Experimental Investigation on Turbo-Matching Appropriateness of Turbo-Chargers B60J67 A58N70 A58N72 A58N75 for TATA 497 TCIC -BS III Engine

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***Abstract*- Turbocharger uses in IC engines for charge boosting especially at higher load. The adaption of turbocharger for the desired engine is tedious task and need more professional care. The arbitrary selection sometimes cause negative results like choke or surge on the flow of charge. The appropriate selection or match of the turbocharger (Turbomatching) is expensive, but perfect match gives many distinguished advantages and the turbo-matching is a onetime task per the engine kind. This study focuses to match the turbochargers with trim 67 (B60J67), trim 70 (A58N70), trim 72 (A58N72) and trim 75 (A58N75) for the TATA 497 TCIC -BS III engine. The objective of the research is to evaluate the appropriateness of matching of those turbo chargers with the engine for suggesting best turbo-match and analysing the matching possibilities of other turbo-chargers. The simulation and experimental (data-logger) methods involved.**

***Index Terms*- Simulation, data-logger, turbo-match, Turbo-charger, trim, Compressor map.**

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 (Guzzella et al, 2000; Cantore et al, 2001; Lecointe and Monnier, 2003; Saulnier and Guilain 2004; and Lake et al, 2004). Due to the character of centrifugal compressor, the turbocharged engine yields lesser torque than naturally aspirated engine at lower speeds (Lefebvre and Guilain, 2005; and Attard et al, 2006;). Comparatively in diesel engine these problems very worse than petrol engine. Some of the system designs were made to mange this problem. They are: adopting the sequential system (Tashima et al, 1994), incorporate the limiting fuel system, reducing the inertia, improvements in bearing, modification on aerodynamics (Watanabe et al, 1996), facilitating the geometrical variation on the compressor and turbine (Kattwinkel et al, 1999), adopting the twin turbo system (Cantemir, 2001), the use of positive displacement charger i.e., secondary charging system and use of either electric compressor or positive displacement charger with turbocharger (Ueda et al, 2001 and Kattwinkel et al, 2003), establishing electrically supported turbocharger (Kattwinkel et al, 2003), and dual stage system Choi et al, 2006). 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 the system is not exact match for petrol engines (Andersen et al, 2006). Even though many researches were done on this case still the problem is exist (Kattwinkel et al, 1999; Brace et al, 1999; Filipi et al, 2001; Arnold et al, 2001 and Andersen et al, 2006). 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. Qingning Zhang et al, 2013 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 tedious 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 affects the engine performance (Watson and Janota, 1982; Lake et al, 2004 and Millo et al, 2005). So it is 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 (Watson and Janota, 1982). 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 (Qingning Zhang et al, 2013). 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 (Qingning Zhang et al, 2013). ¬¬¬¬The on road test type investigation is called Data Logger based Matching method is adopted in this research. Badal Dev et al, 2016 discussed that the data-logger turbo matching method in detail and compared with the result of test bed turbo matching and simulator turbo-matching methods. The authors exhibited that the data logger method outputs are reliable but expensive. 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 appropriateness of matching of the turbochargers with B60J67, A58N70, A58N72 and A58N75 for the TATA 497 TCIC -BS III Engine by simulator method. The validation of the same by Data Logger based turbo-matching method.

MATERIALS AND METHODS

A logical science of combining 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 inlet to the exit in percentage. This parameter is closely related to the turbo matching. Various trim sizes are available, but in this study the trim size 67,68 and 70 are considered for investigation.

A.Turbo-matching by Simulation

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 the engine and turbocharger are enough to find the matching performance by simulation. 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 the particulars of the operating conditions like pressure, mass flow rate, SFC, required power etc. at various speeds. These values are to be marked on the compressor map to know the matching performances. The compressor map is a plot which is used for matching the engine and turbocharger for better compressor efficiency by knowing the position of engine operating points. Based on the position of points and curve join those points the performance of matching will be decided.

B.Turbo-matching by Data Logger Method

This type of data collection and matching is like on road test of the 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 the operating condition of the engine and turbo during the road test. The inputs are gathered from various parts of the engine and turbocharger by sensors. 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 compressor map (plot of pressure ratio versus mass flow rate). The Fig. 1 depicts the setup for the data-logger testing in which the turbocharger is highlighted with a red circle.

C. Decision Making

The decision making process is based on the position of the operating points on the compressor map. The map has a curved region like an expanded hairpin, in which the left extreme region is called surge region. The operating points fall on the curve or beyond, is said to be occurrence of the 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 the 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. It must be ensured at all levels of operation of the engine holds good with the turbocharger. 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 engineis 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 -1 Specification of Engine

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

E. Turbochargers Specifications

The TATA Short Haulage Truck, turbochargers of B60J67, B60J6, A58N708 and A58N72 are considered to examine the performance of matching for TATA 497 TCIC -BS III engine. For example, if specification A58N70 means in which the A58 is the design code and N70 is the Trim Size of the turbocharger in percentage. The other specifications furnished in Table 2.

Table 2 Specification of Turbo Chargers

Description	Trim 67	Trim 70	Trim 72	Trim 75
Turbo max. Speed	200000 rpm			
Turbo Make	HOLSET			
Turbo Type	WGT-IC (Waste gated Type with Intercooler)			
Trim Size (%)	67	70	72	75
Inducer Diameter	46.1mm	48.6 mm	50.1 mm	52.5 mm
Exducer Diameter	68.8 mm	69.4 mm	69.6 mm	70 mm

EXPERIMENTAL OBSERVATION

The simulation and data-logger method is adopted to match the turbo Chargers B60J67, B60J68 and A58N70 for TATA 497 TCIC -BS III simulated by using simulation software. The data of the manufacturer catalogue is enough for the same. The simulated observations (like -pressure ratio and mass flow rate at various speeds) presented in Table 3 for all four turbo-match choices. These observations are important to find match performance. The range of speeds used for observations are: 1000, 1400, 1800 and 2400 rpm. In data-logger method the turbocharger is physically connected to the TATA 497 TCIC -BS III Engine of TATA 1109 TRUCK with sensors. The vehicle loaded to rated capacity 7.4 tonnes of net weight. The grass weight of vehicle is 11 tonnes. The experimental setup for Data logger type matching is shown in Fig. 1. The operating conditions collected while driving at a specific speed in the selected route. For the same set of engine speeds the operating conditions 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 4 to Table 8. The compressor map used for analysing the matching performance of turbochargers for the desired engine. 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. 2 illustrates the comparison of data logger matching at Rough Road route and simulated matching performance of A58N75 turbocharger for TATA 497 TCIC -BS III engine. Similarly for the Fig. 3 for Highway (HW) route, Fig. 4 for the City Drive (CD) route, Fig. 5 for the slope up (SU) route and Fig. 6 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.

Fig. 1 Experimental set up of Data-Logger method

RESULTS AND DISCUSSIONS

The recorded observations were plotted on the respective compressor map in such a way that the simulator solution and data logger solution in combined form in the single compressor map for each route. The Fig.2 illustrates the turbo-match of turbo charger (a) B60J67, (b)A58N70, (c) A58N72 and (d) A58N75 at rough route in data -logger and simulation. Similarly Fig.3 to Fig 6 for simulated match and data-logger match at highway, city drive, slope up, slope down routes of data-logger respectively. This was observed that turbo-match of turbocharger B60J67 with the TATA 497 TCIC -BS III engine exhibits well in particularly in medium and higher speeds, but at lower speeds, the surge occurred. That is the risk of flow reversal at lower speeds by using the B60J67 turbocharger. This can be avoided by raising the minimum engine operating speeds to above 1200 rpm. The turbo match of A58N70 found safe at all engine speeds and routes. There is no alteration of engine speed for matching the turbo charger A58N70 for the TATA 497 TCIC -BS III engine. On other hand match of A58N72 and A58N75, the operating performance found safe and acceptable region at

TABLE 3 SIMULATED OBSERVATIONS FOR B60J67, B60J68, A58N70 AND A58N72 TURBO MATCHING

Engine Speed / Turbo-Charger	Mass Flow Rate (Kg/Sec.sqrt K/Mpa)				Pressure Ratio			
	1000	1400	1800	2400	1000	1400	1800	2400
B60J67	10.67	23.35	30.81	36.40	1.78	2.86	3.40	3.75
A58N70	09.53	20.19	27.96	35.49	1.85	3.04	3.55	3.76
A58N72	13.27	24.79	32.27	36.26	1.28	2.68	3.22	3.43
A58N75	14.23	25.94	34.57	38.46	1.29	2.70	3.39	3.63

TABLE-4 DATA-LOGGERS – ROUGH ROAD ROUTE OBSERVATIONS FOR B60J67, B60J68, A58N70 AND A58N72 TURBO MATCHING

Engine Speed / Turbo-Charger	Mass Flow Rate (Kg/Sec.sqrt K/Mpa)				Pressure Ratio			
	1000	1400	1800	2400	1000	1400	1800	2400
B60J67	07.08	15.11	21.43	27.09	1.38	1.98	2.36	2.58
A58N70	08.43	16.27	23.87	28.49	1.29	1.90	2.29	2.51
A58N72	09.32	17.23	25.73	29.72	0.97	1.77	2.25	2.38
A58N75	10.46	18.45	26.84	30.82	0.84	1.70	2.17	2.32

TABLE 5 DATA-LOGGERS – HIGHWAY ROUTE OBSERVATIONS FOR B60J67, B60J68, A58N70 AND A58N72 TURBO MATCHING

Engine Speed / Turbo-Charger	Mass Flow Rate (Kg/Sec.sqrt K/Mpa)				Pressure Ratio			
	1000	1400	1800	2400	1000	1400	1800	2400
B60J67	07.84	15.62	21.57	27.46	1.38	1.98	2.36	2.59
A58N70	08.52	16.39	23.94	28.91	1.31	1.87	2.30	2.51
A58N72	09.39	17.28	25.79	29.77	0.97	1.77	2.25	2.38
A58N75	10.52	18.51	26.89	30.85	0.84	1.70	2.17	2.32

TABLE 6 DATA-LOGGERS – CITY DRIVE OBSERVATIONS FOR B60J67, B60J68, A58N70 AND A58N72 TURBO MATCHING

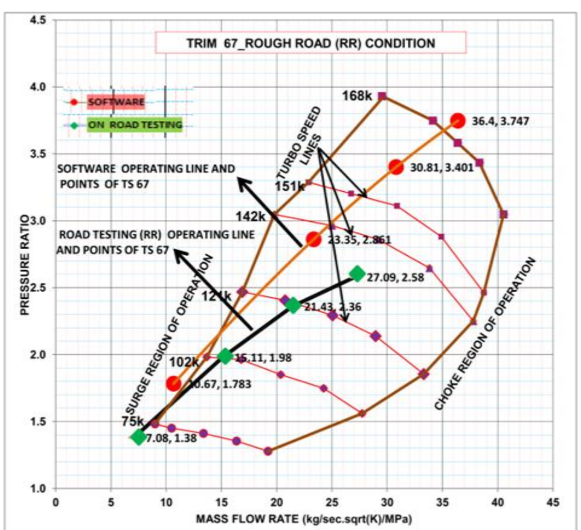
Engine Speed / Turbo-Charger	Mass Flow Rate (Kg/Sec.sqrt K/Mpa)				Pressure Ratio			
	1000	1400	1800	2400	1000	1400	1800	2400
B60J67	07.21	15.32	21.38	26.97	1.39	1.98	2.38	2.61
A58N70	08.49	16.31	23.78	28.37	1.32	1.95	2.33	2.56
A58N72	09.43	17.32	25.84	29.86	0.99	1.83	2.29	2.41
A58N75	10.58	18.54	26.93	30.91	0.88	1.76	2.19	2.36

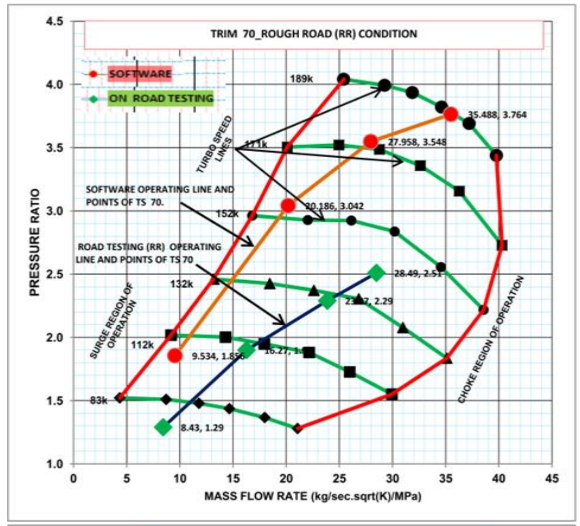
TABLE 7 DATA-LOGGERS – SLOPE UP ROUTE OBSERVATIONS FOR B60J67, B60J68, A58N70 AND A58N72 TURBO MATCHING

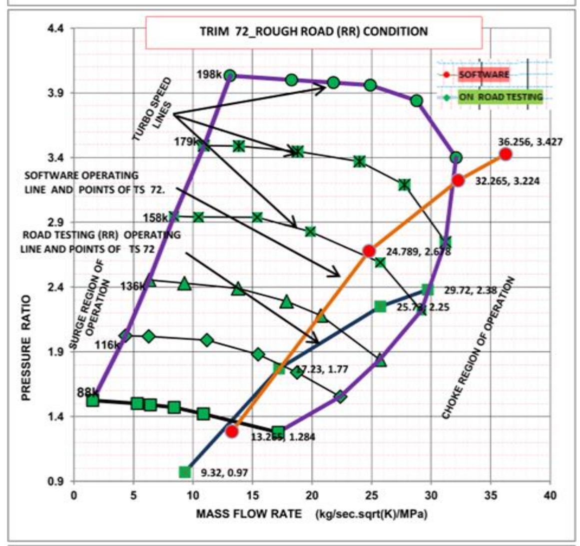
Engine Speed / Turbo-Charger	Mass Flow Rate (Kg/Sec.sqrt K/Mpa)				Pressure Ratio			
	1000	1400	1800	2400	1000	1400	1800	2400
B60J67	07.80	15.51	21.64	27.77	1.41	2.04	2.40	2.64
A58N70	08.58	16.34	23.98	28.98	1.31	2.00	2.37	2.58
A58N72	09.51	17.76	25.95	29.93	0.96	1.85	2.30	2.46
A58N75	10.62	18.60	26.98	30.95	0.88	1.79	2.19	2.39

TABLE 8 DATA-LOGGERS – SLOPE DOWN ROUTE OBSERVATIONS FOR B60J67, B60J68, A58N70 AND A58N72 TURBO MATCHING

Engine Speed / Turbo-Charger	Mass Flow Rate (Kg/Sec.sqrt K/Mpa)				Pressure Ratio			
	1000	1400	1800	2400	1000	1400	1800	2400
B60J67	7.67	15.19	21.46	27.21	1.36	1.96	2.34	2.60
A58N70	8.47	16.32	23.89	28.42	1.30	1.95	2.31	2.50
A58N72	9.27	17.12	25.47	29.59	0.98	1.73	2.18	2.34
A58N75	10.37	18.42	26.53	30.67	0.81	1.68	2.16	2.30







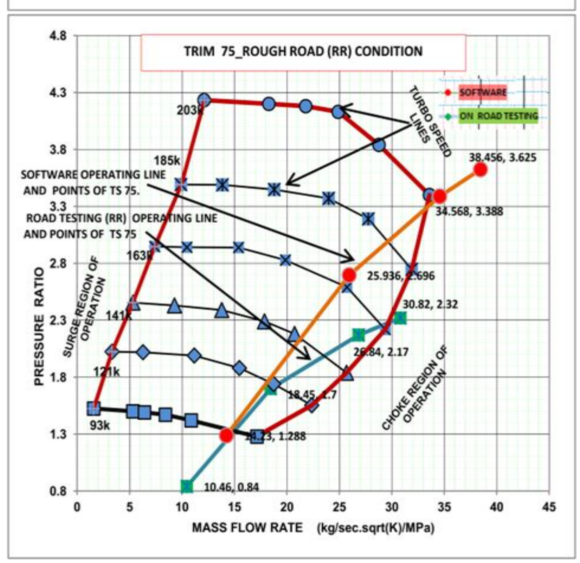
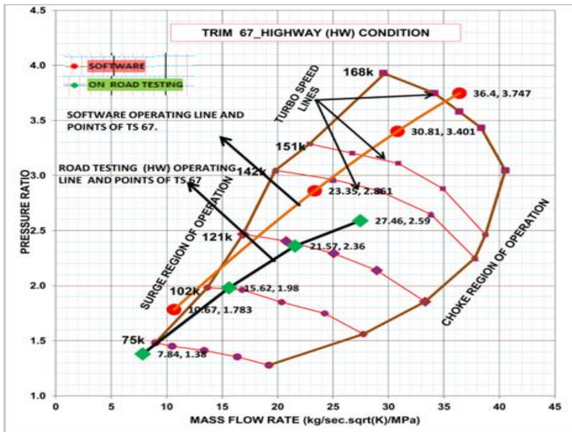
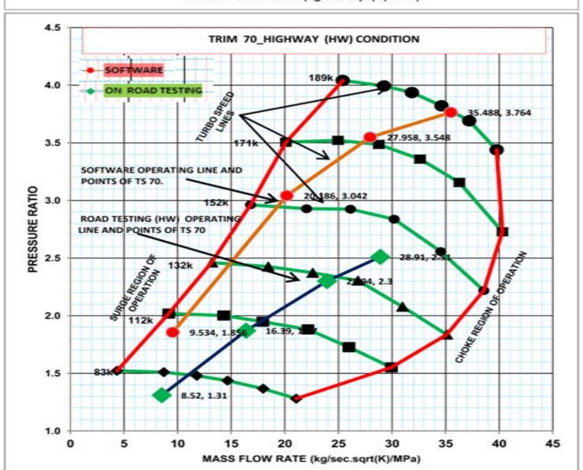
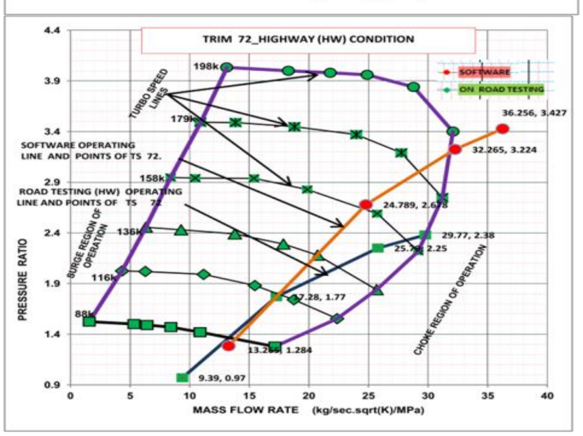


Fig. 2 B60J67, A58N70, A58N72 and A58N75 Turbo-match- by Simulation & Data-logger – Rough Road

lower and medium speeds. But the hazard of choke occurs at higher speed. According data-logger test of turbo match with TATA 497 TCIC -BS III engine, the maximum engine speed to be reduced little minimum from 2400 rpm for A58N72 turbo-charger and the maximum engine speed should be less than 2200rpm for A58N75 turbo-charger. The turbocharger A58N70 exhibits good operating performance in entire speed range and this best match performance was ensured with outputs of all five operated routes (in Data-logger method).







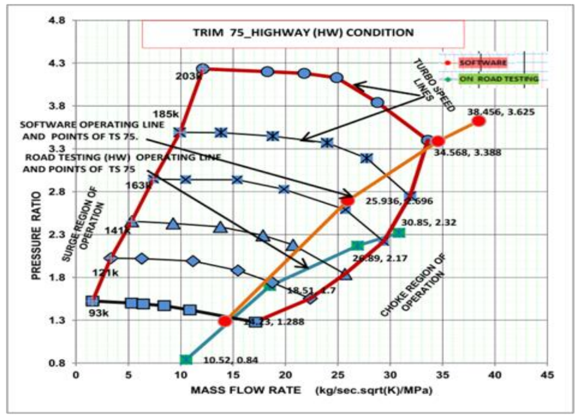
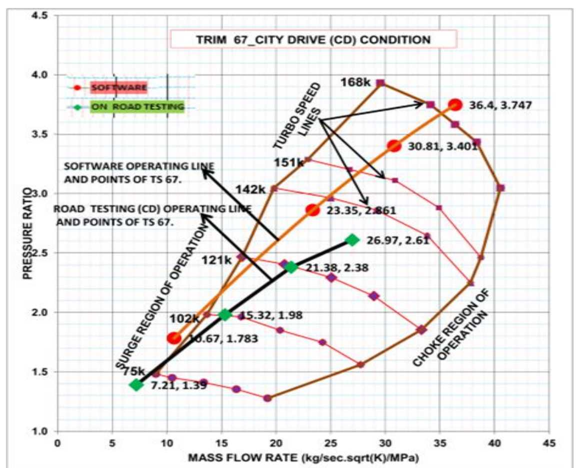
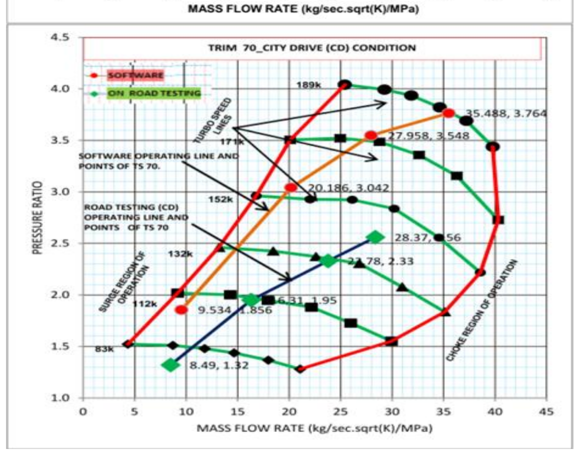


Fig.3 B60J67, A58N70, A58N72 and A58N75 Turbo-match- by Simulation & Data-logger – Highway Route

CONCLUSION

The evaluation of the turbo-matching appropriateness of B60J67, B60J68, A58N70 and A58N72 turbochargers for TATA 497 TCIC - BS III engine is discussed in detail. The simulation method is employed to find the turbo-match





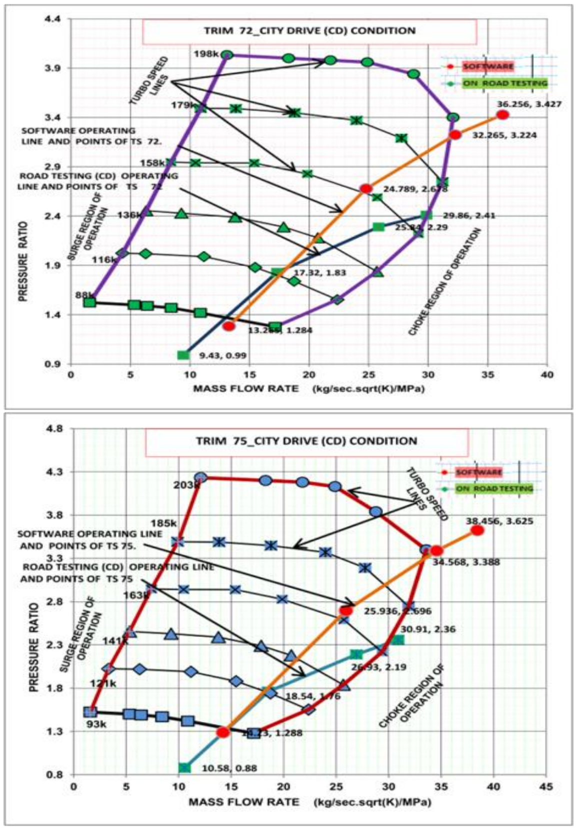


Fig. 4 B60J67, A58N70, A58N72 and A58N75 Turbo-match- by Simulation & Data-logger – City Route

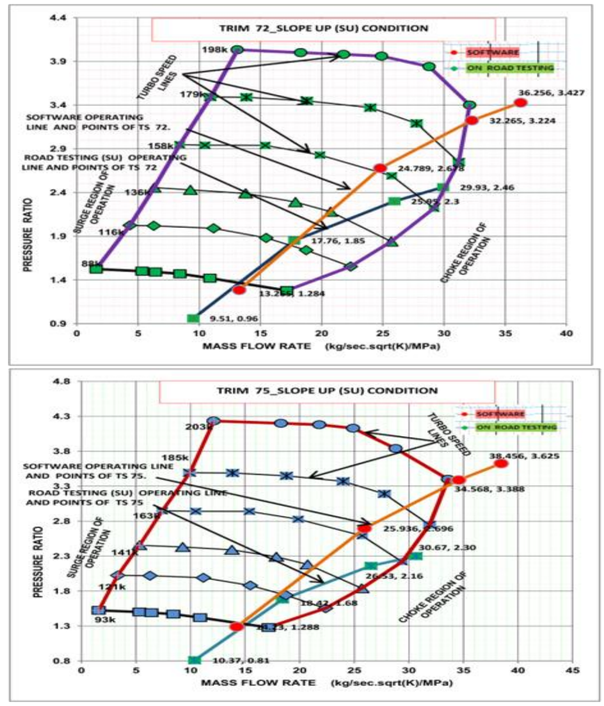
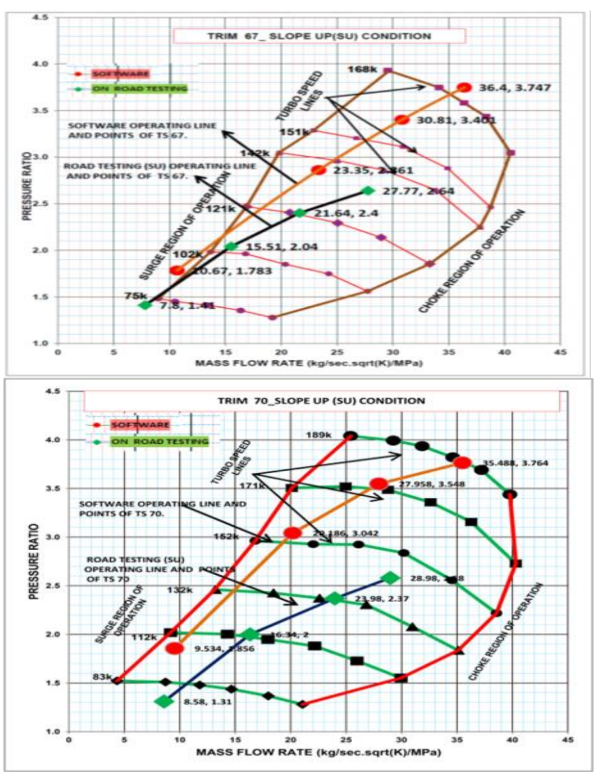
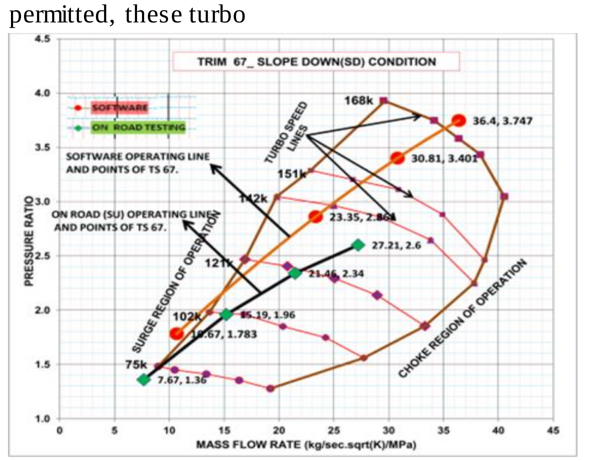


Fig. 5 B60J67, A58N70, A58N72 and A58N75 Turbo-match- by Simulation & Data-logger – Slope-up Route

of turbochargers individually with the engine. The same was verified by experimental method (Data-logger) at different routes. The simulator gives higher values than the actual values obtained through experimentation. 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. The appropriateness presented in the graphical form in compressor map. The results reveal that the choke hazard occurs especially at higher speeds with A58N72 turbocharger. And surge occurred while using Turbo Chargers B60J67 & B60J68. If the alteration of engine speed limits is permitted, these turbo





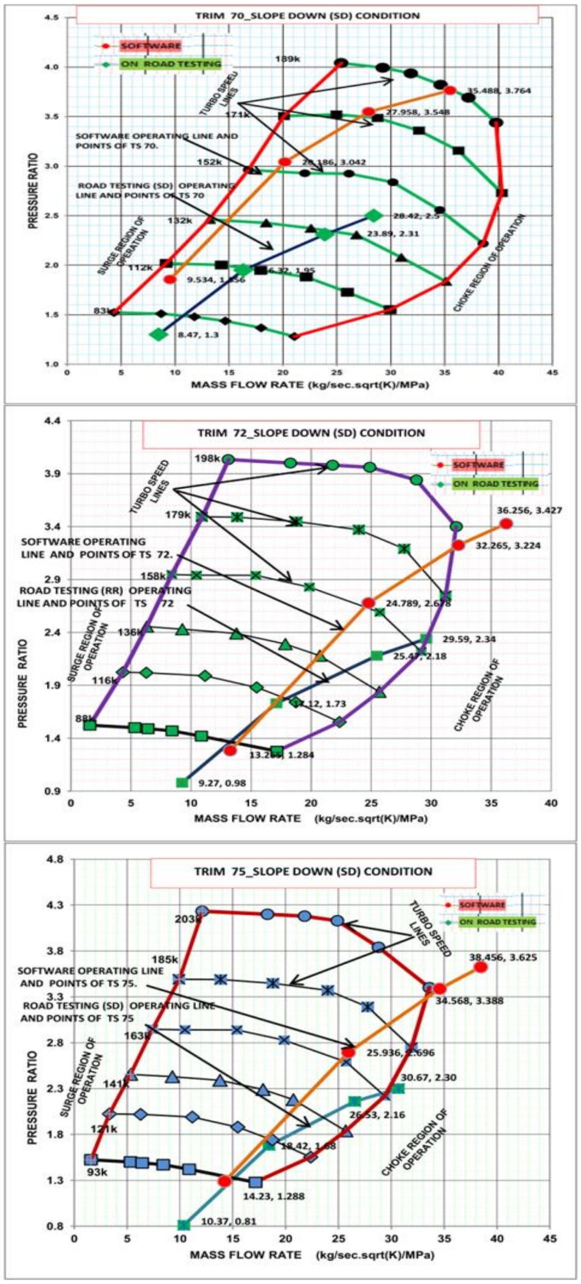


Fig. 6 B60J67, A58N70, A58N72 and A58N75 Turbo-match- by Simulation & Data-logger – Slope-Down Route

chargers can be matched. In the three mismatched turbochargers B60J68 and A58N72, required minimum changes in the speed limit alteration than B60J67. The match of A58N70 turbocharger exhibits safe and well operating conditions at all speeds irrespective of routes in which vehicle operated. Hence it can be concluded that the A58N70 turbocharger is the best match for the TATA 497 TCIC -BS III engine.

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