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STUDY OF APPROPRIATENESS OF TURBO-MATCHING OF A58N75 AND A58N72 TURBOCHARGERS FOR A COMMERCIAL VEHICLE ENGINE

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ABSTRACT

The 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 lead to negative effects like surge and choke in the breathing of the engine. Appropriate selection or match of the turbocharger (Turbo-matching) is a tedious task and expensive. But perfect match gives many distinguished advantages and it is a onetime task per the engine kind. This study focuses to match the turbocharger to desired engine by simulation and on road test. The objective of work is to find the appropriateness of matching of turbochargers with trim 72 (A58N72) and trim 75 (A58N75) for the TATA 497 TCIC -BS III engine. In the road-test (data-logger method) the road routes like Rough road, highway and slope up were considered for evaluation. The operating conditions with respect various speeds, routes and simulated outputs were compared with the help of compressor map.

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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 (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 the 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 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), 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 matching exactly 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 a variable geometry turbine, common rail injection system, and multiple injections, the problem has still persist 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. That is, their

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combination to be *optimized* at full load. The trial and error method cannot be adopted in this case because the matching directly effects as well as affect the engine performance (Watson and Janota, 1982; Lake *et al*, 2004 and Millo *et al*, 2005). 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 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 turbocharger with 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 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 72 and 75 are considered for investigation.

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.

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 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 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.

Table 1. 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
7	Engine speed	2400 rpm (Max power), 1400 rpm (Max Torque)

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.

Turbochargers Specifications

Table 2. Specification of Turbo Chargers

S.No	Description	A58N75	A58N72
1	Turbo maximum Speed	200000 rpm	
2	Turbo Make	HOLSET	
3	Turbo Type	WGT-IC (Waste gated Type with Intercooler)	
4	Trim Size (%)	75	72
5	Inducer Diameter	52.5 mm	50.10 mm
6	Exducer Diameter	70.0 mm	69.58 mm

The TATA Short Haulage Truck, turbochargers of A58N72 and A58N75 are considered to examine the performance of matching for TATA 497 TCIC -BS III engine. For example, if specification A58N72 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.

Experimental Observation

The simulator and data-logger method is adopted to match the turbo Chargers A58N72 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 of specific fuel preferred to examine the matching performance on the Highway, rough road and slope up. The recorded observations were different routes like pressure ratio and mass flow rate at various speeds as a measure of performances for identifying the matching performance of the turbocharger for a desired combination. The simulated observations are presented in Table 3 for turbo Charger A58N75 and A58N72 turbocharger respectively. 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 observations presented from the Table 4 to Table 8. The selected engine speeds are 1000, 1400, 1800 and 2400 rpm. The Figure 2 and Figure 3 are for Rough route for turbochargers A58N75 and A58N72 turbocharger respectively. Similarly, Figure 4 and Figure 5 for Highway route and Figure 6 and Figure 7 for slope up route.

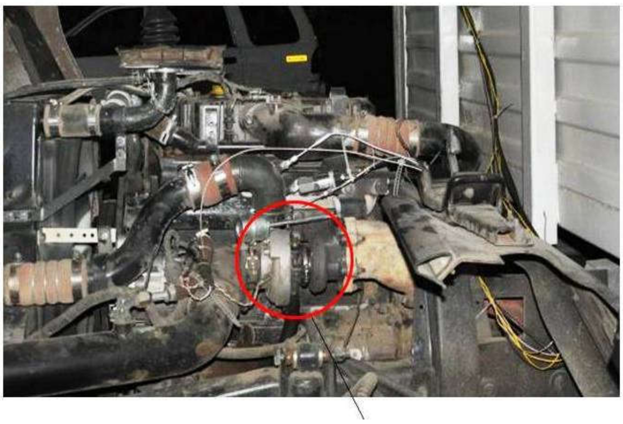

Figure 1. Experimental set up of Data-Logger method

Table 3. Simulated observations

S.No	Engine Speed (rpm)	Mass Flow Rate (Kg/sec.sqrt K/Mpa)		Pressure Ratio	
		A58N75	A58N72	A58N75	A58N72
1	1000	14.230	13.265	1.288	1.284
2	1400	25.936	24.789	2.696	2.678
3	1800	34.568	32.265	3.388	3.224
4	2400	38.456	36.256	3.625	3.427

Table 4. Data-logger – Rough Road Route observations

S.N	Engine Speed (rpm)	Mass Flow Rate (Kg/sec.sqrt K/Mpa)		Pressure Ratio	
		A58N75	A58N72	A58N75	A58N72
1	1000	10.46	9.32	0.84	0.97
2	1400	18.45	17.23	1.7	1.77
3	1800	26.84	25.73	2.17	2.25
4	2400	30.82	29.72	2.32	2.38

Table 5. Data-logger – Highway Route observations

S. N	Engine Speed (rpm)	Mass Flow Rate (Kg/sec.sqrt K/Mpa)		Pressure Ratio	
		A58N75	A58N72	A58N75	A58N72
1	1000	10.58	9.43	0.88	0.99
2	1400	18.54	17.32	1.76	1.83
3	1800	26.93	25.84	2.19	2.29
4	2400	30.91	29.86	2.36	2.41

Table 6. Data-logger – City Drive observations

S.N	Engine Speed (rpm)	Mass Flow Rate (Kg/sec.sqrt K/Mpa)		Pressure Ratio	
		A58N75	A58N72	A58N75	A58N72
1	1000	10.52	9.39	0.84	0.97
2	1400	18.51	17.28	1.7	1.77
3	1800	26.89	25.79	2.17	2.25
4	2400	30.85	29.77	2.32	2.38

Table 7. Data-logger – Slope Up observations

S.N	Engine Speed (rpm)	Mass Flow Rate (Kg/sec.sqrt K/Mpa)		Pressure Ratio	
		A58N75	A58N72	A58N75	A58N72
1	1000	10.62	9.51	0.88	0.96
2	1400	18.60	17.76	1.79	1.85
3	1800	26.98	25.95	2.19	2.30
4	2400	30.95	29.93	2.39	2.46

Table 8. Data-logger – Highway Route observations

S. N	Engine Speed (rpm)	Mass Flow Rate (Kg/sec.sqrt K/Mpa)		Pressure Ratio	
		A58N75	A58N72	A58N75	A58N72
1	1000	10.37	9.27	0.81	0.98
2	1400	18.42	17.12	1.68	1.73
3	1800	26.53	25.47	2.16	2.18
4	2400	30.67	29.59	2.30	2.34

RESULTS AND DISCUSSIONS

The operating conditions obtained in both cases of turbochargers with the engine for both simulator and data-logger method with the rough road route, highway route and slope-up route were obtained. These operating conditions were marked on the respective compressor map.

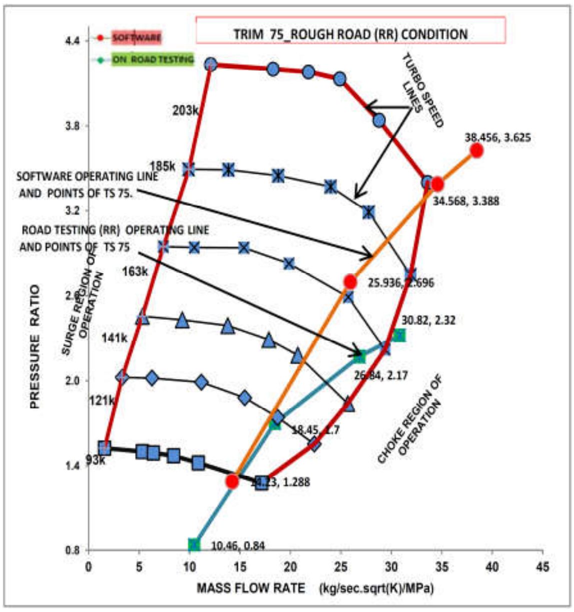

Figure 2. A58N75 Turbo-match-Rough Road

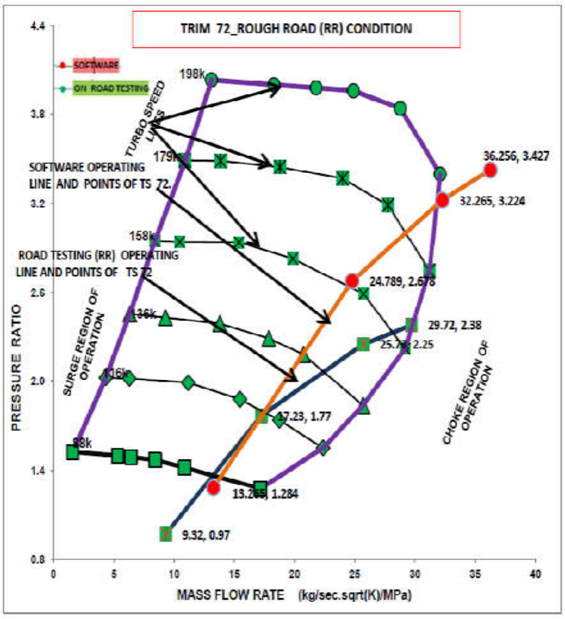

Figure 3. A58N72 Turbo-match-Rough Road

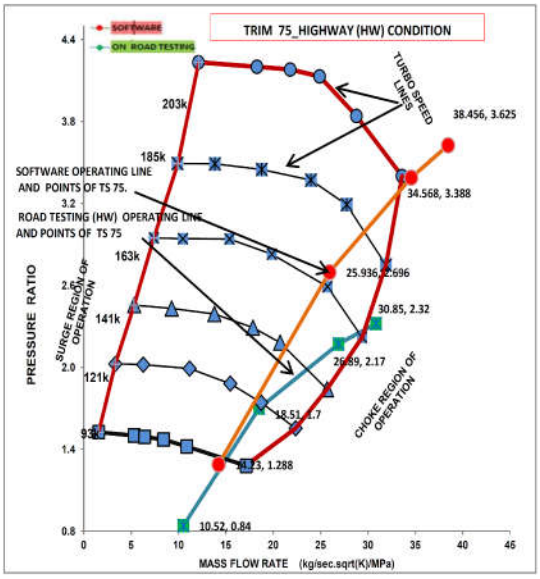

Figure 4. A58N75 Turbo-match- Highway

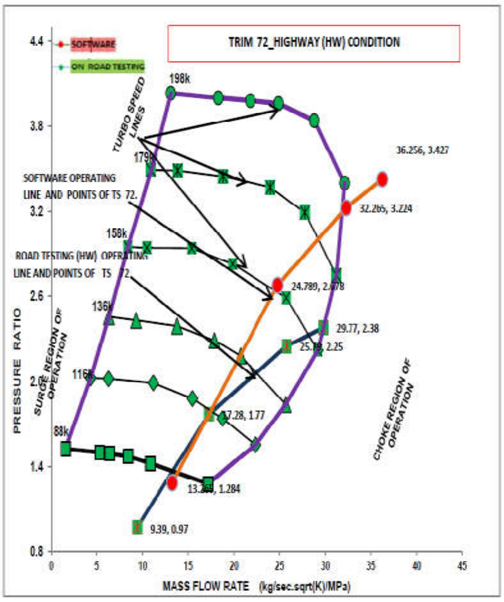

Figure 5. A58N72 Turbo-match – Highway

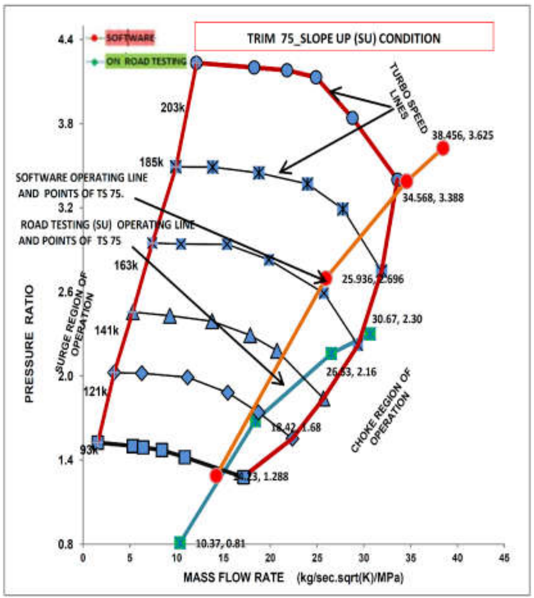

Figure 6. A58N75 Turbo-match- Slope-up

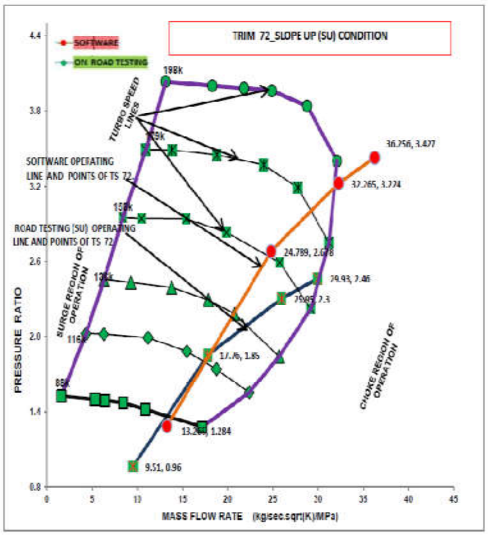

Figure 7. A58N72 Turbo-match - Slope-up

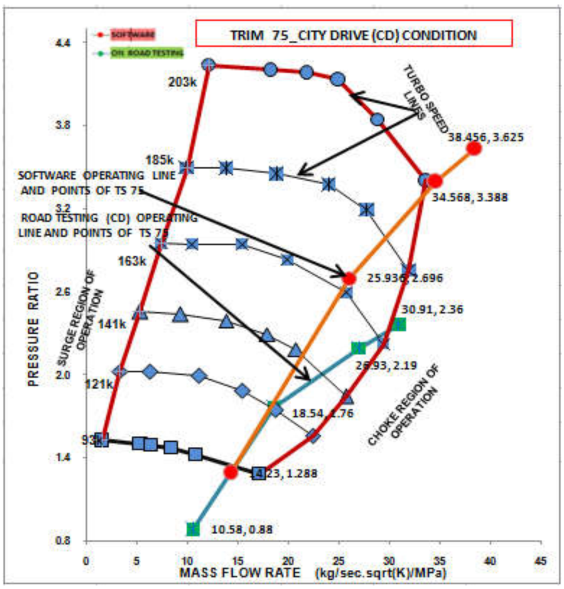

Figure 8. A58N75 Turbo-match- Highway

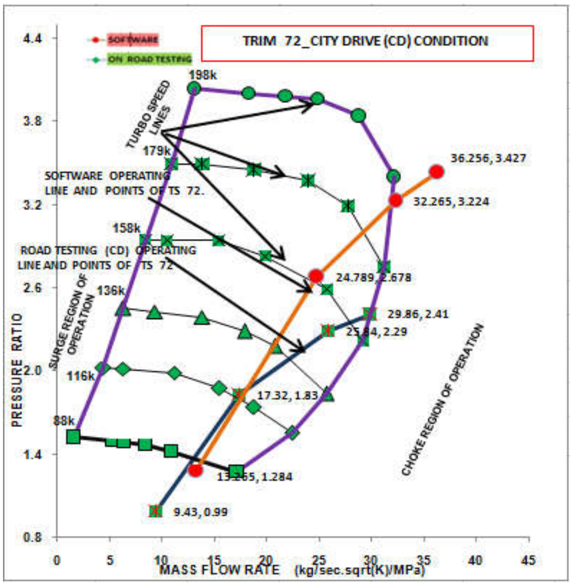

Figure 9. A58N72 Turbo-match - Slope-up

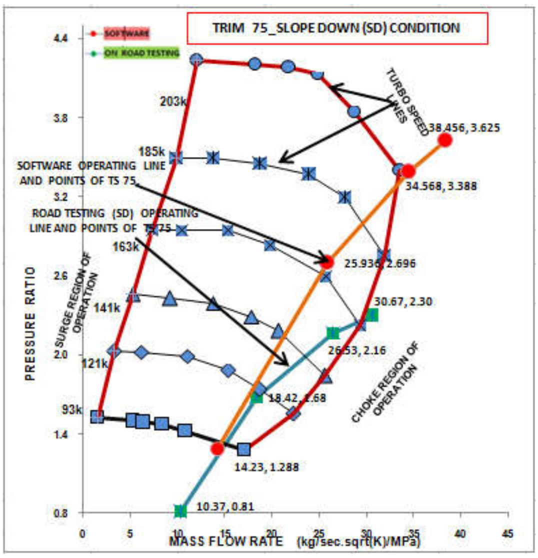

Figure 10. A58N75 Turbo-match- Highway

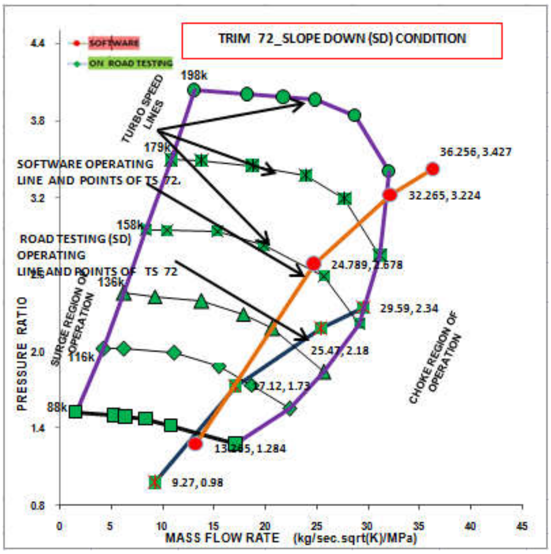

Figure 11. A58N72 Turbo-match - Slope-up

The details of mappings already discussed above. This can be noted that the turbomatch of A58N75 and A58N72 Turbo-charger, match it was observed that performance of operating conditions are safe and acceptable at lower and medium speeds, but at higher speeds choke occurs. Suppose these A58N75 and B60J72 turbochargers adopted for the TATA 497 TCIC -BS III engine, the purpose could not able to fulfilled. But these can be matched by limiting the maximum speeds. Among these, two turbochargers the B60J72 turbocharger match requires a lesser decrement of higher speed.

Conclusion

The turbo-matching of A58N75 turbocharger and A58N72 turbocharger for TATA 497 TCIC -BS III engine is considered. The simulator method is employed to find matches of turbochargers individually with the engine. The same was verified by experimental method called Data-logger with different routes. The simulator gives more values than the actual values obtained by experimentation. The both A58N72and A58N75 turbochargers operating performance exhibits good at lower and medium speed, but at higher speed the choke occurs. Hence complete efforts made to match these turbo chargers for the TATA 497 TCIC -BS III engine. As the occurrences choke at higher speeds with the both A58N72 and A58N75 turbochargers, the purpose could not be achieved. But the maximum speed of the engine can be compromised the little A58N72 turbocharger can be matched for best performance at all speeds. The data-logger method adopted 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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