Performance Enhancement of Multi-Cylinder Common Rail Diesel Engine for Automotive Application

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Abstract:

Modern diesel engines are becoming compact and quieter. The myth that diesel engines are noisy is changing. Thanks to the research and developments in engine downsizing and combustion efficiency improvements that makes achievement of very high specific power and better fuel economy possible. The three major areas in which modern research focuses are optimisation of turbocharging to get best torque especially at the low end, optimisation of fuel injection system for precise and consistent metering and mass optimisation of powertrain parts to realize better fuel consumption.

This thesis focuses on enhancing engine performance by optimisation of turbocharging and improving the combustion efficiency thereby achieving better fuel consumption. Performance enhancement is achieved through careful selection of Turbocharger to meet the increased airflow demand, selection of Charge Air Cooler to reduce the intake air temperature and selection of Piston to withstand higher peak firing pressures.

I. INTRODUCTION

In the race to cut CO_2 emissions and boost fuel economy, there is broad consensus among vehicle manufacturers that downsizing the internal combustion engine or increasing the specific output of the engine. Increasing the power to weight ratio is basic mantra for reducing the fuel economy and meeting the stringent emission norms. Consumers want to drive more fuel efficient vehicles without affecting the Engine Performance.

In the present work, the following targets are taken to increase the specific output of the Engine

- To increase the Power output by 30%
- To increase in the Max Torque by 15%
- To reduce the minimum BSFC by 10%
- To reduce the rated BSFC by 5%.

The above targets can be achieved by means of

- Turbocharging which delivers more air to the combustion chamber to burn additional fuel and to ensure highly efficient and clean combustion.
- Intercooling reduces the temperature of intake air, thereby increases the density of air.
- Efficient combustion by utilizing the maximum capability of Engine Components (Peak Firing Pressure).

A. TURBOCHARGER

Power output of the Engine is directly proportional to

Mass flow rate of air and it can be increased by the following ways,

- By increasing the speed of the engine.
- By increasing the size of the engine.
- By increasing the number of cylinders.
- By means of supercharger.
- By means of Turbocharger.

Of the above, Turbocharger is the efficient way of providing increased mass flow rate of air.

It is a device, which uses the Exhaust energy to drive a Turbine. This Turbine is coupled to Compressor through a shaft. The energy extracted in the Turbine will be utilized to drive the compressor and finally the energy will be imparted to intake air. Thereby, the charge air pressure and mass flow rate is increased.

Schematic layout of TC / CAC Engine is shown Fig. 1

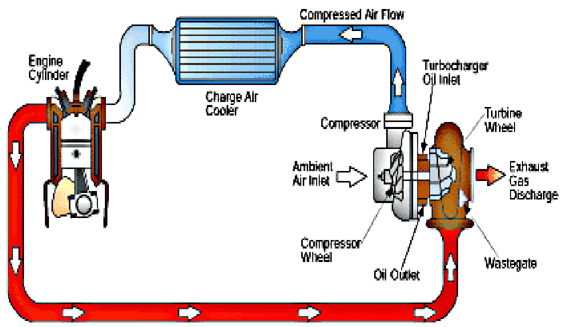

Fig. 1: Schematic Layout of TC / CAC Engine

B. CHARGE AIR COOLER

Charged Air Cooler (CAC) or Intercooler is a Heat Exchanger device, which removes heat from the compressed charge air (after TC) at Constant Pressure and delivers it to the Cylinders through intake valve. By means of cooling the charge air the following benefits can be obtained,

1. Increased air density / Oxygen availability for Combustion
2. Less Exhaust Temperature.
3. Less nox Formation.
4. Increased Volumetric Efficiency.
5. Reduced Compression work.

In the present work, Air to Air CAC type being used for cooling the intake air.

C. PISTON

Piston is a device which reciprocates inside the Cylinder Bore and converts the Heat energy obtained through Combustion of Fuel air mixture into useful work by means of Connecting Rod and Crankshaft. Top surface of the Piston (Crown) is subjected to High pressure and temperature of Combustion.

Piston undergoes thermal fatigue, as the temperature inside the cylinder varies from atmospheric Temperature to Peak Cylinder Temperature. Generally Pistons are made of Aluminum in order to keep reciprocating mass under certain limited / minimum values.

Along with Cylinder Head, Piston and its Bowl, Rings will form the Combustion Chamber. Bowl used in the present work is of re-entrant type, to improve turbulence, thereby better mixing.

II. TURBOCHARGER MATCHING PROCESS

A. TC COMPRESSOR SELECTION PROCEDURE

Step 1:- Air flow Calculation

Based on Engine Power, BSFC and Air Fuel Ratio,

Air flow can be calculated

Fuel Flow (in kg/h) = Power (in kw) * BSFC (in g/kwh) / 1000.

Parameter	Existing Engine Configuration	Proposed Engine Configuration
Rated Power in kw	40.5	55
BSFC in g/kwh	250	235
Fuel Flow in kg/h	10.125	12.92
Air Fuel Ratio	24	24.8
Air flow in kg/h	243	320

Air Flow (in kg/h) = Fuel Flow (in kg/h) * (A/F)

Table 1:- Air flow Calculation @ Rated Power

Step 2:- Boost Pressure Requirement Calculation

To calculate the required engine inlet pressure (kpa)

$$P_{2'} = \frac{120 * m_{air} * R * T_2}{N * \eta_{vol} * V}$$

m_{air} – Air Mass Flow in kg/s

N – Engine RPM

η_{vol} – Volumetric Efficiency

V - Engine Displacement in Litres

T_2 - Compressor Outlet Temperature in K.

R - Specific gas constant of the air (287 J/kg K)

Step 3: Calculation of Compression Pressure Ratio

Pressure before Compressor

$$P_1 = P_{amb} - \Delta P_{filter}$$

Pressure After Compressor

(Taking Intercooler Pressure Drop into account)

$$P_2 = P_{2'} + \Delta P_{intercooler}$$

Pressure Ratio (p_c)

$$p_C = \frac{P2}{P1}$$

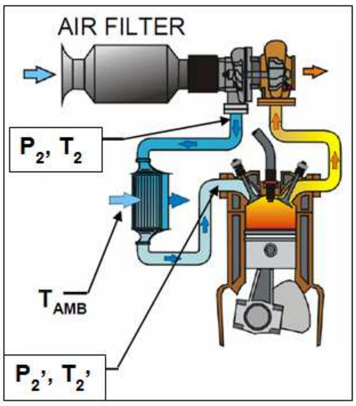

Fig 2 :- Parameters of TCIC Engine

Step 4: Selection by Plotting Results in Compressor Map

- Calculated values of Air Mass Flow, Pressure Ratio for Low Engine Speed, Max Torque & Rated Power to be Plotted on Compressor Map given in Fig. .
- The following parameters to be taken while selecting the Compressor
  - ➢ Good Efficiency at Low Speed, Rated Power and Max Torque
  - ➢ Altitude Reserve
  - ➢ Adequate Surge Margin

Based on the Engine Target Performance, Turbocharger with ø41mm Compressor had been selected. Engine Air flow requirements are plotted on the below compressor Map and all the above parameters for selecting the compressor had been achieved.

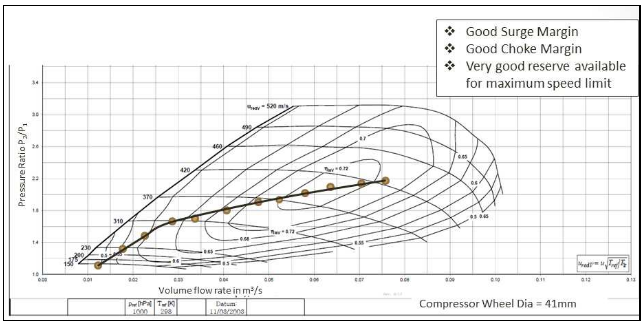

Fig 3 :- Engine Air Flow Curve on Turbo Compressor Map

B. CAC PERFORMANCE TARGETS.

Table 2 :- CAC Performance Targets

Performance condition	Value
Air flow rate (kg/s)	0.089
Cooling air speed (m/s)	9
Inlet Pressure (bar)	2.2
Temperature before intercooler (°C)	170
Ambient Temperature (°C)	35
Performance Target	
Temp after intercooler (°C)	55
Charge air pressure drop (mbar)	50
Air side pressure drop across the Charger (mbar)	8
Heat Rejection (kw)	10.28

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HEAT REJECTION

$$Qr_{int} = m_{air} * C_p * (T_2 - T_2')$$

Qr_{int} – Heat Rejected in Intercooler in kw
M_{air} – Mass Flow Rate of air in kg/s
C_p – Specific Heat of Air at Constant Pressure (1.005 kj / kg K)
T_2 – Temperature of air before Intercooler in °K
T_2' – Temperature of air after Intercooler in °K

III. COMPARISION OF ENGINE PERFORMANCE DATA

The below performance curve provides the comparison between the existing Engine performance data and new proposed Engine’s target Performance.

A. POWER

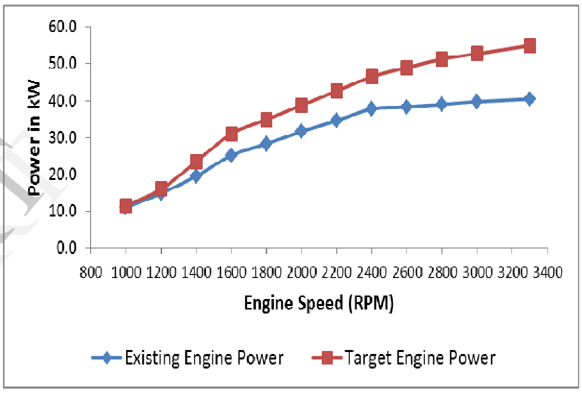

Fig.4 :- Variation of Brake Power with Speed

B. TORQUE

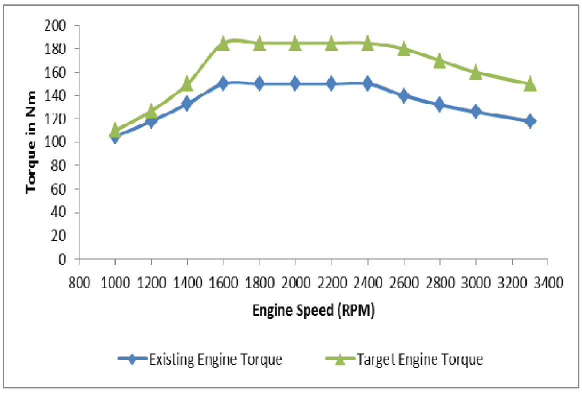

Fig 5:- Variation of Torque with Speed

C. BSFC

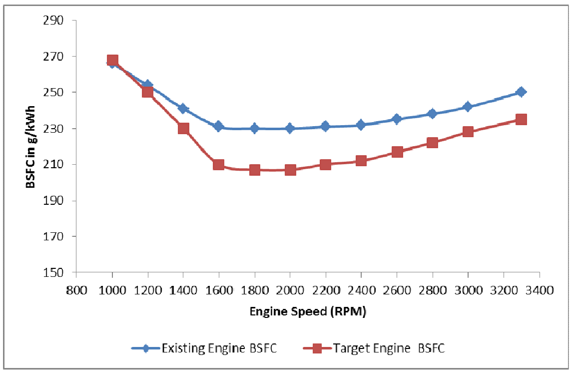

Fig 6:- Variation of BSFC with Speed

D. AIR FLOW

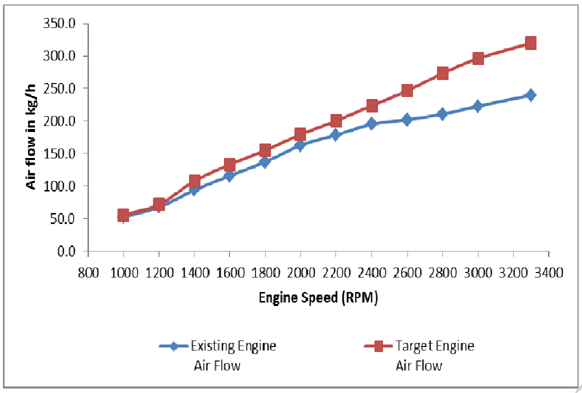

Fig 7 :- Variation Air flow with Speed

IV. ENGINE PERFORMANCE TESTING.

A. TRIAL - 1

Performance Testing conducted on the Engine with the New Turbocharger, Charge Air Cooler and Piston. Fueling increased to increase the power output (55kw) of Engine. Correspondingly, the required air flow (315 kg/h) was achieved by adjusting the Wastegate of the Turbocharger. However, the Turbo Compressor Outlet Temperature was increased to 188°C from the target value of 170°C max., due to the increase in boost pressure (1600mbar Gauge). Moreover the Exhaust Gas pressure also increased up to 2800mbar Gauge approx. And it directly impacts the BSFC, which increases to 247 g/kwh from the target value of 235 g/kwh.

Targets met in the Performance Testing

a. Power of 55kw achieved
b. Torque of 175 Nm achieved
c. Air Flow of 315 kg/h achieved
d. Exhaust Temperature maintained within 720°C

Targets not met in the Performance Testing

e. Turbo Compressor outlet temperature too high (188°C). Results in higher loss of Heat Energy from the CAC.
f. Exhaust Gas pressure before Turbine too high.
g. BSFC not meeting the target of 235 g/kwh

Performance Report of Trial – 1 is as follows,

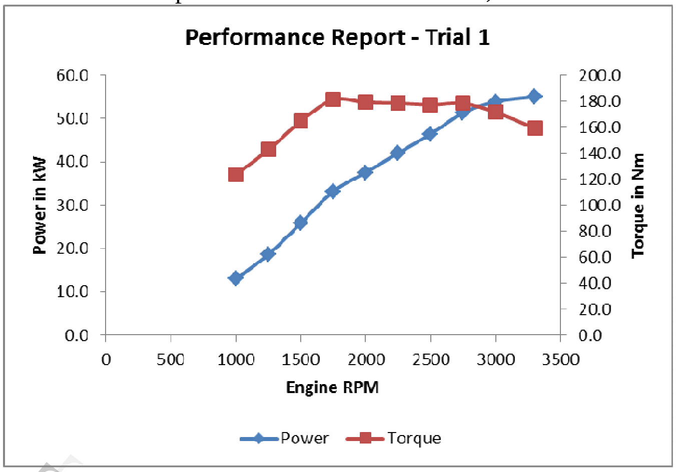

Fig 8 :- Variation Power & Torque with Speed

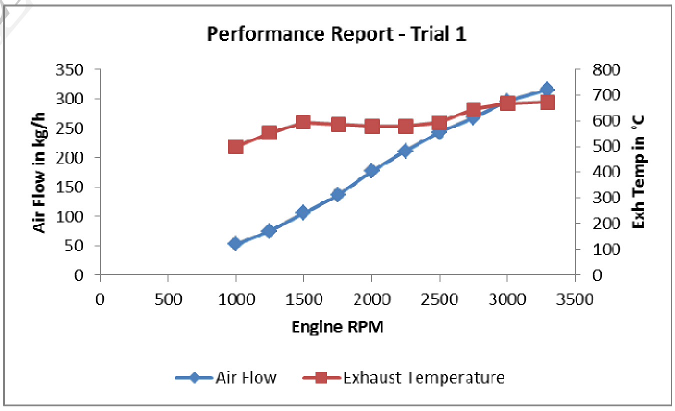

Fig 9 :- Variation Air flow & Exh Temp with Speed

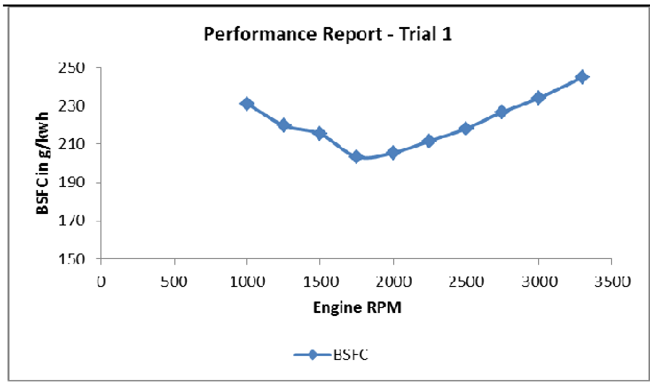

Fig 10 :- Variation BSFC with Speed

B. TRIAL - 2

Engine Performance Testing repeated and the target Power & Torque are achieved by re-adjusting the Turbocharger wastegate setting to reduce the Air flow to 295kg/h inorder to keep the compressor outlet temperature within the acceptable limit of 170°C max. With the reduced Compressor Outlet temperature, the air is cooled to a temperature of 55°C and less heat rejected through the CAC. At the same time, the exhaust gas pressure before Turbine also within limit, such that the BSFC of Engine meets the target value of 235 g/kwh. However there is an increase in the Temperature of Exhaust gas to 703°C, still it is within limit of given Boundary Condition (720°C).

Targets met in the Performance Testing

a. Power of 55kw achieved
b. Torque of 175 Nm achieved
c. BSFC of 235 g/kwh
d. Exhaust Temperature maintained within 720°C
e. Turbo Compressor outlet temperature maintained at 170°C. Results in higher loss of Heat Energy from the CAC.
f. Exhaust Gas pressure before Turbine within the acceptable limits.

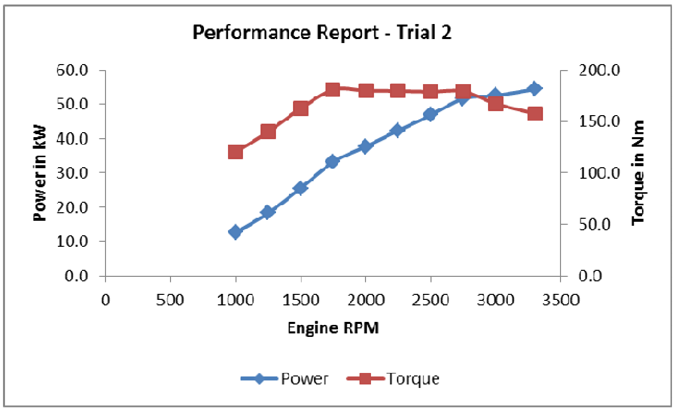

Fig 11 :- Variation Power & Torque with Speed

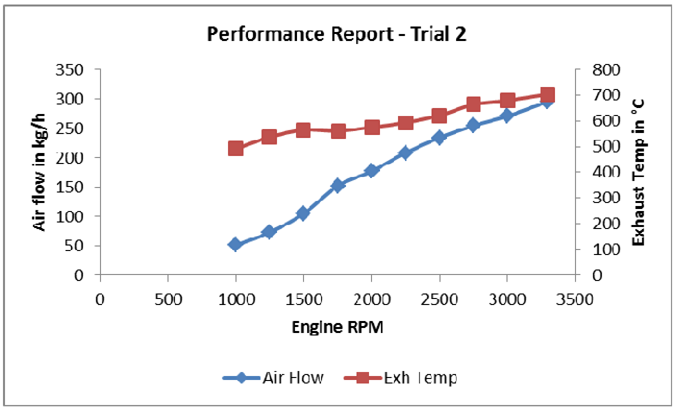

Fig 12 :- Variation Air flow & Exh Temp with Speed

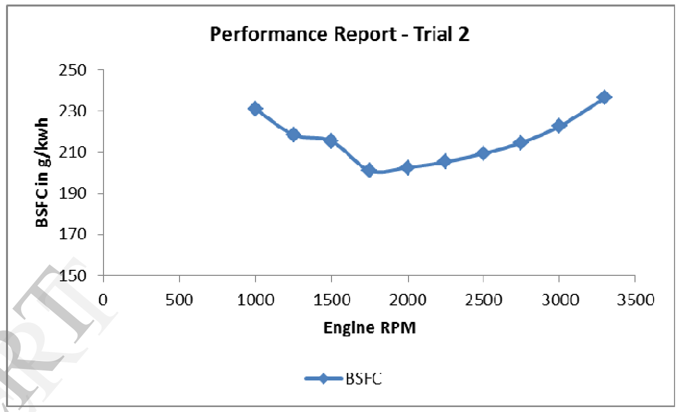

Fig 13 :- Variation BSFC with Speed

V. Conclusions

In both the performance trials the Target Power and Torque have been achieved with the new improved Turbocharger, Piston & Charge Air Cooler. However, BSFC was better in Trial 2, where the air flow was optimised such that the Heat loss through the CAC and the Pumping losses are minimum. Based on these results, Performance Trial 2 had been considered as best optimised solution for the given boundary condition.

Future scope of research in this area involves optmisation of Turbine to handle more gas flow without increasing the back pressure. VNT Turbocharger can be matched to improve the performance of Engine futher without any additonal penalty on the Fuel Consumption.

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