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INTERNATIONAL JOURNAL OF CURRENT RESEARCH

International Journal of Current Research
Vol. 9, Issue, 11, pp.61316-61325, November, 2017

ISSN: 0975-833X

RESEARCH ARTICLE

SIMULATION AND EXPERIMENTAL EVALUATION OF TURBO-MATCHING APPROPRIATENESS OF TURBO-CHARGERS FOR TATA 497 TCIC -BS III ENGINE

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ARTICLE INFO

Article History:
Received 27th August, 2017
Received in revised form
10th September, 2017
Accepted 29th October, 2017
Published online 30th November, 2017

Key words:
Turbo-Matching,
Trim, Turbocharger,
Compressor Map, Surge,
Choke, Simulation,
Data-Logger.

ABSTRACT

The charge booster preferred for load vehicles for ensuring best engine performance at all speeds and road conditions especially at higher load. The arbitrary adaption of turbocharger sometimes gives negative effects like surge and chokes in charge flow to engine. Many approaches reported to match the turbocharger for the desired vehicle engine. Bull all such tasks are tedious and some may be more expensive. But perfect match gives many distinguished advantages and cost worthy. This study focuses on the match of appropriate turbocharger for TATA 497 TCIC -BS III engine and evaluate the alternative possibilities for match other turbochargers. Five turbochargers with different trims were considered they are: trim 67 (B60J67), trim 68 (B60J68), trim 70 (A58N70) trim 72 (A58N72) and 75(A58N75). The Five different road conditions like rough, highway, city drive, slope up and slope down were included for evaluation. The simulation and experimental methods used to find the turbo-match performances. The compressor map used for analysis of appropriateness of turbo-matching.

Citation: Badal Dev Roy and Dr. Saravanan,R., 2017. "Simulation and experimental evaluation of turbo-matching appropriateness of turbo-chargers for tata 497 tcic -bs iii engine", *International Journal of Current Research*, 9, (11), 61316-61325

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 CO_2 emission, etc., (Cantore *et al*., 2001; Guzzella *et al*., 2000; Lecointe, 2003; Saulnier, 2004; Lake *et al*., 2004). Due to the character of a centrifugal compressor, the turbocharger with engine yields lesser torque than naturally aspirated engine at lower speeds (Attard *et al*., 2006; Lefebvre, 2005). 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 (Tashima *et al*., 1994), incorporate the limiting fuel system, reducing the inertia, improvements in bearing, modification on aerodynamics (Watanabe *et al*., 1996), establishing electrically supported turbocharger (Kattwinkel *et al*., 2003), the use of positive displacement charger i.e., secondary charging system and use of either electric compressor or positive the a displacement charger with turbocharger (Kattwinkel *et al*., 2003; Ueda *et al*., 2001), facilitating the geometrical variation on the compressor and a turbine (Kawaguchi *et al*., 1999), adopting the twin turbo system (Cantemir, 2001), 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 findings were reported in this case still the problem is exist. (Kawaguchi *et al*., 1999; Andersen *et al*., 2006; Filipi, 2001; Brace *et al*., 1999; Arnold *et al*., 2002). Though the advancements in system design like the variable geometry turbine, common rail injection system, and multiple injections, the problem has still persisted due to the limiting parameter say the 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.

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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 affected as well as affects the engine performance (Lake *et al*., 2004;),(Millo *et al*., 2005; Watson, 1982). 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 (Watson, 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 (Badal Dev Roy *et al*., 2016). 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 turbo-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 (Watson *et al*., 1982). The on road test type investigation is called Data Logger based Matching method is adopted in this research. (Badal *et al*., 2016) discussed the data-logger turbocharger matching method in detail and compared with the result of the test-bed 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 appropriateness of matching of the turbocharger with B60J67, B60J68, A58N70, A58N72 and A58N75 for the TATA 497 TCIC -BS III Engine by simulator method. The validation of the same by Data-Logger based 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.

Simulator Based Matching

Various kinds of simulation software are being used for turbo matching. 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.

Data Logger based Matching

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 type 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.

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.

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 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	4 Cylinders 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.

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

Trim Size (%)	67	68	70	72	75
Max. Speed	200000 rpm				
Turbo Make	HOLSET				
Turbo Type	WGT-IC (Waste gated Type with Intercooler)				
Inducer Dia. (mm)	46.1	46.9	48.6	50.1	52.5
Exducer Dia. (mm)	68.8	68.9	69.4	69.58	70

Experimental Observation

The simulator and data-logger method is adopted to match the turbo Chargers B60J67, B60J68 and A58N70 for TATA 497 TCIC -BS III engine. The matching performance can be simulated by software. The specification of the manufacture is enough for simulation. The important operating parameters are the pressure raio and mass flow rate for knowing the match performance. The simulated observation for turbo-matching of turbochargers B60J67, B60J68, A58N70, A58N72 and A58N75 were furnished in the Table 3. 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 tonnes of net weight. The grass weight of vehicle is 11 tonnes. The experimental setup is shown in the Fig. 1. The vehicle operated at different route conditions (rough, highway, city drive, slope up and slope down) at specified engine speed (1000, 1400, 1800 and 2400 rpm) one by one. The road condition wise observations presented from Table 4 to Table 8. Those observations presented in the order of rough route, highway, city drive, slope-up and slope-down from Table 6 to Table 10 with respect to various engine speeds. The compressor map used for analysing the matching performance of turbochargers for the desired engine. The recorded observations were plotted on the compressor map in such a way that the simulator solution and data logger solution in combine in single compressor map for each route.

Table 3. Simulated observations for B60J67, B60J68, A58N70, A58N72 and A58N75 Turbo matching

Engine Speed (rpm) / TC	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	36.4	1.783	2.861	3.401	3.747
B60J68	11.449	22.56	29.451	36.872	1.856	3.051	3.556	3.817
A58N70	9.534	20.186	27.958	35.488	1.856	3.042	3.548	3.764
A58N72	13.265	24.789	32.265	36.256	1.284	2.678	3.224	3.427
A58N75	14.23	25.936	34.568	38.456	1.288	2.696	3.388	3.625

Table 5. Data-logger (Rough Road) observations for B60J67, B60J68, A58N70, A58N72 and A58N75 Turbo matching

Engine Speed (rpm) / TC	Mass Flow Rate (Kg/Sec.sqrt K/Mpa)				Pressure Ratio			
	1000	1400	1800	2400	1000	1400	1800	2400
B60J67	7.08	15.11	21.43	27.09	1.38	1.98	2.36	2.58
B60J68	7.37	15.41	21.73	27.43	1.35	1.95	2.33	2.55
A58N70	8.43	16.27	23.87	28.49	1.29	1.9	2.29	2.51
A58N72	9.32	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	1.7	2.17	2.32

Table 6 Data-logger (Highway) observations for B60J67, B60J68, A58N70, A58N72 and A58N75 Turbo matching

Engine Speed (rpm) / TC	Mass Flow Rate (Kg/Sec.sqrt K/Mpa)				Pressure Ratio			
	1000	1400	1800	2400	1000	1400	1800	2400
B60J67	7.84	15.62	21.57	27.46	1.38	1.98	2.36	2.59
B60J68	8.12	15.92	21.87	27.87	1.35	1.95	2.33	2.56
A58N70	8.52	16.39	23.94	28.91	1.31	1.87	2.3	2.51
A58N72	9.39	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	1.7	2.17	2.32

Table 6 Data-logger (City Drive) observations for B60J67, B60J68, A58N70, A58N72 and A58N75 Turbo matching

Engine Speed (rpm) / TC	Mass Flow Rate (Kg/Sec.sqrt K/Mpa)				Pressure Ratio			
	1000	1400	1800	2400	1000	1400	1800	2400
B60J67	7.21	15.32	21.38	26.97	1.39	1.98	2.38	2.61
B60J68	7.41	15.52	21.68	27.39	1.36	1.95	2.35	2.59
A58N70	8.49	16.31	23.78	28.37	1.32	1.95	2.33	2.56
A58N72	9.43	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-logger (Slope up) observations for B60J67, B60J68, A58N70, A58N72 and A58N75 Turbo matching

Engine Speed (rpm) / TC	Mass Flow Rate (Kg/Sec.sqrt K/Mpa)				Pressure Ratio			
	1000	1400	1800	2400	1000	1400	1800	2400
B60J67	7.8	15.51	21.64	27.77	1.41	2.04	2.4	2.64
B60J68	8.02	15.81	21.94	27.97	1.38	2	2.39	2.62
A58N70	8.58	16.34	23.98	28.98	1.31	2	2.37	2.58
A58N72	9.51	17.76	25.95	29.93	0.96	1.85	2.3	2.46
A58N75	10.62	18.6	26.98	30.95	0.88	1.79	2.19	2.39

Table 8 Data-logger (Slope down) observations for B60J67, B60J68, A58N70, A58N72 and A58N75 Turbo matching

Engine Speed (rpm) / TC	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	2.6
B60J68	7.97	15.79	21.76	27.41	1.35	1.95	2.33	2.6
A58N70	8.47	16.32	23.89	28.42	1.3	1.95	2.31	2.5
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	2.3

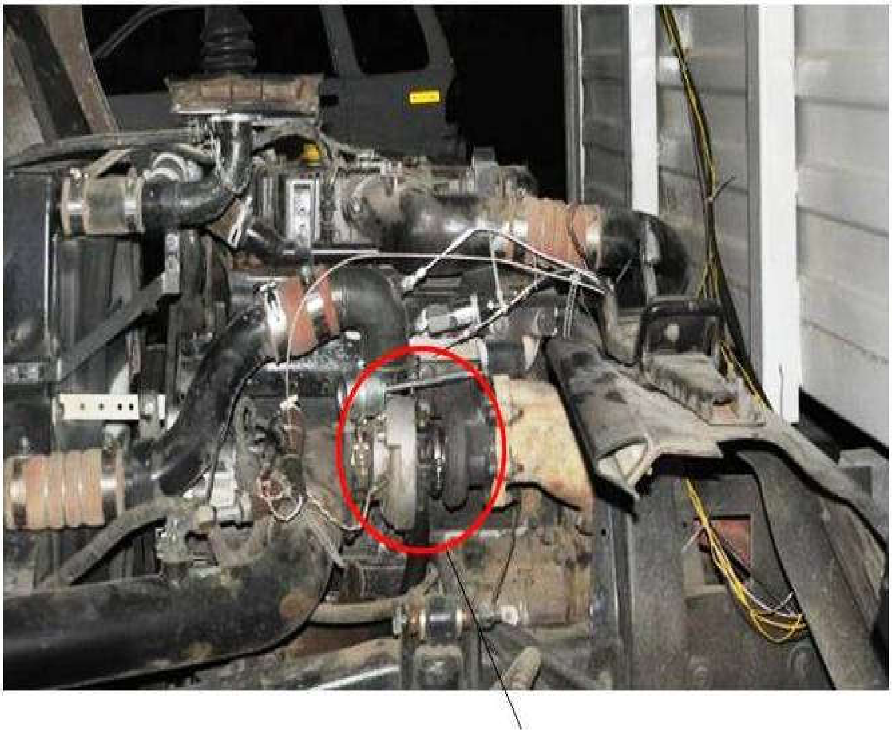

Figure 1. Experimental set up of Data-Logger method

The Fig. 2 is for turbo-match of B60J67, B60J68 and A58N70 turbochargers (left to right) at rough route and simulated solution. Similarly Fig. 3 to Fig. 6 for highway, city drive, slope up, slope down routes respectively.

RESULTS AND DISCUSSIONS

The operating conditions obtained separately for turbo matching of each turbochargers with engine in both methods (simulated and data-logger). In the Data-logger method road condition wise (rough road, highway route and the slope-up route) observations obtained by operating vehicle at desired engine speeds (1000,1400, 1800 and 2400 rpm). 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. Those observed operating conditions marked on the respective compressor map and presented road condition wise from Figure 2 to Figure 6.

This was observed that turbo-match of turbochargers B60J67 and B60J68 with the TATA 497 TCIC -BS III engine exhibits well in particularly in medium and higher speeds, but at lower speeds, the surge occurred. Surge causes the reversal of flow. According to data-logger at all the road conditions the increase of minimum speeds the engine from 1000 rpm and 1200 rpm helps to matching of B60J68 and B60J67 respectively.

The turbocharger A58N70 exhibits well operating performance in entire speed range and this best match performance was ensured with outputs of all five operated routes (in Data-logger method) and simulated matching. The turbo match of turbo chargers A58N72 and A58N75 reveals that the operating performance found safe and acceptable region at lower and medium speeds. But the hazard of choke occurs at higher speed. The Chock causes the quick fall of compressor efficiency, Chances for compressor end oil leakage and insufficient air supply.

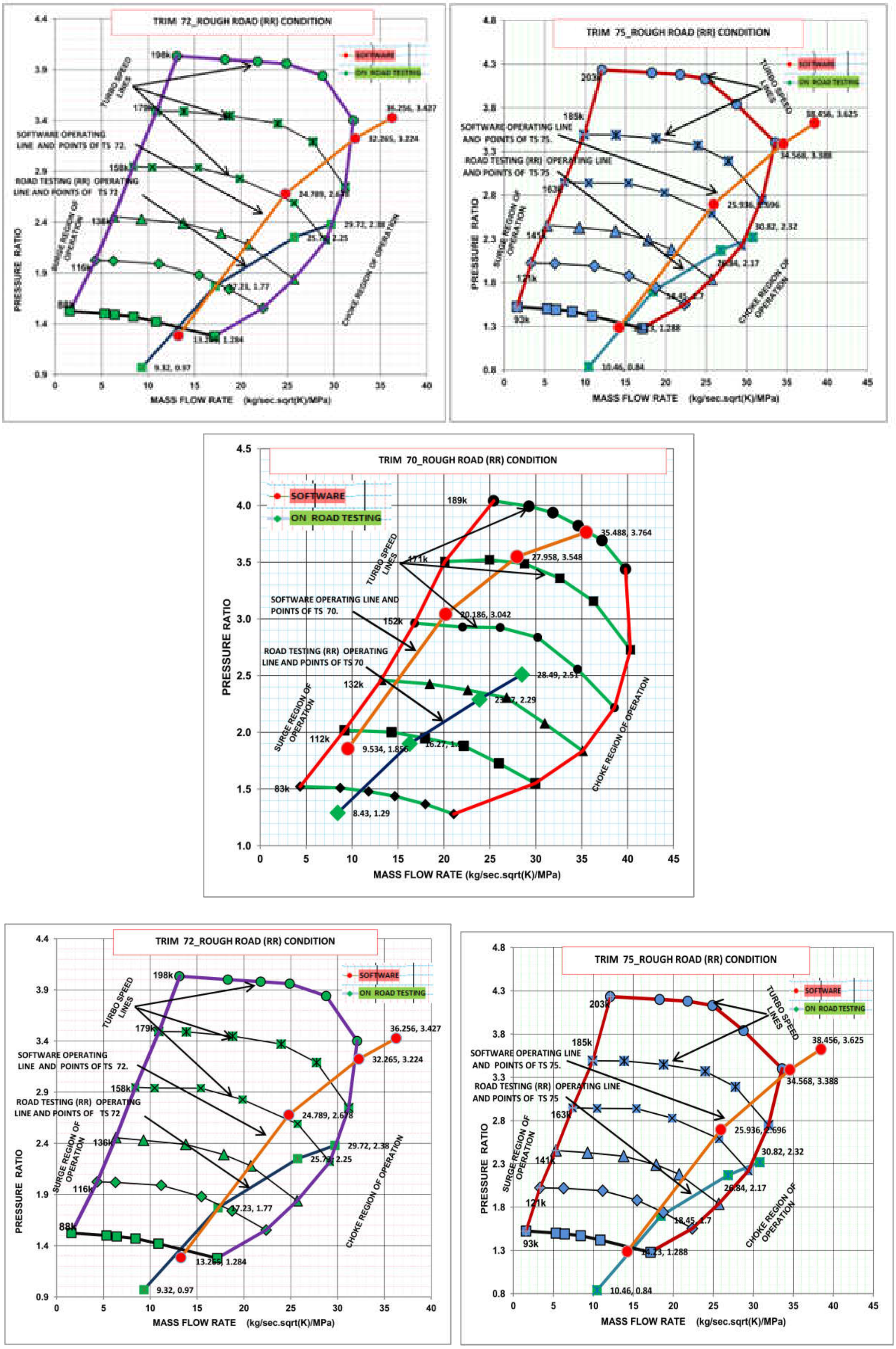

Figure 2. Turbo-match of Turbo Chargers by Simulation & Data-logger (Rough Road)

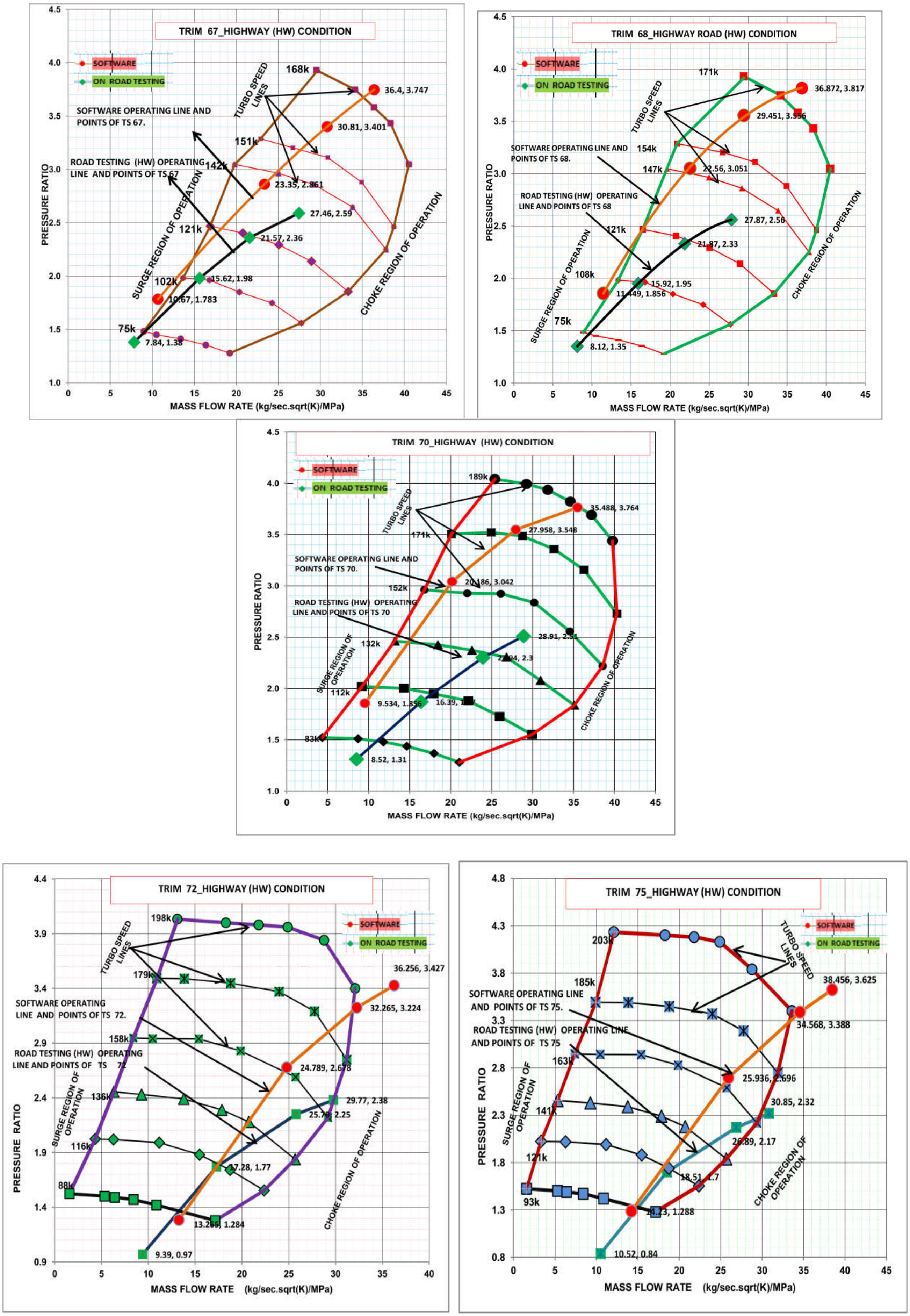

Figure 3. Turbo-match of Turbo Chargers by Simulation & Data-logger (Highway Route)

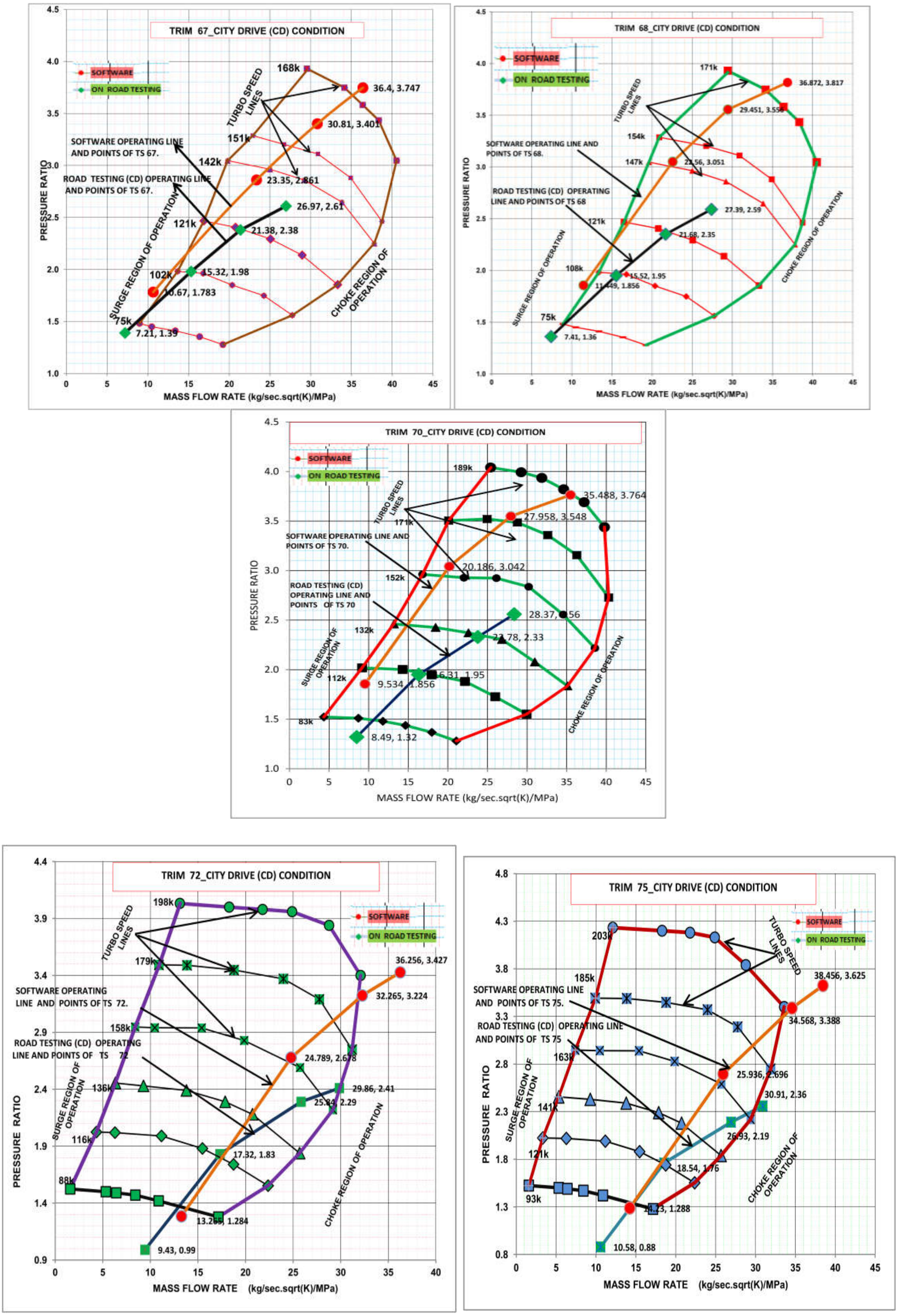

Figure 4. Turbo-match of Turbo Chargers by Simulation & Data-logger (City Route)

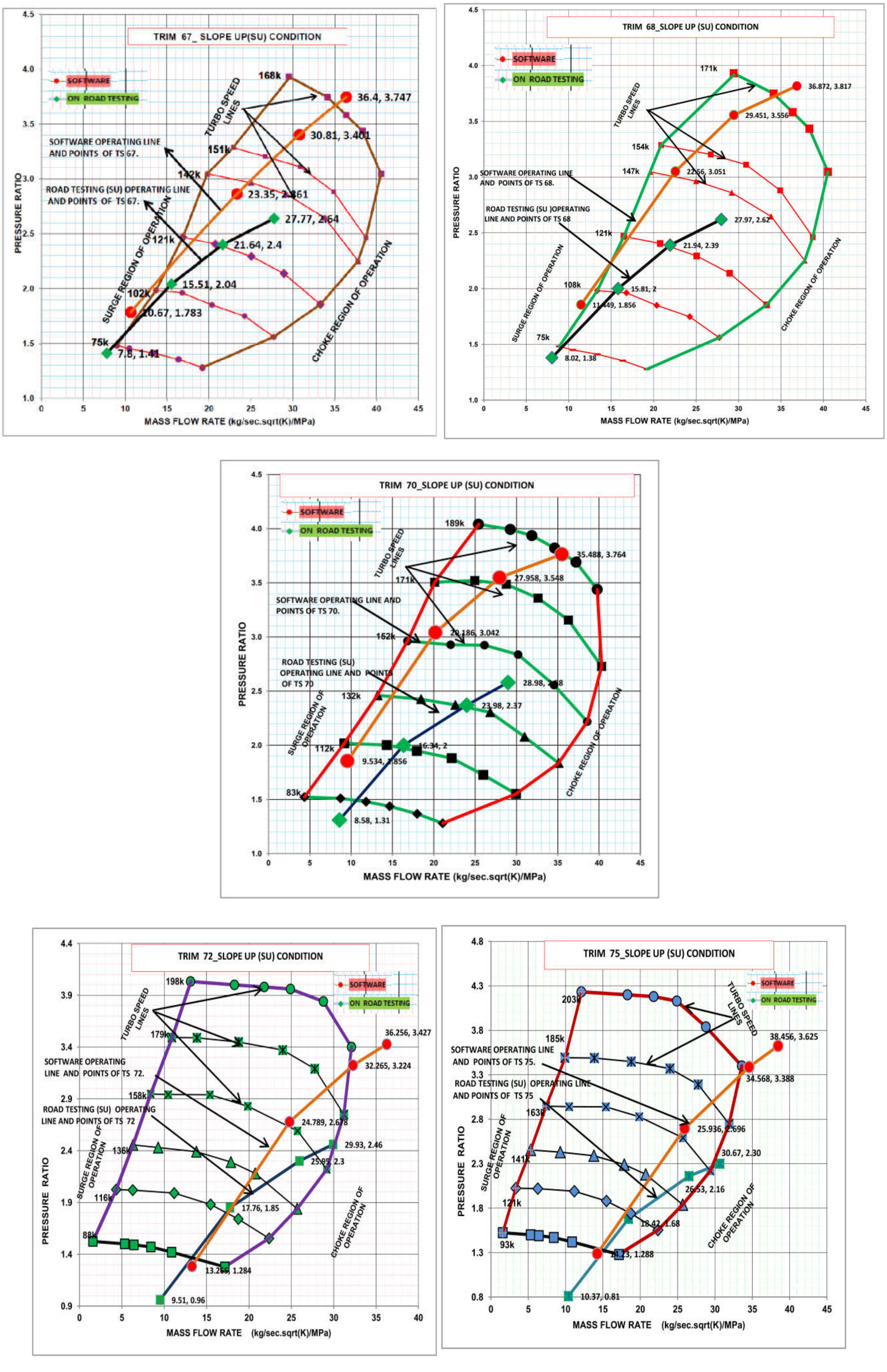

Figure 5. Turbo-match of Turbo Chargers by Simulation & Data-logger (Slope-up Route)

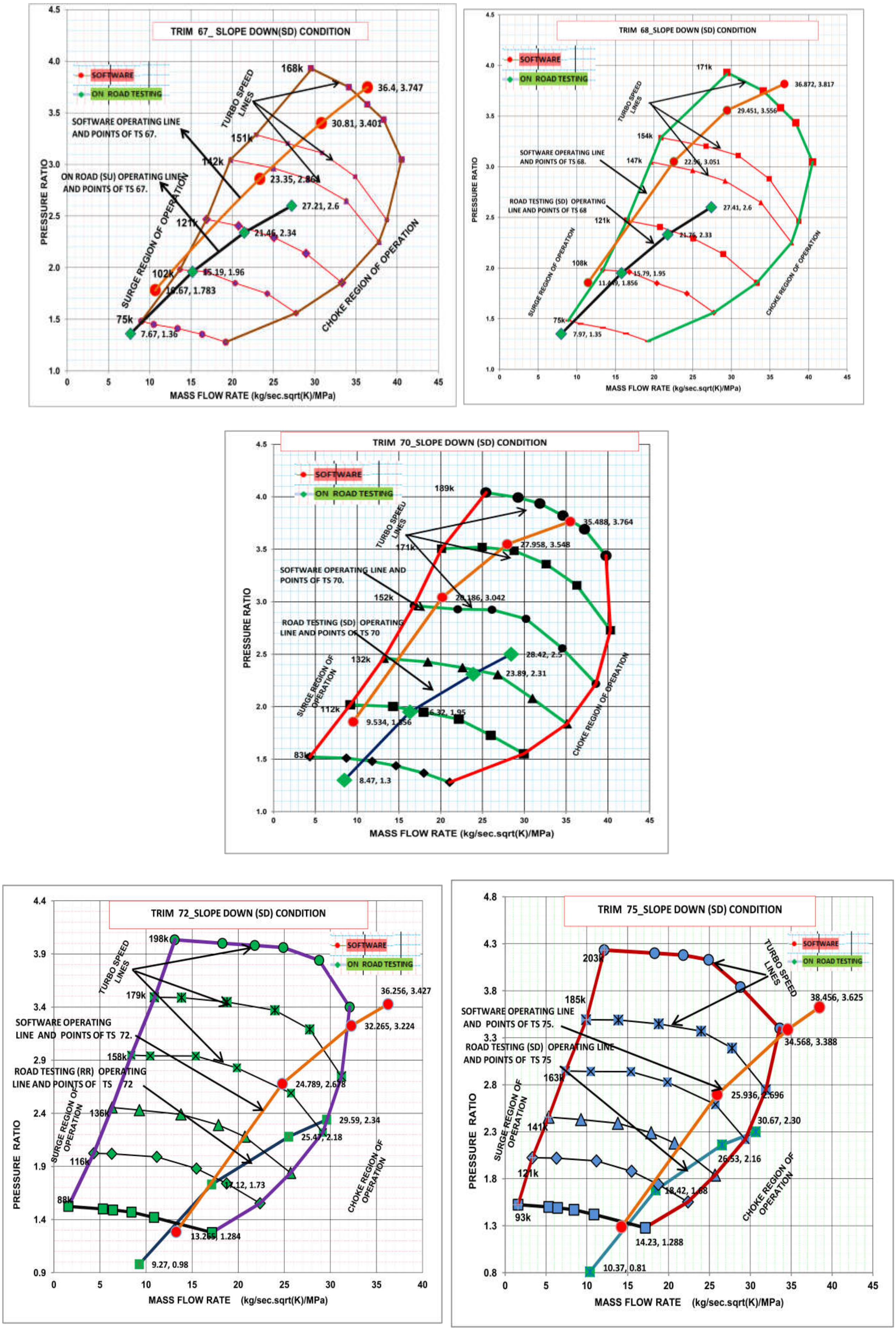

Figure 6. Turbo-match of Turbo Chargers by Simulation & Data-logger (Slope-Down Route)

For avoiding these problem and matching with desired engine, the maximum engine speed to be reduced from the 2400 rpm and 2200 rpm for turbo chargers A58N72 and A58N75 respectively.

Conclusion

The evaluation of the turbo-matching appropriateness of B60J67, B60J68, A58N70, A58N72 and A58N75 turbochargers for TATA 497 TCIC - BS III engine is discussed in detail. The simulation method is employed to find the turbo-match 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 and A58N75 turbochargers. And surge occurred while using Turbo Chargers B60J67 & B60J68. If the alteration of engine speed limits is permitted, these turbo - chargers can be matched. In the four 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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