|| Volume 2 || Issue 5 || November 2017 || ISSN (Online) 2456-0774
INTERNATIONAL JOURNAL OF ADVANCE SCIENTIFIC RESEARCH
AND ENGINEERING TRENDS

Simulation and Experimental Study on Turbo Matching Appropriateness of Turbo Chargers with Trims 67, 68, 70 &75 for Commercial Vehicle

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***Abstract*— Turbocharger is a charge booster for internal combustion engines to ensure best engine performance at all speeds and road conditions especially at the higher load. Random selection of Turbocharger may cause ill effect like surge and choke in the breathing requirements of the Engine. Appropriate match or selection of the turbocharger is a tedious task. But perfect match gives more distinguished advantages on increasing the performance of the engine. This study focuses to match the turbocharger with engine through simulation and on road test. The objective of this work is to find matching appropriateness of turbochargers with trim 67 (B60J67), trim 68 (B60J68), trim 70 (A58N70) and trim 75 (A58N75) for the TATA 497 TCIC -BS III engine. In data-logger method the road routes like Rough road, highway, City Drive, Slope up and slope down were considered for evaluation. The operating conditions with speeds, routes and simulated outputs were compared with the help of compressor map.**

Keywords:-*Turbo-Matching, Turbocharger, Simulation, On-Road Testing, Compressor Map, Surge, Choke.*

I INTRODUCTION

A 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 a centrifugal compressor, the turbocharger with 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 on bearing, modification on-aerodynamics [9], establishing electrically supported turbocharger [10], the usage of positive displacement charger i.e., secondary charging system and use of either electric compressor or positive the a displacement charger with turbocharger [10],[11] facilitating the geometrical variation on the compressor and a 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 the system is not exact, match for petrol engines [15]. Even though many findings were reported in this case still the problem is exist. [12],[15]-[18]. 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. [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 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 affected as well as affects 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 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 and A58N75 for 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 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 and 75 are considered 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 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. 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.

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 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 Table1

Table -1 : Specification Of Engine

Sr.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 speed	2400 rpm (Max power), 1400 rpm (Max Torque)

E. Turbochargers Specifications

The TATA Short Haulage Truck, turbochargers of B60J67, B60J6, A58N70 and A58N75 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

|| Volume 2 || Issue 5 || November 2017 || ISSN (Online) 2456-0774
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Table 2: Specification Of Turbo Chargers

S.No	Description	B60J67	B60J68	A58N70	A58N75
1	Turbo maximum Speed	200000 rpm			
2	Turbo Make		HOLSET		
3	Turbo Type		WGT-IC (Waste gated Type with Intercooler)		
4	Trim Size (%)	67	68	70	75
5	Inducer Diameter	46.1mm	46.9mm	48.6 mm	52.50 mm
6	Exducer Diameter	68.8 mm	68.9 mm	69.4 mm	70.00 mm

III EXPERIMENTAL OBSERVATION

The simulator and data-logger method is adopted to match the turbo Chargers B60J67, B60J68 and A58N70 and A58N75 for TATA 497 TCIC -BS III engine. The matching performance can be obtained in the simulator by feeding necessary data from the manufacturer catalogue.

The simulator simulates and presented the values like -pressure ratio and mass flow rate at various speeds. These data were used for identifying the matching performance of the turbocharger for the desired engine. The simulated observations for matching of the turbochargers B60J67, B60J68, A58N70 and A58N75 turbochargers were furnished in the Table 3. 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.

Figure. 1 Experimental set up of Data-Logger method

The experimental setup is shown in the Fig. 1. The same operating speeds (1000, 1400, 1800 and 2400 rpm) were set for making observations. The on road test conducted and recorded data at different routes, namely rough route, highway, city drive, slope-up and slope-down and the same was–logger database. 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 analyzing 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 combined form in the single compressor map for each route. 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.

TABLE 3 SIMULATED OBSERVATIONS FOR B60J67, B60J68, A58N70 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
A58N75	14.23	25.936	34.568	38.456	1.288	2.696	3.388	3.625

TABLE 4 DATA-LOGGER (ROUGH ROAD) OBSERVATIONS FOR B60J67, B60J68, A58N70 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
A58N75	10.46	18.45	26.84	30.82	0.84	1.7	2.17	2.32

TABLE 5 DATA-LOGGER (HIGHWAY) OBSERVATIONS FOR B60J67, B60J68, A58N70 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
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 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
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 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
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 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
A58N75	10.37	18.42	26.53	30.67	0.81	1.68	2.16	2.3

IV RESULTS AND DISCUSSIONS

The operating conditions obtained in both cases of turbochargers with engine for both simulated and data-logger method with the rough road route, highway route and the slope-up route were obtained. These operating conditions were marked on the compressor map. The details of mappings already discussed above. 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. It also shows that B60J68 also shows the same pattern as B60J67, that is the risk of flow reversal at lower speeds by using the B60J67 and B60J68 turbocharger. Generally Lower speed operations are unavoidable for commercial vehicles. Suppose the B60J67 and B60J68 turbocharger adopted for the TATA 497 TCIC -BS III engine, the purpose could not able to meet. On other hand match of A58N75, the operating performance found safe and acceptable region at lower and medium speeds, but the hazard of choke occurs at higher speed according to simulated solution. Simulated solution state that the vehicle can operate safe with less than 1800 rpm of engine speed. But the actual test through data logger show the vehicle is safe by operating less than 2400 rpm of engine speed. The same results obtained all tests at five different routes. 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).

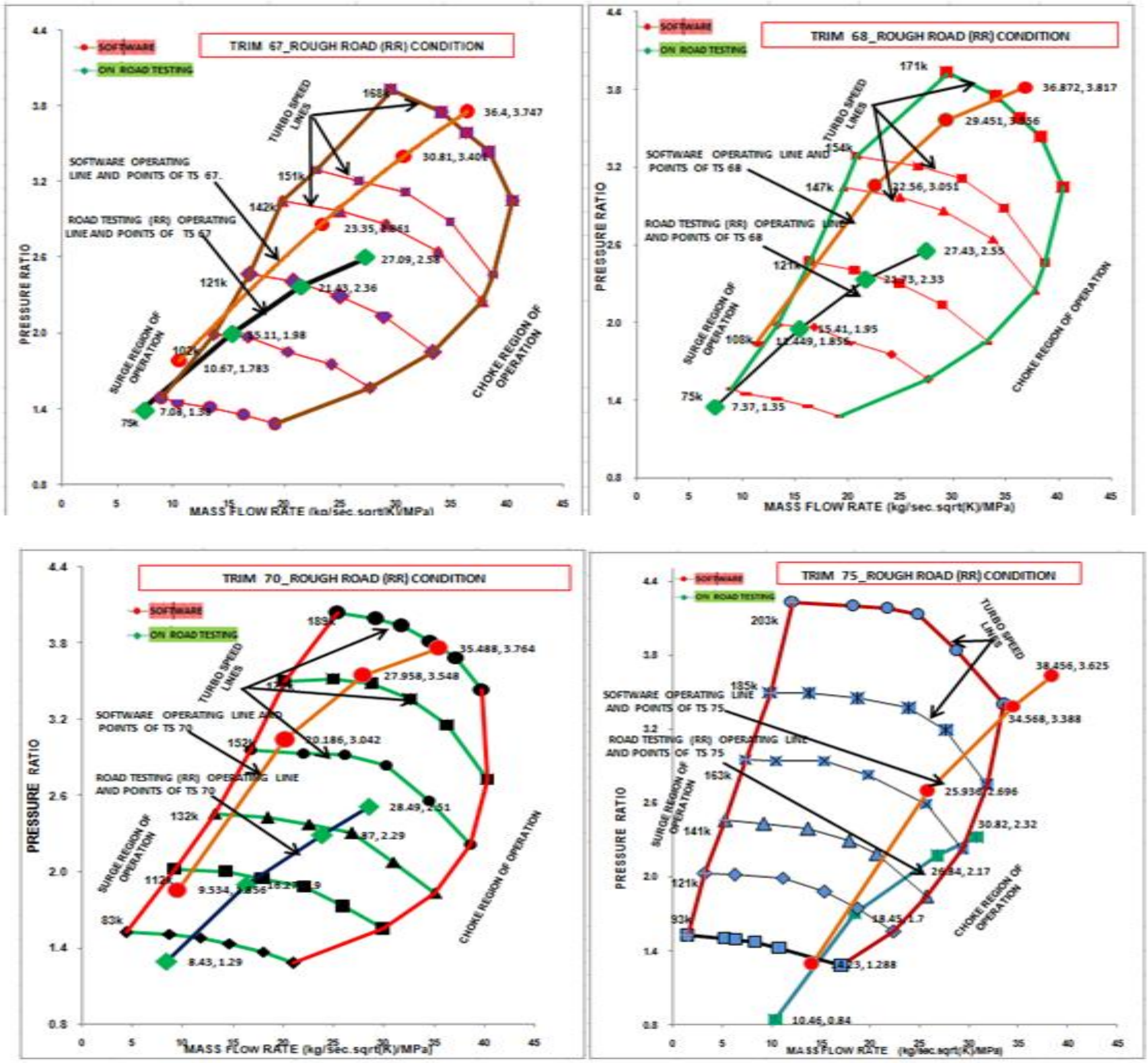

Figure.2 B60J67, B60J68, A58N70 AND A58N75 –Matching by simulation & data-logger Rough Road.

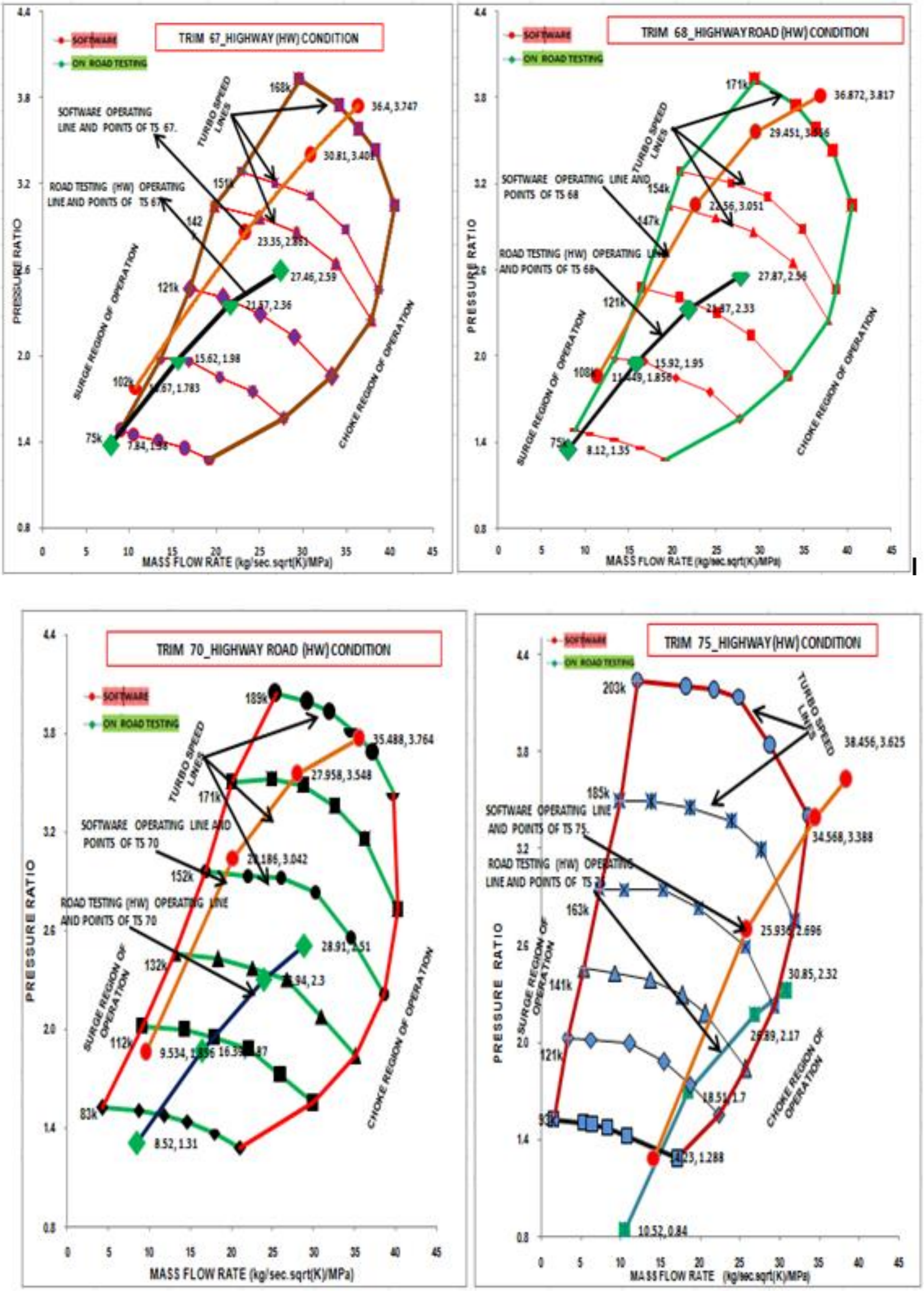

Figure. 3 B60J67, B60J68, A58N70 and A58N75 Matching by Simulation & Data-logger – Highway Route

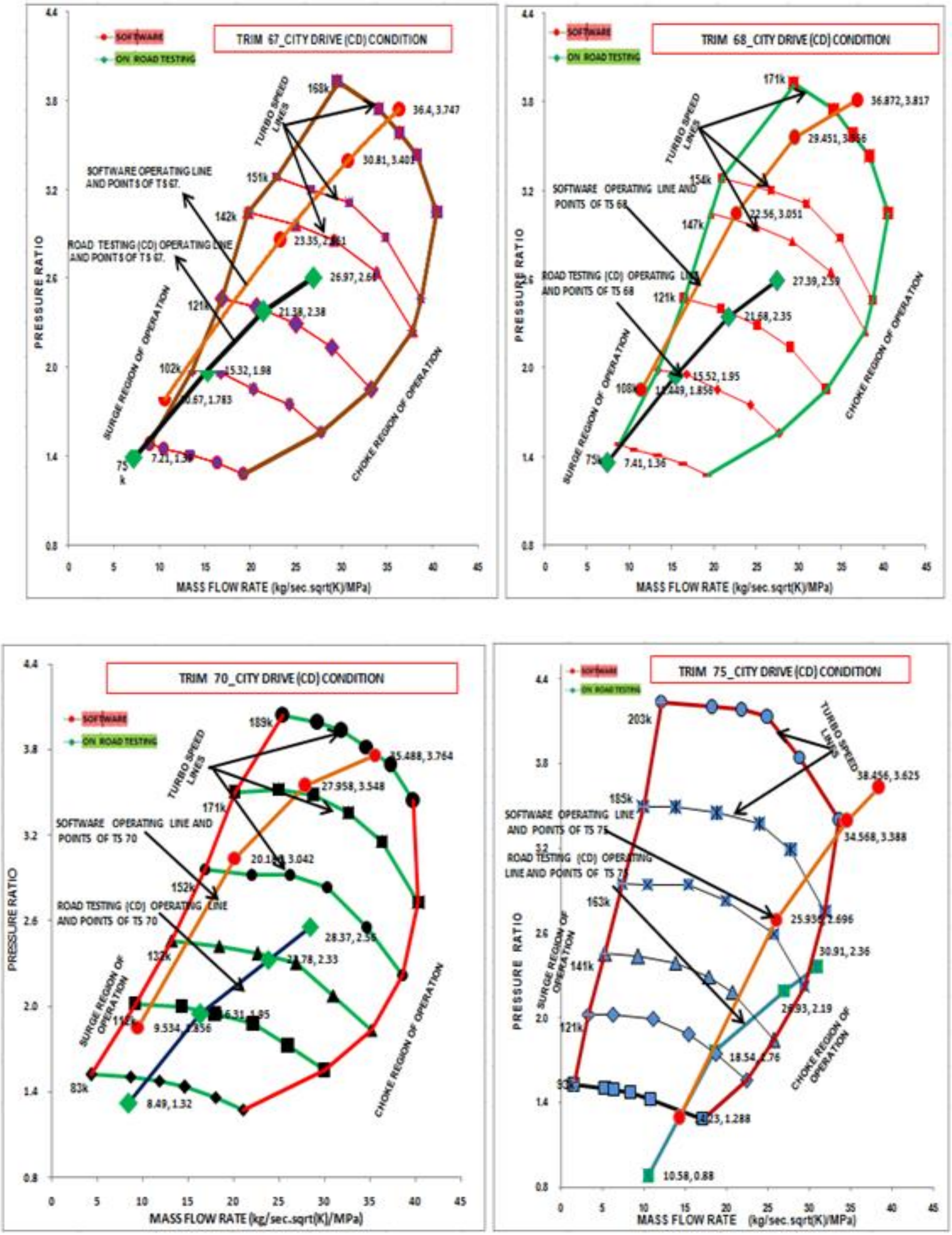

Figure. 4 B60J67, B60J68, A58N70 and A58N75- Matching by Simulation & Data-logger - City Route

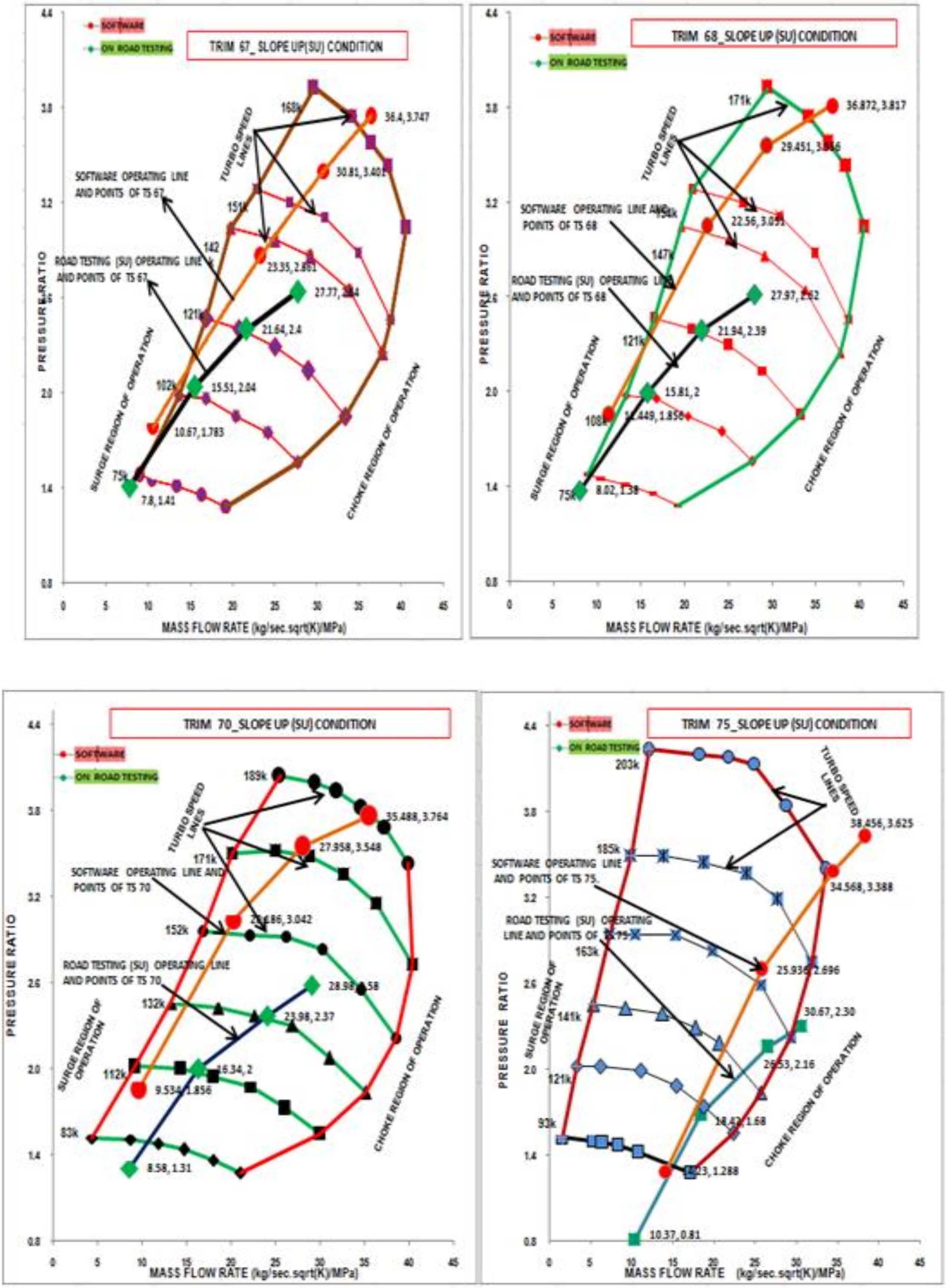

Figure. 5 B60J67, B60J68, A58N70 and A58N75- Matching by Simulation & Data-logger - Slope-up

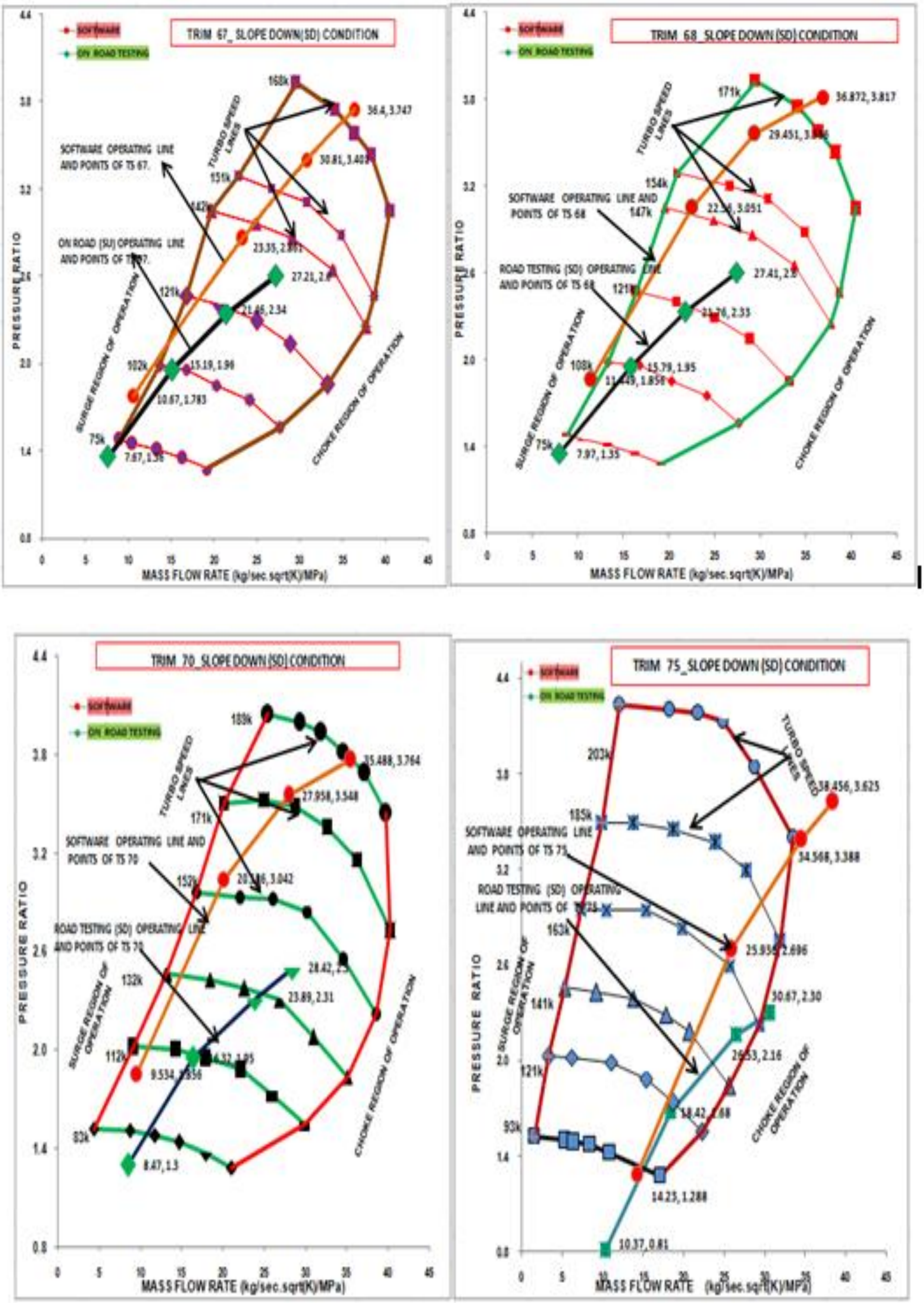

Figure. 6 B60J67, B60J68, A58N70 and A58N75- Matching by Simulation & Data-logger – Slope-Down

V CONCLUSION

The turbo-matching of B60J67, B60J68, A58N70 and A58N72 turbochargers for TATA 497 TCIC - BS III engine is considered. The simulator method is employed to find the turbo-match of turbochargers individually with the engine. The same was verified by experimental method called Data-logger at different routes. 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 simulator gives higher values than the actual values obtained through experimentation. The appropriateness presented in the graphical form in compressor map. The result depicts surge hazard occurs for B60J67 and B60J68 turbocharger at lower speed and choke hazard occurs especially at higher speeds with A58N72 turbocharger. The reduction operating speed certain extent can be compromised. But this case lowering the operating speed to safe range is operating the engine less than 1800 rpm and it is not recommended. .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.

ACKNOWLEDGMENT

The authors acknowledge M/s The Cummins Turbo Technologies and ARAI, Pune for their support and contribution for this research work. The authors also acknowledge to the Dr. M. Chandrasekaran, Joint Supervisor, Professor & Director / Mechanical Engineering, Dr. C. Dhanasekaran, Professor & Head / Mechanical Engineering, Co-ordinator for School of Engineering, Vels University, Chennai. Dr. V. Muthukumar, Professor, Saveetha Engineering College, Chennai & Dr.S.Santhanam, Professor, Rajalaskmi Engineering College, Chennai. TN. India. for their valuable suggestion to carry out this piece of research.

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