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# Investigation on Turbo-matching appropriateness Turbochargers with Trim 70, 72 and 75 for a Commercial Truck Engine

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**ABSTRACT**
The turbocharger is a charge boosting device in Internal Combustion engines and which helps to maintain good operating performance even at at high load condition. Inappropriate selection of turbocharger may leads to havoc effects like choke and surge in the charger flow and degrade the engine performance. The proper selection termed as Turbo-matching which is a tiresome task, expensive and requires enormous skills. But exact or perfect turbo-match gives distinguished performance improvement on Engine. This research work focuses on finding appropriateness of matching of turbochargers with trim sizes 70 (A58N70), trim 72 (A58N72) and trim 75 (A58N75) for the TATA 497 TCIC -BS III engine. The Simulation and Data-Logger Method adapted for finding matching performances. In data logger method, the road conditions like rough, Highway, City Drive, slope up and slope down were considered for vehicle operation at full load. The compressor map used for evaluating matching appropriateness in simulation, data-logger with road condition wise for each turbo-matching problem. The best match suggested and the possibilities of matching other turbochargers also discussed.
***Keywords*** – Turbo-Matching, Turbocharger, Simulation, Surge, choke, Data-Logger.

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## 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 $CO_2$ 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 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 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 A50N70, 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.

## II. MATERAIAL 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 70, 72 and 75 are considered for investigation.

### 2.1. 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.

### 2.2 Turbo-matching by Data Logger

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.

### 2.3. 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 a choke. In 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.

### 2.4. 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 1,500 rpm. The other specifications can be found in Table1.

**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. |

### 2.5 Turbochargers Specifications

The TATA Short Haulage Truck, turbochargers of B60J67, A58N72 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 N72 is the Trim Size of the turbocharger in percentage. The other specifications furnished in Table 2. All the turbo chargers are Waste gated Type with Intercooler (WGT-IC)

**Table 2:** Specification of Turbo Chargers

| Description | A58N70 | A58N72 | A58N75 |
|---|---|---|---|
| Turbo max. Speed | 200000 rpm | | |
| Turbo Make | HOLSET | | |
| Trim Size (%) | 70 | 72 | 75 |
| Inducer Diameter | 48.6 mm | 50.10 mm | 52.50 mm |
| Exducer Diameter | 69.4 mm | 69.58 mm | 70.00 mm |

## III. EXPERIMENTAL OBSERVATION

The simulator and data-logger method is adopted to match the turbo Chargers A58N70, A58N72 and A58N75 for TATA 497 TCIC -BS III engine. The matching performance can be simulated by using the manufacturer specifications. The outputs are pressure ratio and mass flow rate at various speeds. These data are essential to know the turbo-match performance. The simulated observations for matching of the turbochargers A58N70, A58N72 and A58N75 turbochargers 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 gross weight of vehicle is 11 tonnes. The experimental setup is shown in the Fig. 1. The same operating speeds (1000, 1400, 1800 and 2400 rpm) were considered for observations. The data-logger observations presented in the order of rough route, highway, city drive, slope-up and slope-down from Table 4 to Table 8. The compressor map used for analysing the matching performance of turbochargers for the desired engine. The recorded observations of data logger and simulation were plotted on the respective compressor map according route its operated in data-logger method. That is the Fig. 2 illustrates the turbo-match of A58N70, A58N72 and A58N75 turbochargers (left to right) in data-logger (rough route) and simulation. Similarly, the Fig. 3 illustrates the turbo-match of A58N70, A58N72 and A58N75 turbochargers (left to right) in data-logger (Highway route) and simulation, The Fig. 4 illustrates, the turbo-match of A58N70, A58N72 and A58N75 turbochargers (left to right) in data-logger (City Drive) and simulation, The Fig. 5 and Fig. 6 illustrate the turbo-match of A58N70, A58N72 and A58N75 turbochargers (left to right) in data-logger (slope up and slope down) with simulated observations respectively.

**Fig. 1** Experimental set up of Data-Logger method

**Table 3** Simulated observations for A58N70, A58N72 and A58N75 Turbo matching

| S.N | Engine Speed (rpm) | Mass Flow Rate (Kg/sec.sqrt K/Mpa) | | | Pressure Ratio | | |
|---|---|---|---|---|---|---|---|
| | | A58N70 | A58N72 | A58N70 | A58N72 | A58N70 | A58N72 |
| 1 | 1000 | 9.534 | 13.265 | 14.230 | 1.856 | 1.284 | 1.288 |
| 2 | 1400 | 20.186 | 24.789 | 25.936 | 3.042 | 2.678 | 2.696 |
| 3 | 1800 | 27.958 | 32.265 | 34.568 | 3.548 | 3.224 | 3.388 |
| 4 | 2400 | 35.488 | 36.256 | 38.456 | 3.764 | 3.427 | 3.625 |

**Table 4** Data-logger-Rough Road observation for A58N70, A58N72 and A58N75 Turbo matching

| S.N | Engine Speed (rpm) | Mass Flow Rate (Kg/sec.sqrt K/Mpa) | | | Pressure Ratio | | |
|---|---|---|---|---|---|---|---|
| | | A58N70 | A58N72 | A58N70 | A58N72 | A58N70 | A58N72 |
| 1 | 1000 | 8.43 | 9.32 | 10.46 | 1.29 | 0.97 | 0.84 |
| 2 | 1400 | 16.27 | 17.23 | 18.45 | 1.90 | 1.77 | 1.70 |
| 3 | 1800 | 23.87 | 25.73 | 26.84 | 2.29 | 2.25 | 2.17 |
| 4 | 2400 | 28.49 | 29.72 | 30.82 | 2.51 | 2.38 | 2.32 |

**Table 5** Data-logger – Highway observations for A58N70, A58N72 and A58N75 Turbo matching

| S.N | Engine Speed (rpm) | Mass Flow Rate (Kg/sec.sqrt K/Mpa) | | | Pressure Ratio | | |
|---|---|---|---|---|---|---|---|
| | | A58N70 | A58N72 | A58N70 | A58N72 | A58N70 | A58N72 |
| 1 | 1000 | 8.52 | 9.39 | 10.52 | 1.31 | 0.97 | 0.84 |
| 2 | 1400 | 16.39 | 17.28 | 18.51 | 1.87 | 1.77 | 1.70 |
| 3 | 1800 | 23.94 | 25.79 | 26.89 | 2.3 | 2.25 | 2.17 |
| 4 | 2400 | 28.91 | 29.77 | 30.85 | 2.51 | 2.38 | 2.32 |

**Table 6** Data-logger – City Drive observations for A58N70, A58N72 and A58N75 Turbo matching

| S.N | Engine Speed (rpm) | Mass Flow Rate (Kg/sec.sqrt K/Mpa) | | | Pressure Ratio | | |
|---|---|---|---|---|---|---|---|
| | | A58N70 | A58N72 | A58N70 | A58N72 | A58N70 | A58N72 |
| 1 | 1000 | 8.49 | 9.43 | 10.58 | 1.32 | 0.99 | 0.88 |
| 2 | 1400 | 16.31 | 17.32 | 18.54 | 1.95 | 1.83 | 1.76 |
| 3 | 1800 | 23.78 | 25.84 | 26.93 | 2.33 | 2.29 | 2.19 |
| 4 | 2400 | 28.37 | 29.86 | 30.91 | 2.56 | 2.41 | 2.36 |

**Table 7** Data-logger – Slope up Route observations for A58N70, A58N72 and A58N75 Turbo matching

| S.N | Engine Speed (rpm) | Mass Flow Rate (Kg/sec.sqrt K/Mpa) | | | Pressure Ratio | | |
|---|---|---|---|---|---|---|---|
| | | A58N70 | A58N72 | A58N70 | A58N72 | A58N70 | A58N72 |
| 1 | 1000 | 8.58 | 9.51 | 10.62 | 1.31 | 0.96 | 0.88 |
| 2 | 1400 | 16.34 | 17.76 | 18.60 | 2.00 | 1.85 | 1.79 |
| 3 | 1800 | 23.98 | 25.95 | 26.98 | 2.37 | 2.3 | 2.19 |
| 4 | 2400 | 28.98 | 29.93 | 30.95 | 2.58 | 2.46 | 2.39 |

**Table 8** Data-logger – Slope down Route observations for A58N70, A58N72 and A58N75 Turbo matching

| S.N | Engine Speed (rpm) | Mass Flow Rate (Kg/sec.sqrt K/Mpa) | | | Pressure Ratio | | |
|---|---|---|---|---|---|---|---|
| | | A58N70 | A58N72 | A58N70 | A58N72 | A58N70 | A58N72 |
| 1 | 1000 | 8.47 | 9.27 | 10.37 | 1.30 | 0.98 | 0.81 |
| 2 | 1400 | 16.32 | 17.12 | 18.42 | 1.95 | 1.73 | 1.68 |
| 3 | 1800 | 23.89 | 25.47 | 26.53 | 2.31 | 2.18 | 2.16 |
| 4 | 2400 | 28.42 | 29.59 | 30.67 | 2.50 | 2.34 | 2.30 |

## IV. RESULTS AND DISCUSSIONS

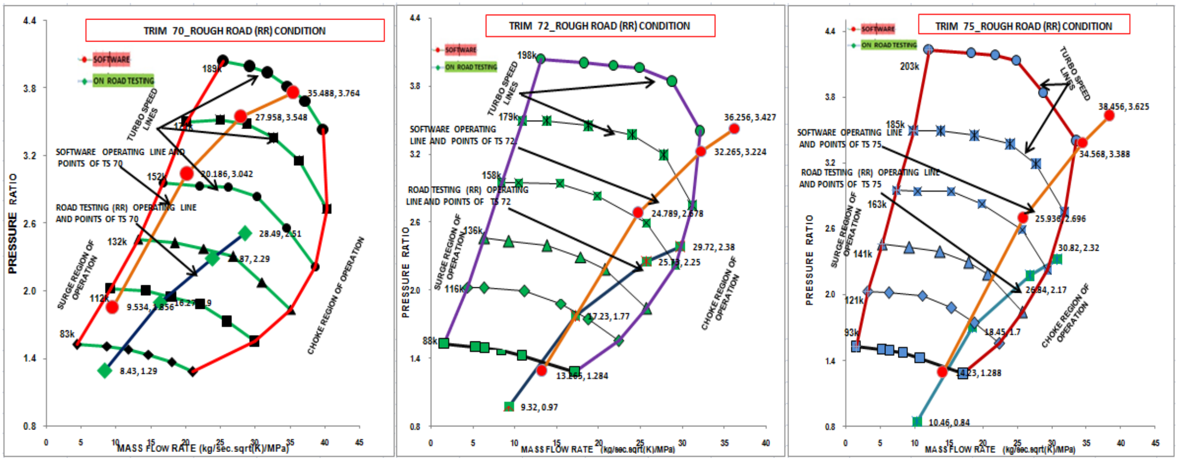


**Fig. 2** A58N70, A58N72 and A58N75 Turbo-match- by Simulation & Data-logger – Rough Road

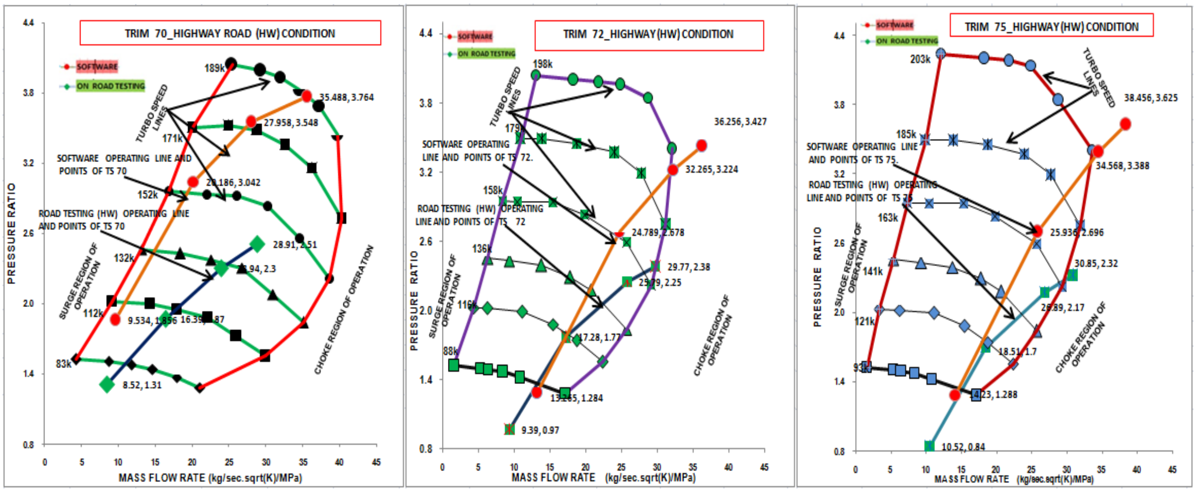


**Fig. 3** A58N70, A58N72 and A58N75 Turbo-match- by Simulation & Data-logger – Highway Route

The operating conditions obtained in three cases of turbochargers with engine for both simulated and data-logger method with the rough road route, highway route, City Drive, Slope Up and the slope-Down route were obtained. These operating conditions were marked on the compressor map. The details of mappings already discussed above. This was observed that Turbocharger A58N72 and A58N75 shows almost good performance at low speed, but at high speed a choke occurred. At this speed overall efficiency decreases. For matching A58N72 turbocharger the maximum speed must be reduced slightly from 2400 rpm. In case of A58N75 turbocharger, the matching requires to limit the maximum speed to 2200 rpm. On other hand match of A58N70 turbocharger exhibits well at low, medium and as well good at higher speed also. The same was ensured in simulator test, data-logger with all the road conditions like Rough, City Drive, Highway, slope up and slope down.

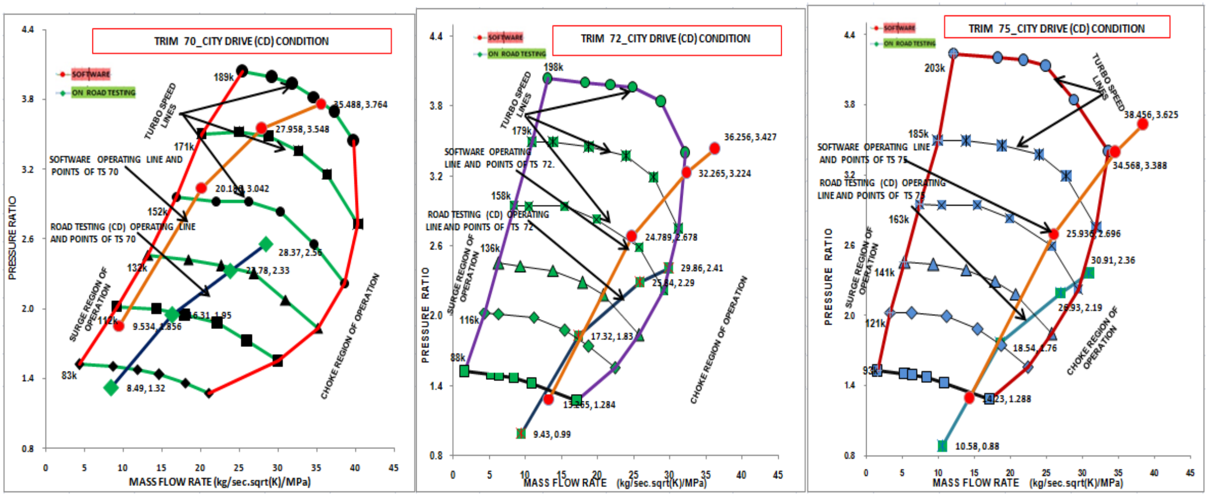


**Fig. 4** A58N70, A58N72 and A58N75 Turbo-match- by Simulation & Data-logger – City Route

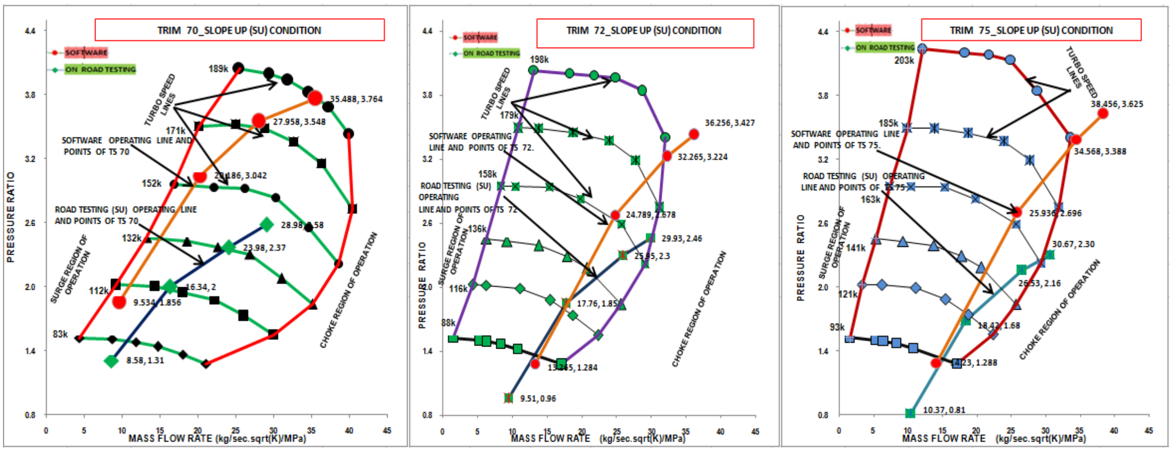


**Fig. 5** A58N70, A58N72 and A58N75 Turbo-match- by Simulation & Data-logger – Slope-up Route

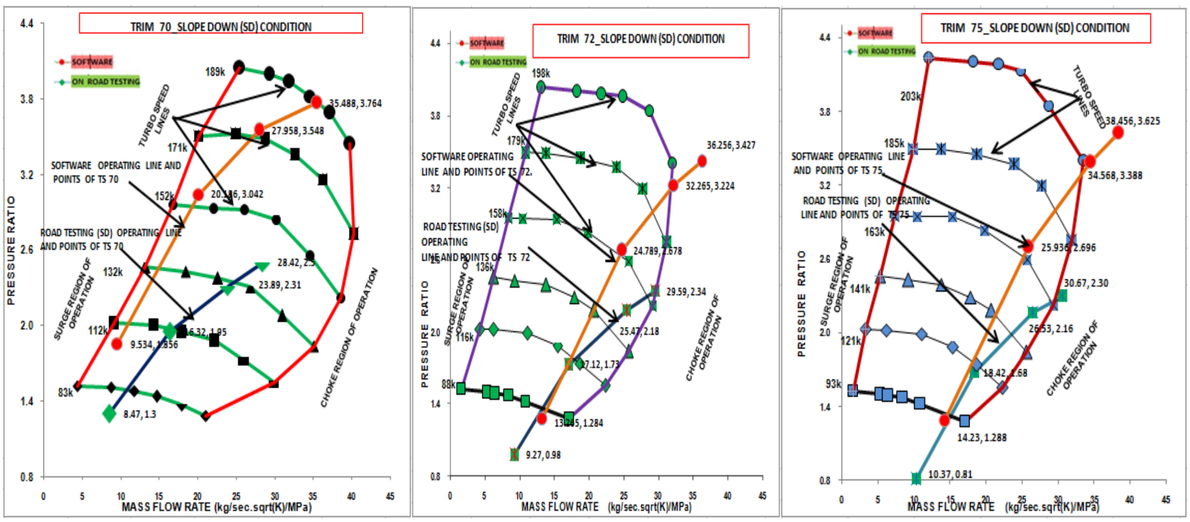


**Fig. 6** A58N70, A58N72 and A58N75 Turbo-match- by Simulation & Data-logger – Slope-Down Route

## V. CONCLUSION

The turbo-matching of A58N70, A58N72 and A58N75 turbochargers for TATA 497 TCIC - BS III engine is discussed. The turbo-matching appropriateness evaluated with help of compressor map and observations of simulation and data-logger method. The simulated values found much higher than the data-logger values. The appropriateness can be easily observed from the self explanatory graphs (Fig, 2 to Fig. 6). The results reveal that choke occurred with A58N72 and A58N75 turbocharger. The reduction operating speed certain extent can be compromised. Comparatively A58N72 turbocharger requires very small reduction of maximum speed and the same can be matched easily. The A58N70 Turbocharger perfectly matched and no more engine speed alteration required. Hence it can be concluded that among all the three trim size A58N70, A58N72 and A58N75 turbocharger, trim A58N70 meet the engine breathing requirement and it is suggested to adopt A58N70 turbocharger for TATA 497 truck i.e., TATA 497 TCIC -BS III engine. The turbo-charger A58N72 can be matched by minimal change in the maximum engine speed (if permits). 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.

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