matching at simulation and Highway drive

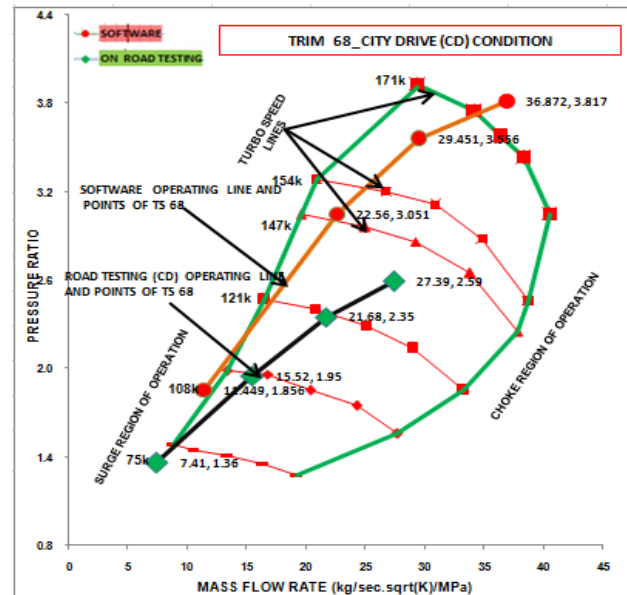


Figure 4 Turbo-matching at simulation and city

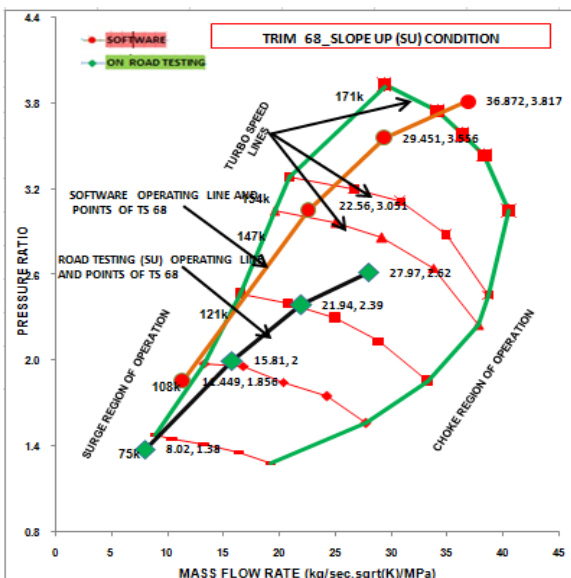


Figure 3 Turbo-matching at simulation and Slope-Up
Slope- down

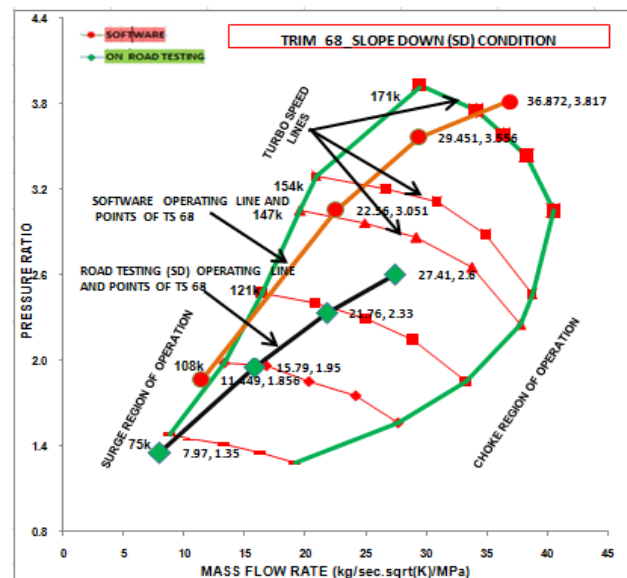


Figure 4 Turbo-matching at simulation and

V. CONCLUSION

The evaluation of turbo matching performance of turbocharger HE 221W-4045 series with trim 68 for TATA 497 TCIC -BS III Engine discussed in this paper. The primary turbo matching was obtained by simulation. The turbo matching was further evaluated by experimentally. For experimental method the data-logger method adopted. The road conditions like rough road, highway, city drive, slope up and slope down were included. The turbo matching was found unsuitable in simulation, but it found suitable by data-logger method. That is, the simulated operating conditions predicted that the surge occur at lower speed. So the investigation was pursued further by data-logger to confirm the predicted decision. This evaluation concluded that the turbocharger B60J68 may be adopted for TATA 497 TCIC -BS III Engine. The data-logger method adapted in this research may feel as expensive but it is one time job of finding the best turbo-match for an engine category.

VI. Acknowledgment

The authors acknowledge M/s Cummins Turbo Technology and ARAI, India., for their support and contribution for this research work. The authors also acknowledge to Dr.M.Chandrasekaran, Joint Supervisor, Professor & Director / Mechanical Engineering, Dr.C.Dhanasekaran, Professor & Head / Mechanical Engineering & Coordinator for School of

Engineering, Vels University. Chennai., Dr.V.Muthukumar, Professor, Saveetha Engineering College, Chennai. And Dr.S.Santhanam, Professor, Rajalaskmi Engineering College, Chennai. TN. India., for their valuable suggestion for this research.

REFERENCES

1. G.Cantore, E.Mattarelli, and S.Fontanesi, "A New Concept of Supercharging Applied to High Speed DI Diesel Engines," SAE Technical Paper 2001-01-2485, 2001, doi:10.4271/2001-01-2485, pp.1-17, 2001.
2. L.Guzzella, U.Wenger, and R.Martin, "IC-Engine Downsizing and Pressure-Wave Supercharging for Fuel Economy," SAE Technical Paper 2000-01-1019, 2000, doi:10.4271/2000-01-1019, pp.1-7, 2000.
3. B. Lecoite and G.Monnier, "Downsizing a Gasoline Engine Using Turbocharging with Direct Injection," SAE Technical Paper 2003-01-0542, 2003, doi:10.4271/2003-01-0542, pp.1-12, 2003.
4. S.Saulnier and S.Guilain, "Computational Study of Diesel Engine Downsizing Using Two-StageTurbocharging," SAE Technical Paper 2004-01-0929, 2004, doi:10.4271/2004-01-0929, pp.1-9, 2004.
5. T.Lake, J.Stokes, R.Murphy and R.Osborne, "Turbocharging Concepts for Downsized DI Gasoline Engines," SAE Technical Paper 2004-01-0036, 2004, doi:10.4271/2004-01-0036, pp.1-13,2004.
6. W.Attard, H.Watson, S.Konidaris and M.Khan, "Comparing the Performance and Limitations of a Downsized Formula SAE Engine in Normally Aspirated, Supercharged and Turbocharged Modes," SAE Technical Paper 2006-32-0072, 2006, doi:10.4271/2006-32-0072, pp.1-22, 2006.
7. A.Lefebvre and S.Guilain, "Modelling and Measurement of the Transient Response of a Turbocharged SI Engine," SAE Technical Paper 2005-01-0691, 2005, doi:10.4271/2005-01-0691, pp.1-15, 2005.
8. S.Tashima, H.Okimoto, Y.Fujimoto, and M.Nakao, "Sequential Twin Turbocharged Rotary Engine of the Latest RX-7," SAE Technical Paper 941030, 1994, doi:10.4271/941030, pp.1-10,1994.
9. T.Watanabe, T.Koike, H.Furukawa, N.Ikeya, "Development of Turbocharger for Improving Passenger Car Acceleration," SAE Technical Paper 960018, 1996, doi:10.4271/960018, pp.1-9, 1996.
10. T.Kattwinkel, R.Weiss and J.Boeschlin, "Mechatronic Solution for Electronic Turbocharger," SAE Technical Paper 2003-01-0712, 2003, doi:10.4271/2003-01-0712, pp.1-8, 2003.
11. N.Ueda, N.Matsuda, M.Kamata, H.Sakai, "Proposal of New Supercharging System for Heavy Duty Vehicular Diesel and Simulation Results of Transient Characteristics," SAE Technical Paper 2001-01-0277, 2001, doi:10.4271/2001-01-0277, pp.1-9, 2001.
12. J.Kawaguchi, K.Adachi, S.Kono and T.Kawakami, "Development of VFT (Variable Flow Turbocharger)," SAE Technical Paper 1999-01-1242, 1999, doi:10.4271/1999-01-1242, pp.1-8, 1999.
13. C.Cantemir, "Twin Turbo Strategy Operation," SAE Technical Paper 2001-01-0666, 2001, doi:10.4271/2001-01-0666, pp.1-11, 2001.
14. C.Choi, S.Kwon and S.Cho, "Development of Fuel Consumption of Passenger Diesel Engine with 2 Stage Turbocharger," SAE Technical Paper 2006-01-0021, 2006, doi:10.4271/2006-01-0021, pp.1-9, 2006.
15. J.Andersen, E.Karlsson and A.Gawell, "Variable Turbine Geometry on SI Engines," SAE Technical Paper 2006-01-0020, 2006, doi:10.4271/2006-01-0020, pp.1-15, 2006.
16. Z.Filipi, Y.Wang and D.Assanis, "Effect of Variable Geometry Turbine (VGT) on Diesel Engine and Vehicle System Transient Response," SAE Technical Paper 2001-01-1247, 2001, doi:10.4271/2001-01-1247, pp.1-21, 2001.
17. C.Brace, A.Cox, J.Hawley and N.Vaughan, et al., "Transient Investigation of Two Variable Geometry Turbochargers for Passenger Vehicle Diesel Engines," SAE Technical Paper 1999-01-1241, 1999, doi:10.4271/1999-01-1241, pp.1-17, 1999.
18. S.Arnold, M.Groskreutz, S.Shahed and K.Slupski, "Advanced Variable Geometry Turbocharger for Diesel Engine Applications," SAE Technical Paper 2002-01-0161, 2002, doi:10.4271/2002-01-0161, pp. 1-12. 2002.
19. Qingning Zhang, Andrew Pennycott, Chris J Brace, 'A review of parallel and series turbocharging for the diesel engine' Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering. Volume: 227 issue: 12, pp. 1723-1733 Sep. 2013. doi: 10.1177/0954407013492108.
20. F.Millo, F.Mallamo and G.Mego, , "The Potential of Dual Stage Turbocharging and Miller Cycle for HD Diesel Engines," SAE Technical Paper 2005-01-0221, 2005, doi:10.4271/2005-01-0221, pp. 1-12, 2005.
21. N.Watson and M.S.Janota, Wiley-Interscience Ed. "Turbocharging the internal combustion engine," Diesel motor - 608 pages1982.
22. Badal Dev Roy, R.Saravanan, R.Pugazhenthir and M.Chandrasekaran, "Experimental Investigation of Turbocharger Mapped by Data-logger in I.C. Engine" ARPN Journal of Engineering and Applied Sciences, VOL. 11, NO. 7, pp. 4587 – 4595, April 2016.