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TURBOCHARGER OPTIMIZATION FOR GENSET ENGINE

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Abstract

In general, the internal combustion engine requires air and fuel as input and gives mechanical power output. The air quantity depends on the engine cylinder size and volumetric efficiency. Limited power can be generated from a particular size of engine due to limitation of air availability for combustion. Turbocharger is required to increase air quantity for same size of engine. Turbocharging technique is more and widely employed on CI and SI internal combustion engines to improve performance of same size of engine. Diesel engine operates with excess air and can be operated with higher compression and peak firing pressure. SI engines compression pressure limitation due to knocking. Turbocharger is more advantageous for CI engines to increase power and improve fuel consumption and exhaust emissions. Turbocharger is a significant contributor to meet fuel consumption and stringent emission norms. Turbocharger optimization required a systematic approach for best optimum results. Selection of a proper turbocharger is very important for engine performance and emissions.

Keyword- Turbocharger, EGR, Genset, CPCB II

Introduction

The Purpose of this thesis work is to demonstrate and validate the methodology of turbocharger optimization for constant speed Genset application engine. AVL Boost simulation software was used for 1-D thermodynamic simulation and the optimized configurations of turbochargers were validated with experimental test results. The study was meant to optimize the turbocharger to meet performance and emission for best specific fuel consumption. During optimization the design target were achieved. Compressor and turbine configurations were optimized and verified for best efficiency operation. The EGR flow rates were also optimized to meet CPCB II emission targets and brake specific fuel consumption.

This paper describes the metodology to optimize a turbocharger for higher power rating of a existing base engine model. The main objectives are :-

- The Engine Performance
- Emissions
- Turbocharger effciency
- Turbocharger operating limits
- Better Fuel Economy

For constant speed engine, the engine speed is constant with varying the load. The test cycle contained 100 %, 75%, 50%, 25% and 10 % load points. The weightage factor for each mode is mentioned in table 1. The weightage factor for rated load is 5% only because the operation of full load is very less in actual application and similarly for 10 % load. The 75%, 50% and 25% load points are major contributor in emission cycle. The major emission parameters are CO, HC, NOx, Smoke and PM in diesel engines. For any Genset application diesel engine all the emission parameters must be within the limits as per given in Table **1.**

TABLE 1 ISO: 8178 D2 5 MODE EMISSION TEST CYCLE

Mode No.	Engine Speed	% Load	Weighting Factor
1	Rated Speed	100	0.05
2	Rated Speed	75	0.25
3	Rated Speed	50	0.30
4	Rated Speed	25	0.30
5	Rated Speed	10	0.10

The emission pollutants for Constant speed engines of different power ratings are as shown in Table 2.

TABLE 2 CPCB II EMISSION NORMS

Engine Power (P)	CO	NOx+HC	PM	Smoke
	g/kWh			*1/m*
P ≤ 19 kW	3.5	7.5	0.3	0.7
19 kW < P ≤ 75 kW	3.5	4.7	0.3	0.7
75 kW < P ≤ 800 kW	3.5	4	0.2	0.7

The paper also present the methodology and optization of a turbocharger for Genset engine with better fuel consumption by proper selection of turbine and compressor selection to reduce pumping losses. EGR flow rate is also a most important parameter for emission control.

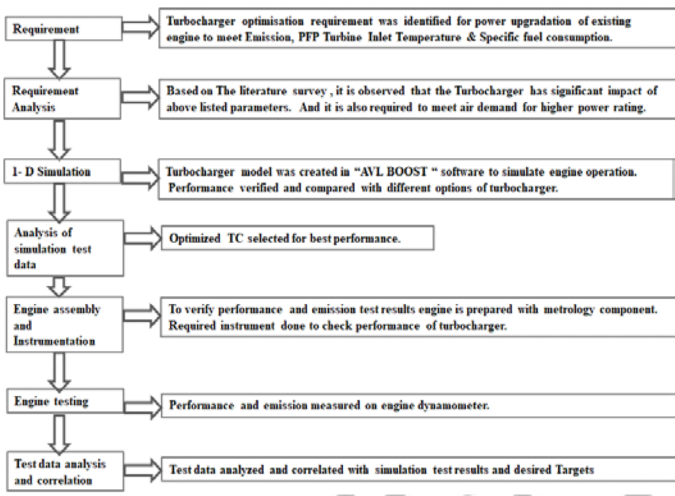
The study was done on a 4 - Cylinder Comman rail engine for Genset application. The Base engine configuration was from existing 125 kVA engine.

TABLE 3 BASIC ENGINE CONFIGURATION COMPARISON

Description	Unit	Base Engine	New Engine
Genset Power rating	kVA	125	140
No. of Cylinders	nos.	4	4
Stroke	mm	134	134
Bore	mm	108	108
Total displacement	cc	4910	4910
Rated power	kW	118	132
Compression ration	-	17:01	17:01
Fuel Injection System	-	CRDI	CRDI
Aspiration	-	Turbocharged Intercooler	Turbocharged Intercooler
Type of Cooling	-	Water cooled	Water cooled

METHODOLOGY AND TARGET SETTING

For the new power rating the major changes were required in fuel and air system. The required fuel quantity and Injection timing were achieved by the ECU calibration. From air system, the turbocharger is selected based on simulation and the experimental results. As per current government legislation CPCB II emission norms are applicable for Genset application engines. The work started with the thermodynamic simulation after the target setting.



Target Setting: - Performance and emission Targets were decided based on competitor and existing similar platform engine. There was some constraint from component design side which were also required to meet within specification. The Targeted performance and emission along with design constraint are mentioned in Table 4.

TABLE 4 TARGETED PERFORMANCE AND EMISSIONS

	Parameters @ 100 % Load (Rated)					Weighted D2 Cycle Emission		
	Power	Max SFC	T_ Turbine Inlet	T_ Comp. Outlet	Cylinder Peak Firing	Nox +HC	CO	PM
	bhp	g/bhphr	deg C	deg C	bar	g/kWhr		
Target	180±3.5	150	650	200	185	4.0	3.5	0.2
Remarks		Lower is better				Lower is better		

DESCRIPTION OF THE AVL BOOST

AVL BOOST software is used for thermodynamic cycle calculations. 1-Dimensional model is created for in –cylinder conditions. Apart from in- cylinder conditions simulation software calculated unsteady 1-D gas flow in the intake and exhaust manifolds. Godunov type finite volume method with ENO reconstruction is used to calculate flow charterstics in engine manifolds. Intake and exhaust pipes are divided into cells and Riemann solver is used to calculate air mass flow. Intake air depression and exhaust backpressure values are maintained as per targeted for rated speed and load conditions. The pressure losses at rest load conditions are outcome of calculation. Pressure losses across the intake air filter and intercooler are simulated with design-targeted values. The gas properties are determined from solution of the conservations laws for fuel and air.

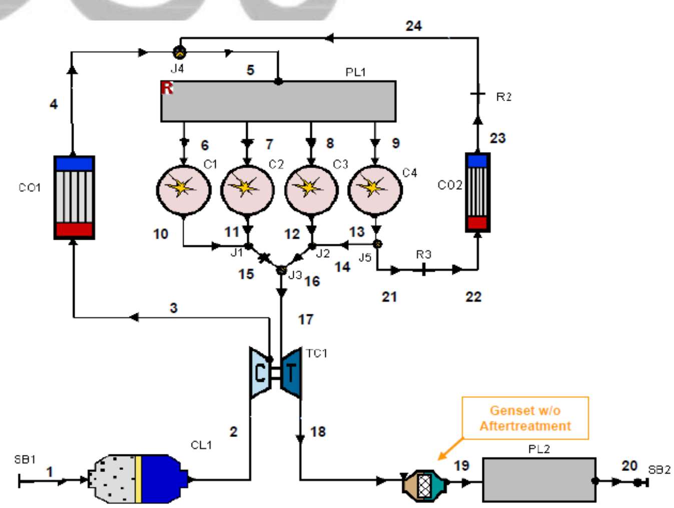


Figure 1- Simulation Model

The thermodynamic cycle calculations for Genset were carried out from part load 25 % up to full load at 1500 rpm constant speed. The 110 % over load operation was performed at 1485 rpm. These calculations were performed with respect to the characteristics of a Common Rail injection system, but no limitation of maximum injected fuel mass is considered. The exhaust gas temperature at standard ambient conditions is below the turbine entry limit of 650°C over the whole load range. This temperature limit accords to TEL info for standard ambient conditions. The maximum compressor out temperature is in the range of 200°C. The compressor out let temperature depends on compressor efficiency and final boost pressure level. The temperature after charge air cooler is adjusted to the contracted value: 50°C @ rated power is maximum temperature after charge air cooler.

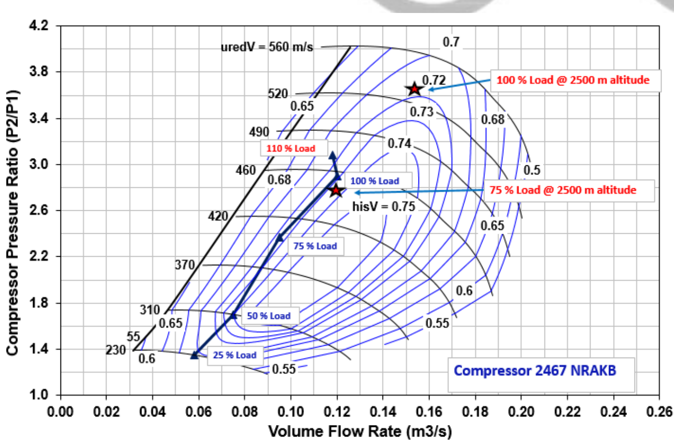


Figure 2- Compressor curve 2467 NRAKB

The best suitable configurations of compressor are 2467 NRAKB and 2267 NRAAA along with 55 mm turbine wheel diameter. The Turbine housing area need to optimize in experimental test results based on airflow and EGR flow rate requirement. The turbine housing area is the main parameters for airflow and pressure ratio variation. Bigger turbine housing area provides lower pressure ratio and lower pumping losses but it is not good for better EGR flow rates. Lower turbine housing area provides good suitability for EGR flowrate but leads to higher pumping losses. There is a significant effect of pumping losses on brake specific fuel consumption. The following are the recommended configurations for experiential trial.

TABLE 5 SUITABLE TURBOCHARGER CONFIGURATIONS

Turbocharger 1	TR55 2267 5.12	Compressor Variation with 5.12 Turbine
Turbocharger 2	TR55 2467 5.12	
Turbocharger 3	TR55 2267 4.82	Compressor Variation with 4.82 Turbine
Turbocharger 4	TR55 2467 4.82	

EXPERIMENTAL SETUP AND TEST PROCEDURE

To measure engine performance and engine component related parameters, the required instrumentation was identified. To assess the turbocharger performance certain pressures and temperatures are required along with mass air flow. The mass air flow measured with ABB sensy flow meter. The schematic diagram of pressure and temperature instrumentation is shown in Figure 3. Measurement positions are taken at the followings locations.

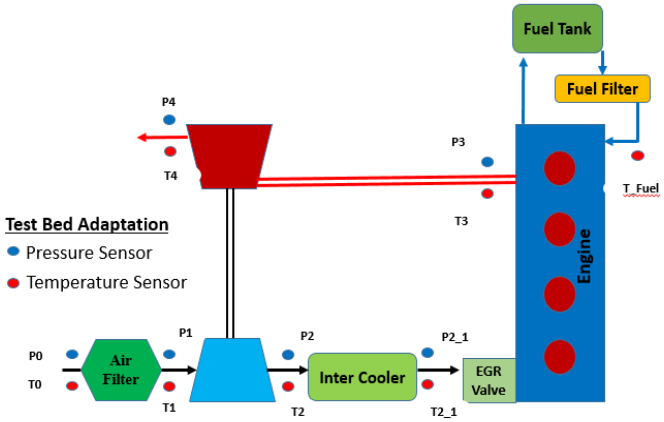


Figure 3- Instrumentation Details

TABLE 6 ENGINE TESTING EQUIPMENT DETAIL

Dynamometer	AVL ALPHA 350
Fuel Consumption Meter	AVL 733S
Fuel Conditioning Unit	AVL 735S
Coolant Conditioning Unit	AVL
Particulate Measurement Unit	AVL SPC
Opacimeter	AVL 439
Emission Analyzer	HORIBA, MEXA – 1600 D
Air Flow Meter	ABB
Smoke Meter	AVL 415 S
Inlet Air Conditioning Unit	CP Engineering
Blow By Meter	AVL 442
Fuel	Commercial Diesel
Fuel Specific Gravity	0.835

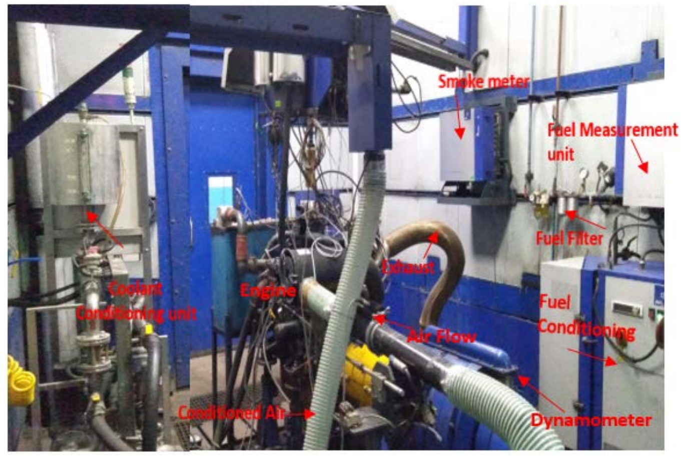


Figure 4- Engine Test Setup

TABLE 7 MAINTAINING PARAMETERS FOR EMISSION

Maintaining parameters for Emission		
Parameter	Unit of parameter	Limit
Fuel temperature	°C	38±2°C
Inter cooler outlet temperatur	°C	50±2°C
Water outlet temperature	°C	85±5°C
Oil temperature	°C	> 95
Air intake temperature	°C	25±2°C
Relative humidity	%	30±5%

TEST RESULTS AND ANALYSIS

ISO: 8178 D2 -5-mode test cycle used for emission optimization. The same test cycle is applicable for CPCB II emission norms for constant speed application. The engine was run on 1500 rpm with varying load condition as per test cycle. To judge the Turbocharger performance EGR was deactivated to eliminate the effect of EGR rate variation. After finalization of turbocharger EGR, flowrate was optimized to meet specific fuel consumption and emission target. There was some design limitation from Turbocharger supplier, which was required to meet for turbocharger operation. Following are the limiting temperatures for turbocharger.

- **Max. Turbine Inlet Temperature – 650° C.**
- **Max. Compressor outlet Temperature – 200° C**

TABLE 8 SUMMARY OF TEST RESULTS

S.NO.	Turbocharger Configuration	EGR	100 % Load						Weighted Emission of ISO 8178 D2 Emission Cycle		
			Power	SFC	Mass Air Flow	Smoke	T_ Turbine Inlet	T_ Comp. Outlet	Nox +HC	CO	PM
			bhp	g/bhp-hr	kg/hr	m-1	deg C	deg C	g/kwh		
1	TR55 2267 5.12	NO	179.3	148.51	535	0.03	662.4	182.5	8.25	0.27	0.040
2	**TR55 2467 5.12**	**NO**	**179.6**	**146.1**	**559**	**0.02**	**616.46**	**172.87**	**8.48**	**0.26**	**0.038**
3	TR55 2267 4.82	NO	179.5	150.2	537	0.03	656.31	189.54	8.66	0.21	0.039
4	TR55 2467 4.82	NO	179.6	147.7	552	0.02	633.83	169.84	8.87	0.19	0.040
5	TR55 2467 5.12	YES	179.4	147.2	519	0.2	630.50	183.27	3.69	0.47	0.081

CORRELATION OF TEST RESULTS

Based on above test results, it observed that the Turbine inlet temperature and compressor out temperature are sensitive to turbocharger's compressor and turbine configuration. The TR55 2467 5.12 turbocharger showed best results in terms of both turbine inlet and compressor out temperatures. The simulation and experimental test results shows a good correlation within 10% deviation. The correlation very good matched at 100 % and 75% load conditions and the deviation is within 5%. The other design parameters are also well within limits. Observations on emission and performance test results are –

- NOx+HC is achieved with 7.7 % of margin.
- CO is achieved with 86.5 % of margin.
- PM is achieved with 59.5 % of margin.
- Targeted required power and break specific fuel consumption are achieved.

Turbine Inlet and compressor outlet temperatures are well within limits.

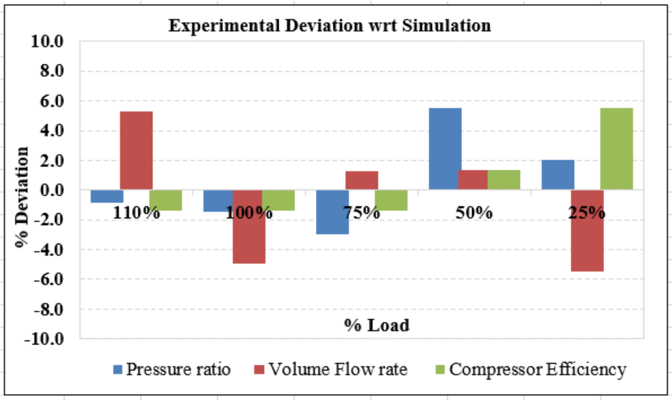


Figure 5. Experimental Deviation wrt Simulation

The experimental and simulation compressor efficiency maps are shown in figure 6. Experimental compressor map curve is very well matched with simulation curve. The performance and emission targeted vs actual shown in Table 9.

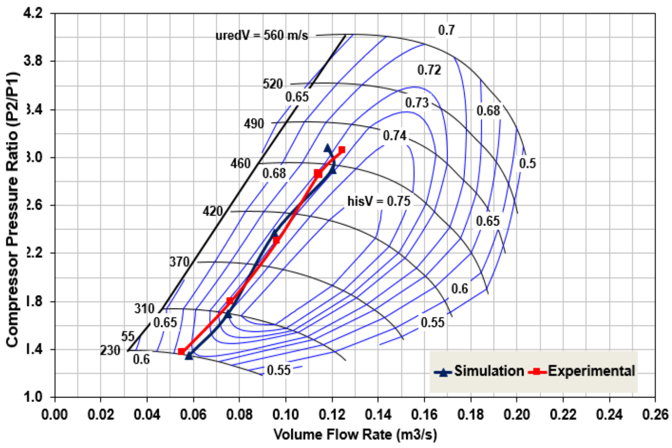


Figure 6. Compressor Map Correlation (Simulation Vs Experimental)

TABLE 9 TARGETED VS ACHIEVED

	Parameters @ 100 % Load (Rated)					Weighted D2 Cycle Emission		
	Power	Max SFC	T_ Turbine Inlet	T_ Comp. Outlet	Peak Firing Pressure	Nox +HC	CO	PM
	bhp	g/bhphr	deg C	deg C	bar	g/kWhr		
Target	180±3.5	150	650	200	185	4.0	3.5	0.2
Achieved	179.4	147.2	630.5	183.3	180.0	3.69	0.47	0.081
Remarks		Lower is better				Lower is better		

CONCLUSION

This thesis presents the systematic methodology of turbocharger optimization for Genset application engines. A proper optimized turbocharger gives better specific fuel consumption and lower emissions. Based on simulation test results and experimental test results, the turbocharger configuration TR 55 2467 5.12 is giving best results. The main parameters for a turbocharger performance are pressure ratio, volume flow rate and compressor efficiency. The simulation and experimental test results shows a good correlation at all operating conditions. For pressure ratio the deviation is 8.6 % for all operating load conditions. Experimental and simulation test results are very closely matching up to 50% load conditions.

The correlation is very good for compressor efficiency and the deviation is within 7% at all engine operating load conditions. Compression efficiency is well matched at major engine operating region from 110% load to 50% load. The compressor efficiency is the main parameter to judge the effectiveness of a turbocharger.

FURTHER WORK

The methodology can be deployed on similar engine models and also can be expended for variable speed engines with required modifications. Waste gate turbocharger and actuator tuning can be explored for better fuel consumption and emission test results.

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