International Journal of Current Engineering and Technology E-ISSN 2277 – 4106, P-ISSN 2347 – 5161

Available at http://inpressco.com/category/ijcet

Research Article

Selection and experimental validation of turbocharger for five cylinder CNG engine

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Accepted 15 June 2016, Available online 20 June 2016, **Special Issue-5 (June 2016)**

The world is having two crisis of environmental pollution and fossil fuel depletion. Use of alternative fuels is good solution for low exhaust emissions. Development of alternatively fuelled engines has become important to meet the stringent emission norms being implemented globally. CNG is better alternative fuel for automotive sector to reduce demand of petrol and diesel. Engine power is proportional to the amount of air and fuel that can get into the cylinders. The power of a CNG engine can be increased by installing turbocharger. In this work a base naturally aspirated SI engine (which is converted from CI to SI) is converted to a TC intercooled natural gas engine. BorgWarner make turbocharger is selected from compressor maps with the help of a mathematical model giving pressure ratio and air flow rate of compressor. The power of engine is increased to 83kW from 70kW at rated speed of 3400rpm. Also maximum torque is increased from 205Nm to 242Nm in between 1400-2000rpm. BSFC is reduced to 210 gr/kWh along with improvement in volumetric efficiency. Use of 3-way Catcon improved emission levels significantly .

Keywords: *CNG, Turbocharger, Compressor map, Torque, Power, BSFC.*

1. Introduction

A baseline CNG engine compliant with BS-III emissions norms was initially developed by converting an existing five cylinder diesel naturally-aspirated engine by addition of a suitable CNG fuel-system kit and an electronic digital ignition system. The selection of suitable piston geometry is done to obtain compression ratio of 10.5:1. The base NA CNG engine having maximum power of 70kW at a rated speed of 3400rpm and maximum torque as 205Nm in the range of 1400-2000rpm. In order to achieve desired performance characteristics and reduction in emission focus on intake system and after treatment system had done. A NA engine has a limited supply of air for combustion. The air has only atmospheric pressure pushing it into the cylinders. A turbocharger provides pressurized air, which allows denser air to be packed into a cylinder for each firing. This provides more power and much better combustion efficiency. Thus, more power is obtained from a given engine size also fuel economy improves, and emissions are reduced. In this work BorgWarner make turbocharger is selected from available compressor maps in catalogue with the help of a mathematical model giving pressure ratio and air flow rate of compressor. Natural gas is world's most abundant fossil fuel. The main constituent of CNG is methane composed of one carbon atom and four hydrogen atoms. The use of CNG as an alternative fuel results in significant reduction in level of vehicular pollution like CO, HC, NOx and PM. Since the fuel system of CNG vehicles is completely closed, evaporative emissions are practically eliminated. Also reactive organic gas emissions form fuel storage and refueling of CNG vehicles are small (K. S Iyengar *et al*, 2007). The CNG has a high knock resistance value with an octane number of 130. For that reason compression ratio 13.1 could be expected to reach the best thermal efficiency taking advantage of such octane number. In spark ignition engines it can be used in bi-fuel mode or as a dedicated CNG engine. Whereas in compression ignition engines natural gas cannot be used directly since lower cetane number. Natural gas can be used in dual fuel mode in CI engines. CNG engines are noiseless in heavy duty vehicles than diesel engines.

Although is flammable gas it has narrow flammability range making it safer fuel. It's not toxic to skin and lungs. It has auto ignition temperature of 540°C. CNG gas is stored in cylinders at a 200bar pressure. Cost of CNG is one third of gasoline. Cost of CNG vehicles is higher than gasoline vehicles due to higher cost of cylinders. Natural gas engines can be operated either on lean or stoichiometric operation, Lean operation means operating engine with excess air i.e. lambda greater than one whereas stoichiometric means lambda equal to one. An study on application of CNG on a 2- stroke engine used for three wheeler shows drop in power and torque in CNG mixture as compared with gasoline.

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CO_2 reduced by 20%, CO reduced by 42.5%, HC increased and NOx reduced (Agarwal *et al*, 2009).

An experimentation on four cylinder CNG turbocharged spark ignition engine shows that maximum thermal efficiency of turbocharged engine is 4% more than naturally aspirated engine at 2500 rpm. Also the maximum engine efficiency of CNG engine is 4.5% more than gasoline engine. Therefore by using turbocharger and natural gas as a fuel in the engine, thermal efficiency of the engine increased by 8.5%. By using turbocharger a part of wasted energy in exhaust gases can be converted to useful power and therefore improve exergetic efficiency 3.6% higher than naturally aspirated engine averagely. (A.Ghareghani *et al*, 2013). A research was performed on 4-stroke direct injection CNG SI engine with a compression ratio of 14. Supercharging was done using a DC motor and the boost pressure was adjusted by varying the motor speed using a controller. This work was performed on engine by variation in speed from 2000rpm to 5000rpm and by varying boost pressure from 2.5kPa to 12kPa in an interval of 2.5kPa. Boost pressure above 7.5kPa resulted in a better engine performance compared to NA engine at all engine speeds (G. Tadesse *et al*,2009).

The compressed air coming from the compressor of the turbocharger is at higher pressure and temperature. If the higher temp air is used in the engines there is possibility of auto ignition taking place which is detrimental for engine life. Intercooling of compressed air is the only solution to reduce the temp. A naturally aspirated engine was converted to a turbocharged intercooled otto engine that uses CNG as a fuel. Study on same shows that due to intercooling charge temperature was lowered by 47°C reducing NOx by 37%.There was a slight reduction in CO and HC values also (Y. Takada *et al*,1993). A 1.2 litre 4 cylinder CNG engine with compression ratio of 10:1 and a garret high performance turbocharger was regulated through waste gate valve so as to impose selectable levels of boost. Tests were performed at constant speed of 3000rpm and load of 800kPa for spark advance set at maximum brake torque. The boost pressure varied in the range of 100 to 300kPa and throttle angle in the range of 24.4 to 31.2°. There was a decrease in in-cylinder pressure as the boost pressure is augmented.

Turbine inlet temperature increases with boost pressure due to lower expansion ratio attained (D' Ambrosio *et al*, 2006). The selection of turbocharger was done for OM355 naturally aspirated 6 cylinder diesel engine. This work gives idea about selection of TC based on power requirements. (Mohamadamin *et al*, 2014). Fuel economy of turbocharged engine is determined by maximum utilization of exhaust energy in turbine. The usable enthalpy potential of exhaust gas is determined by exhaust back pressure at the turbine exit, which is controlled by exhaust diffuser, catalysts and silencer. In a study Kesgin varied exhaust back pressure from 65mbar to 105mbar. An increase in back pressure resulted in decrease of .05% engine efficiency and approximately .017bar reduction in indicated mean effective pressure (Kesgin U, 2005).

2. Turbocharger Selection

Selection of correct turbocharger to CNG engine is of great importance and vital for successful operation of a turbocharged CNG engine. Match of turbocharger is only possible at a particular point in the operating range of the engine. For example if engine is required to run most of its life at constant speed and full load, the turbocharger will be chosen such that its high efficiency operating area coincides with pressure ratio and mass flow requirements at those conditions. For selecting turbocharger for specific application needs many primary inputs. Important primary input is to have target power in mind. This should be realistic for the application. For selecting turbocharger it is necessary to calculate the mass flow requirement and boost pressure for target power.

The air mass flow requirement and pressure ratio for various engine speeds was found with the help of following mathematical model. These points were plotted on various compressor maps available. and correct turbocharger is selected i.e. BorgWarner make 2074 KCB waste gate type with inducer diameter as 51mm and exducer diameter is 37.80mm. Compressor trim (inducer/exducer)^2 x100 is 55. The compressor map is a graph that describes a particular compressor's performance characteristics, including efficiency, mass flow range, boost pressure capability, and turbo speed. Correct turbocharger will have a maximum points in high efficiency zone of compressor map. Surge line is left hand boundary and choke is right hand boundary. Operating points should be in high efficiency zone i.e. . at the centre of compressor map. Fig.1 shows typical compressor map on which three engine operating points are plotted.

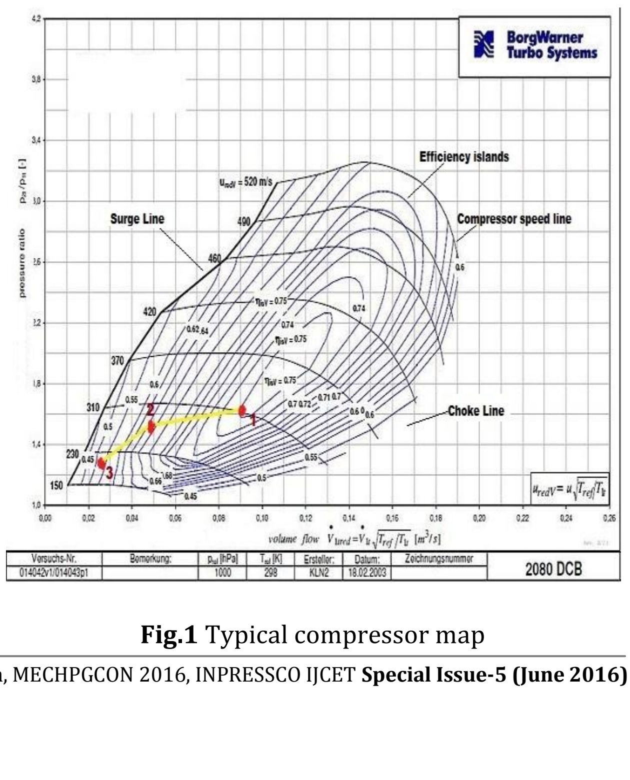

Fig.1 Typical compressor map

Nomenclature

A/F	Air to Fuel ratio =17.2
BSFC	Brake Specific fuel Consumption in gr/kWh
MAP	Manifold Absolute Pressure in kPa
N	Engine rpm
NA	Naturally Aspirated
m	Mass flow rate in gr/min
p	Power in kW
P	Pressure in kPa
ΔP	Pressure Loss in kPa
R	Gas Constant = 0.287 kJ/kg K
r	Compressor pressure ratio
T	Temperature in K
TC	Turbocharger
V	Engine Volume in m^3
VE	Volumetric efficiency

Subscripts

1c	Compressor inlet
2c	Compressor outlet
a	Actual airflow
amb	Ambient air condition
m	Intake manifold
req	Required
target	Target power in kW

Mass flow rate of air required to develop target power is given by equation 1

$$\dot{m}_a = p_{target} \times A/F \times \frac{BSFC}{60} \quad [1]$$

Now, Manifold absolute pressure is obtained by equation 2

$$MAP_{req} = \frac{\dot{m}_a \times R \times (T_m + 273.15)}{VE \times \frac{N}{2} \times V_d} \quad [2]$$

There is a pressure drop in between compressor outlet and engine manifold due to piping, bends etc. So, Compressor outlet pressure is found by adding this loss in manifold absolute pressure found by equation 2

$$P_{2c} = MAP_{req} + \Delta P_{loss} \quad [3]$$

Also air filter offers some restriction for air flow at compressor inlet. So, Compressor inlet pressure is given by equation 4

$$P_{1c} = P_{amb} - \Delta P_{filter} \quad [4]$$

Pressure ratio is given by equation 5

$$r = \frac{P_{2c}}{P_{1c}} \quad [5]$$

3. Experimental Set up

The project work is carried out in Powertrain Engineering Department of Automotive Research Association of India (ARAI) Pune. Fig.2 shows schematic diagram of experimental set up. Table 1 gives specifications of base naturally aspirated engine. The test bed pressure and temperature is 1.01325bar and 25°C and it is maintained constant throughout the test with the help of room conditioning system. The test bed is equipped with an Eddy current dynamometer with an accuracy of ±1Nm and ±1rpm.

Ambient temp, engine charge air temp after intercooler, air temp at inlet manifold , exhaust temp before turbocharger turbine and inlet and outlet coolant temp were measured by K-type thermocouple with a accuracy of ±0.5°C. Pressure was measured by a strain gauge absolute pressure transducer calibrated with a accuracy of ±136Pa. The CNG control system consisted of Impco-make ECU, exhaust gas oxygen sensor, MAP sensor. The engine is operated at stoichiometric condition throughout the test by maintaining lambda equal to one with the help of O_2 sensor in exhaust system. Power, Torque and BSFC were measured at full throttle condition at six speeds from 1000 to 3400rpm at a interval of 500rpm. An air to air intercooler was fitted to reduce exhaust temperature of air after compressor in order to avoid auto ignition which leads to knocking if supplied directly to engine.

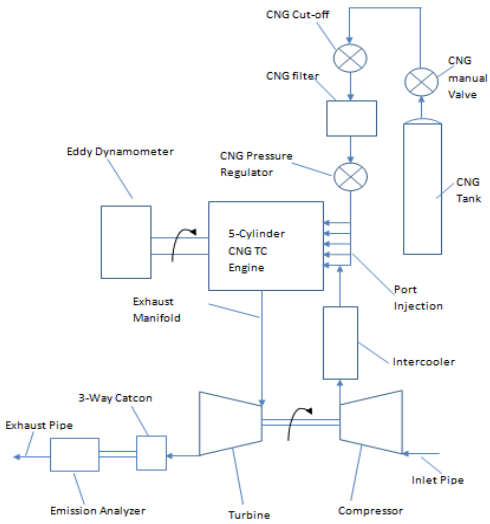

Fig.2 Experimental set up schematic diagram

The exhaust gas emission level is reduced by using a three way catalytic converter with monolithic substrate. The cell density of catcon is 400 CPSI. After fitment of TC to engine testing was done on test bench at ARAI.

Table 1 Base NA engine specifications

S. No	Parameters	Values
1	Operating Cycle	SI / 4 Stroke
2	No. of Cylinders	5
3	Bore x Stroke	90.9 x 100mm
4	Engine Displacement	649cc
5	Compression Ratio	10.5
6	Maximum Power	70kW @3400rpm
7	Maximum Torque	205Nm @1400-1600rpm
8	BSFC	260 g/kWh

Fig.3 Actual experimental set up diagram

4. Results and discussion

The below results are based on full throttle performance on existing and modified engine.

Fig.4 shows that engine with turbocharger produces more power as compared to naturally aspirated engine. This increase in power is attributed to the fact that due to turbocharging the amount of air entering the engine increases, which results in better combustion. The maximum power produced by TC engine is 83kW @3400rpm. At maximum speed 12% increase in power was observed for TC engine.

Fig.5 shows that more torque produced by TC engine compared with NA engine. Maximum torque of 242Nm is produced at 1500rpm.

Fig.6 shows superior fuel economy of TC engine. There was a significant drop in fuel consumption by TC engine. The fuel consumption by TC engine is lowest in between 1500-2000rpm. Because of complete combustion of fuel at maximum speed 15% reduction in BSFC was found for TC engine.

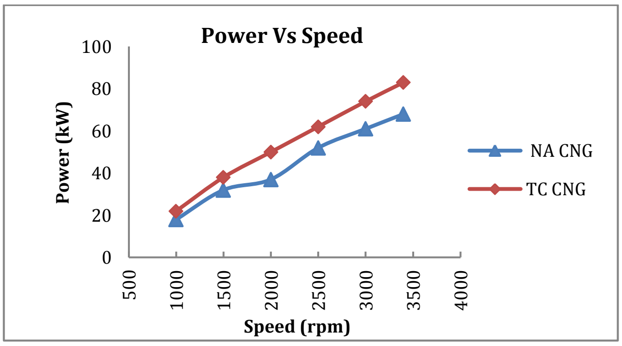

Fig. 4 Engine power results.

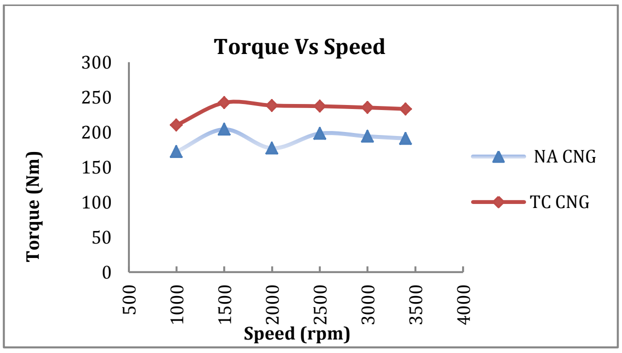

Fig.5 Engine torque results

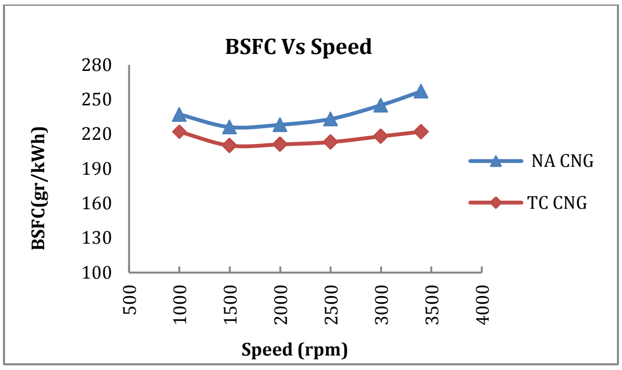

Fig. 6 Engine BSFC results

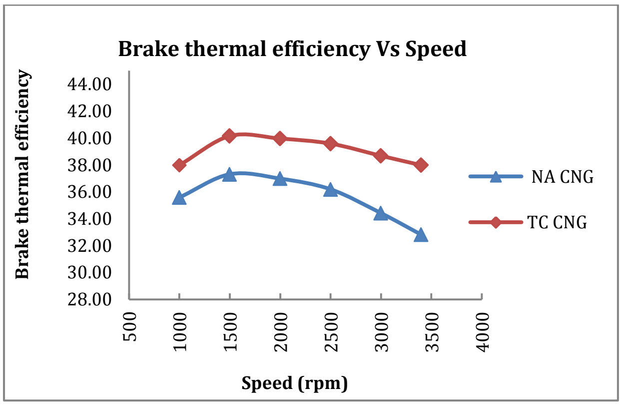

Fig.7 Brake thermal efficiency Vs Speed results

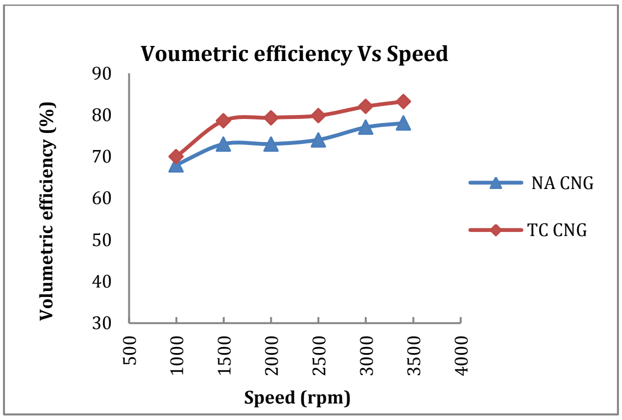

Fig.8 Volumetric efficiency Vs Speed results

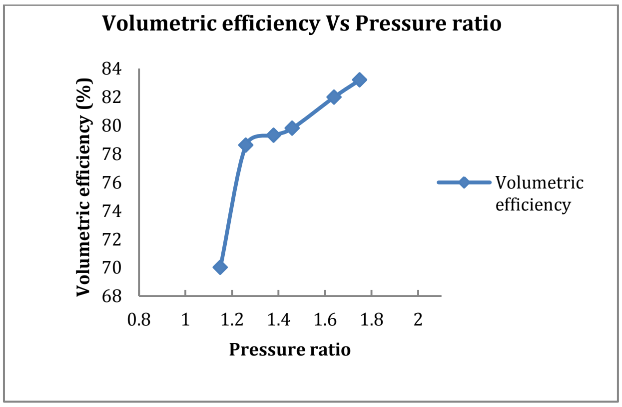

Fig.9 Volumetric efficiency Vs Pressure ratio results

Fig.7 gives variation in brake thermal efficiency with engine speed. Brake thermal efficiency of turbocharged engine is more as compared with NA engine. Brake thermal efficiency is improved by 4% throughout the speed range.

Fig.8 compares the volumetric efficiency of the engine. Due to turbocharging , the amount of air entering the engine increases as the compressor of the turbocharger compresses the air , resulting in increase in density of air.

Fig.9 Shows that Volumetric efficiency increases as the boost pressure developed by compressor increases.

Conclusion

In this study effect of turbocharging on NA CNG engine was investigated experimentally. From the results following conclusions can be deduced.

1. Turbocharging improves efficiency by using exhaust gas energy that would otherwise be lost. Turbocharging is important in meeting current & future fuel economy and performance goals.
2. With the help of compressor maps turbocharger can be selected for required power output. Improved rated power and torque are observed in modified engine as compared to base NA engine.
3. Use of air to air intercooler reduced the boosted air temperature. Improvement in BSFC level is observed.

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