Performance analysis and fabrication of turbocharger in single cylinder four stroke petrol engine

[1]Ajayakumar A G, [2]Jithin A S,[3]Anverlal A N, [4]Nandagopan A.S, [5]Pankaj Balaji & [6]Gokul M
[1,2,3,4,5,6]Department of Mechanical Engineering, Vidya Academy of Science and Technology-Technical Campus, Kilimanoor, Kerala

Received: January 28, 2019 Accepted: March 19, 2019

ABSTRACT: *Improving performance of an Internal Combustion (IC) engine without increasing the engine displacement is a present challenge. It can also be achieved by increasing the volumetric efficiency, which can be increased by providing combustion chamber with maximum amount of air. Turbocharging is one of the method to increase the efficiency and to control the exhaust emissions from the engine. Turbochargers are conventionally employed in Diesel engines because Spark Ignition (SI) engine tend to knock under high induction pressure. But researches are focusing on supercharging in SI engines without knocking. In the present work, a turbocharger is implemented to a single cylinder SI engine and its performance and exhaust emissions are evaluated with and without Turbocharger. The analysis shows that the Brake Power and Mechanical Efficiency of the engine is increased by 12.33% and 3.25% respectively. Also the Carbon Monoxide (CO) and Hydrocarbon (HC) exhaust emissions are reduced by 0.009% and 15.2% respectively.*

***Key Words**: S I Engine, Supercharging, Mechanical efficiency*

Introduction

Turbocharging simply is a method of increasing the output of the engine without increasing its size. The basic principle is simple and is already being used in big diesel engines. European car makers installed small turbines turned by the exhaust gases of the same engine. This turbine compresses the air that went on to the combustion chamber, thus ensuring a bigger explosion and an incremental boost in power. The fuel-injection system, on its part, made sure that only a definite quantity of fuel went into the combustion chamber.

A Turbocharger is a small centrifugal pump driven by the energy of the exhaust gases of an engine. A turbocharger consists of a turbine and a compressor on a shared shaft. The turbine converts kinetic energy and potential energy from the engine exhaust into rotational kinetic energy, which is in turn used to drive the compressor. The compressor draws in ambient air and pumps it into the intake manifold at increased pressure, resulting in a greater mass of air entering the cylinders on each intake stroke.

The principal aim of any engine designer is to achieve the twin goals: Improved power output and minimum exhaust emission. The power output of a naturally aspirated engine depends mainly on the following five factors:

a. Amount of air inducted into the cylinder
b. Extent of utilization of the inducted air
c. The speed of the engine
d. Quantity of the fuel admitted and its combustion characteristics
e. Thermal efficiency of the engine

The last two factors are inter-dependent and major modifications might be required to achieve complete combustion and therefore may not be a preferred method. The most preferred method of increasing the power output is by means of increasing the mean effective pressure. This can be achieved by supplying air or air-fuel mixture at a pressure which is higher than the atmospheric pressure. This will increase the density, thereby the mass of air or air-fuel mixture inducted for the same swept volume. This in turn will increase the power output of the engine. This method of supplying air or air-fuel mixture higher than the pressure at which the engine naturally aspirates, by means of a booting device called as Supercharging. The device which boots the pressure is called Supercharger.

Experimental setup

Connect the turbo inlet with the engine exhaust port with the help of stud nut and welding. The turbine shaft is connected to a compressor, which draws in combustion air, compresses it and then supplies it to the engine. Now connect air filter with the turbo compressor section. Connect turbo air inlet with hose pipe with bike air cleaner. Now connect carburetor with air cleaner and with the engine. Connect silencer with the waste gate from where the waste gas will flow.

A Turbocharger consists of a turbine and a compressor on a shared shaft. The Turbine in the turbocharger converts heat to rotational force, which is in turn used to drive the compressor. The compressor draws in ambient air and pumps it in to the intake manifold at increased pressure, resulting in a greater mass of air entering the cylinders on each intake stroke. The output of the engine exhaust gas is given to the input of the turbine blades, so that the pressurized air is produced. This power, the alternate power must be much more convenient in availability and usage.

The performance and emission tests is carried out, with and without turbocharger. The turbocharged engine is connected to a Brake Dynamometer for Load Test Setup. The performance parameters are calculated and tabulated. The Emission tests are carried out using an Automatic Exhaust Analyzer, using a Pollution Testing Gun. The emission tests mainly include the analysis of Carbon Monoxide (CO) and Hydrocarbon (HC) emissions.

The performance, combustion and emission tests were carried out on a four stroke, single cylinder, naturally aspirated, Bajaj Pulsar 180cc DTSi Engine. It is connected to a spring balance set up for loading. Some provisions is also made for the measurement of volumetric fuel flow. It can be used to calculate indicated power, brake power, thermal efficiency, and mechanical efficiency. The components of the turbocharged engine setup are :

The engine test rig

Illustrates the basic setup of the test bench. The engine is coupled with its original shaft to the dynamometer. Brake drum dynamometer is used for loading. The engine is assembled with a turbocharger into its exhaust line, without any chance of gas leakage.

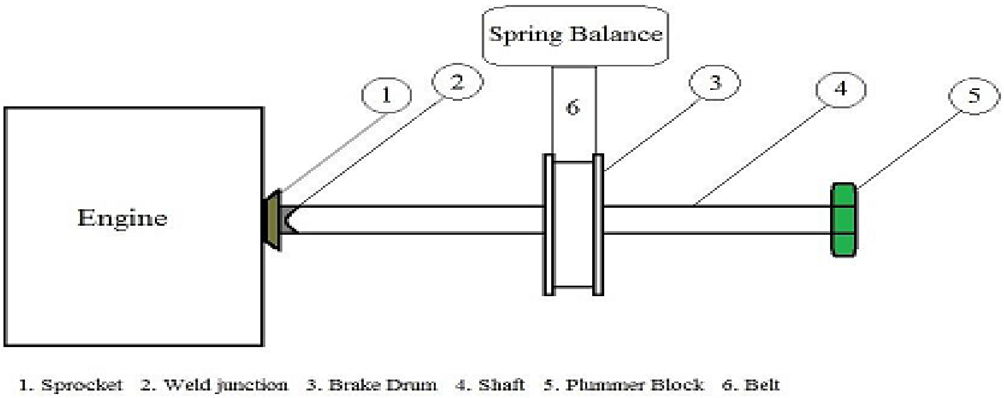

Fig.1. Schematic Diagram of a Brake Dynamometer (Load Test Setup)

Fig.1 shows the schematic of a Load Test Setup (Brake Dynamometer). A shaft (which has to be designed) is welded to the sprocket connected to the drive shaft. By this means, the rotation of the brake drum can be achieved which is connected to the designed shaft. At the other end, a Plummer block is used to support the shaft. The shaft is given load by means of a belt connected to brake drum. The amount of load applied can be read by a Spring Balance. The main parts of a Brake Dynamometer are:

1.Brake Drum

Brake Drum is used to apply the load against the rotation of shaft by the application of friction belt on its surface. The specifications are as follows:

Material	: Aluminium	Weight	: 5 Kg (49 N)
Inner Diameter	: 125mm	Outer Diameter	: 254mm
Bore Diameter	: 38mm		

2.Shaft

Shaft is a rotating machine element which is used to transmit power from one place to another. The power is delivered to the shaft by some tangential force and the resultant torque (or twisting moment) setup within the shaft permits the power to be transferred to various machines linked up to the shaft.

For this experiment, the engine so used have a power of 11KW at 8000rpm. So the shaft should transmit the power without failure.

The Design of Shaft is as follows:

Material	= Mild Steel	Yield Shear Strength, τ	= 103 MPa
Length of Shaft	= 5000mm	Max load can apply	= 11Kg (108N)

Weight of Drum = 5Kg (49N) Total Downward Force, FD = 208N
Factor of Safety = 1.5

Neglecting the weight of shaft and considering only the weight of brake drum, the bending moment diagram of shaft is as follows:

From the Bending Moment diagram,
Maximum Bending Moment, M = 52 Nm
Maximum Torque, τ = 14 Nm

So the shaft is designed on the basis of Maximum shear stress theory.

$D^3 = 16\pi\, \tau_{max} \sqrt{(C_m M)^2+(C_t T)^2}$ (1)

Assuming steady load or gradually applied load,
C_m =1.5
C_t =1
(C_m And C_t are fatigue factor for bending moment and torque respectively)

From the equation (1), Diameter of the shaft, D = 15.77 mm

This is the minimum required size of the shaft to transmit 11KW power, without failure. Since the bore diameter of brake drum is 38mm, the shaft is also taken with the same diameter, to avoid slipping off or tightening of the shaft.

3.Plummer Block

A Plummer block or bearing housing is a pedestal used to provide support for a rotating shaft with the help of compatible bearings and various accessories. Housing material for a Plummer block is typically made of cast iron or cast steel. Here, a bearing unit is used to support the rotating shaft.

4. Frame

While the test is ongoing, there is a chance of vibration due to the dynamic force developed on the shaft, engine and brake drum. To withstand this vibration, there is a need to construct a frame, with the capability of absorbing the dynamic force.

5. The Engine

A four stroke, single cylinder, naturally aspirated, Bajaj Pulsar 180cc DTSi Engine, having the following specifications is used.

Type	: Four Stroke, Air Cooled, DTSi Engine	No of Cylinders	: One
Bore	: 63.50mm	Stroke	: 56.4mm
Engine Displacement	: 178.6cc	Compression Ratio	: 9.5± 0.5: 1
Max Net Power	: 16.01 bhp (11.77 kW) at 8000 rpm	Max Net Torque	: 14.72 Nm at 6500 rpm
Ignition System	: Microprocessor Controlled Digital CDI unit		
Ignition Timing	: 10° BTDC at 1500 r/min 28 ° BTDC at 3500 r/min	Spark Plug	: 2 No's
Fuel	: Unleaded Petrol		

6. The turbocharger

The specifications of the Turbocharger used are:

Turbine Inlet Diameter : 3”
Compressor Wheel
Inducer : 2.36”
Exducer : 2.48”
Compressor Outlet Diameter : 2”
Exducer : 2.07”
Turbine Wheel
Inducer : 2.89”

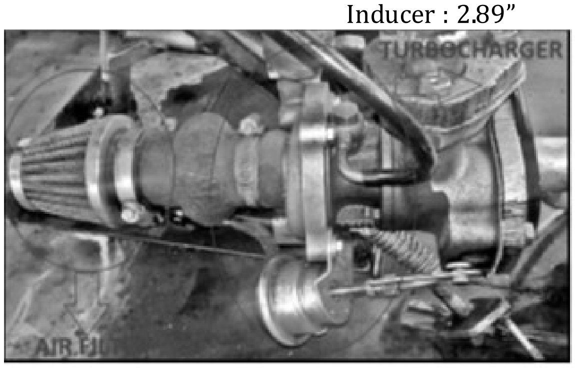

Fig.2. Turbocharged System Assembly

7. Air filter

It is important to appropriately size the air filter for the maximum flow rate of the application. The basic function of air filters is to prevent dust from entering the engine, which could cause serious damage to the performance of the bike. And if the engine is fitted with paper filter then change it regularly according to the instructions given by the manufacturer. If the turbo does not have access to the proper amount of air, excessive restriction can occur and cause:

i. Oil leakage from the compressor side piston ring, which results in oil loss, a fouled CAC and potentially smoke out of the tailpipe.

ii. Increased pressure ratio, which can lead to turbo over speed.

iii. Over speed will reduce turbo durability and could result in an early turbo failure.

8. Oil line and oil pump

We are using oil line for good and smooth working of turbocharger. In this case, we are using 20 W 40 mineral based oil is being used as the effective lubricant. Here Turbocharger is lubricated with the same oil, which is used or engine lubrication. Oil pump is used to supply oil into the turbocharger. The hoses delivering the oil to the turbocharger and returning it to the engine should withstand high pressures and temperatures. In general, the larger the oil drain, the better.

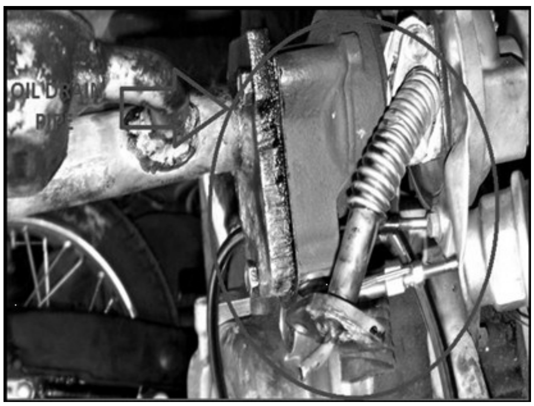

Fig.3. Oil Drain Pipe for Lubrication in Turbochargers

Performance and emission analysis

Performance analysis

The performance analysis is carried out by conducting Load Test at constant speed in the Engine Test Rig. The performance parameters such as Brake Power (BP), Total Fuel Consumption (TFC), Specific Fuel Consumption (SFC), Brake Mean Effective Pressure (BMEP), Brake Thermal Efficiency (BTE), Indicated Power (IP), Indicated Mean Effective Pressure (IMEP), Indicated Thermal Efficiency (ITE), and Mechanical Efficiency (ME) are evaluated with turbocharging and without turbocharging.

Experimental observations and calculations

Variations in the performance parameters of the engine, with and without Turbocharger are being provided in the Tables shown below:

Sl. No	N (rpm)	Load (N)	Time (sec)	BP (KW)	TFC (Kg/hr)	SFC (Kg/KWhr)	BMEP (KN/m2)	BTE (%)	IP (KW)	IMEP (KN/m 2)	ITE (%)	ME (%)
1	4256	20	19	1.11	0.745	0.671	170.8	11.16	2.11	317.68	20.15	52.6
2	2569	39	17	1.34	0.845	0.63	319.4	11.89	2.34	582.49	20.31	57.26
3	2402	59	13	1.88	1.11	0.59	497.6	12.71	2.88	778.5	20.54	65.27
4	2166	78	11	2.26	1.29	0.57	668	13.12	3.36	939.3	120.73	67.26
5	2599	98	8	3.39	1.77	0.522	811.3	14.36	4.39	1120.13	21.14	77.2

Table.1 Observations without Turbocharger

Sl. No	N (rpm)	Load (N)	Time (sec)	BP (KW)	TFC (Kg/hr)	SFC (Kg/KWhr)	BMEP (KN/m2)	BTE (%)	IP (KW)	IMEP (KN/m2)	ITE (%)	ME (%)
1	4716	20	18	1.23	0.8	0.65	175.22	11.22	2.23	333	20.53	55.18
2	2895	39	16	1.51	0.9	0.59	350.4	12.2	2.51	611.9	20.65	60.23
3	2658	59	13	2.08	1.1	0.53	525.7	13.32	3.08	805.5	2.78	67.57
4	2818	78	11	2.94	1.3	0.44	700.9	13.89	3.94	1042.1	20.8	74.61
5	2753	98	8	3.59	1.8	0.5	876.1	14.6	4.59	1134.8	21.39	78.2

Table.2 Observations with Turbocharger

The Performance Analysis for the engine, with and without Turbo charging are as follows:

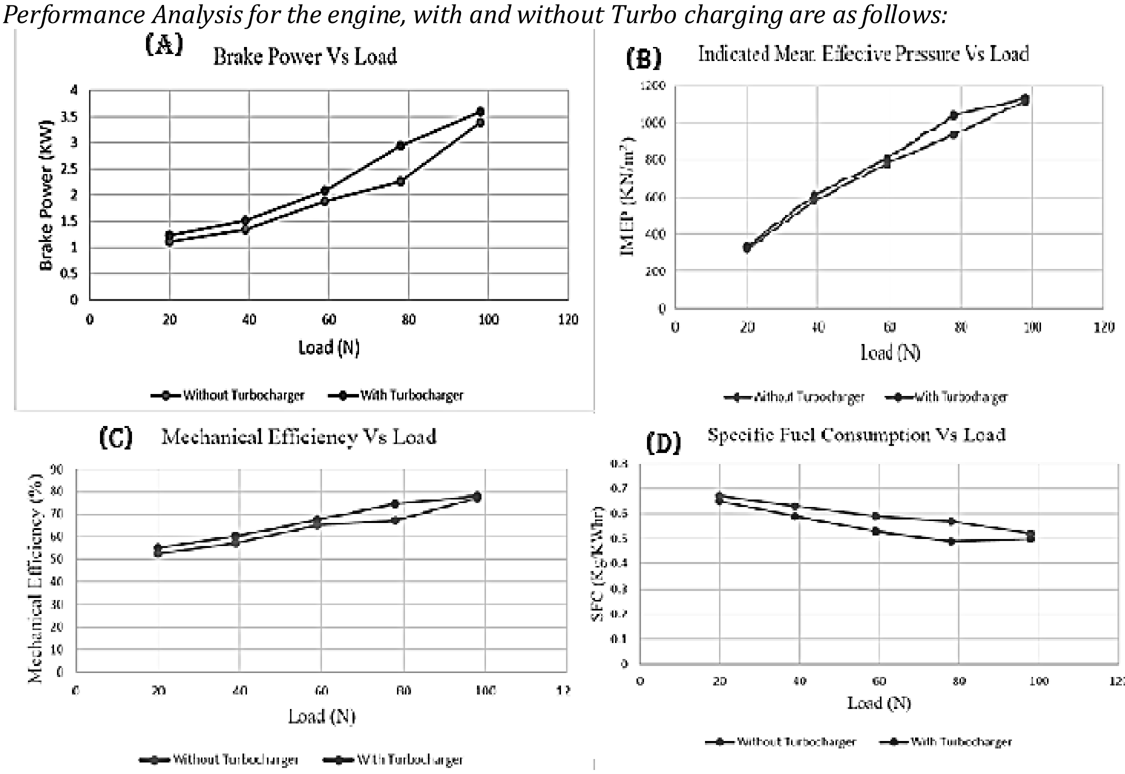

Fig.4 Brake Power Vs. Load

Fig.4a shows the variation of Brake Power for different load conditions with and without Turbocharger. It can be seen that for the same engine, figure shows a gradual increase in Brake Power when Turbocharger is used.Fig.4bshows the variation of Indicated Mean Effective Pressure for different load conditions with and without Turbocharger. It is clear that IMEP increases for the engine, by using a Turbocharger. Thus more pressure is developed inside the engine, which means more power.Fig.4c shows the variation of Mechanical Efficiency for different load conditions with and without Turbocharger. It can be clearly understood that mechanical efficiency is higher for a Turbocharged engine.Fig.4d shows the variation of Specific Fuel Consumption for different load conditions with and without Turbocharger. Figure reveals the decrease in SFC for the same engine, when Turbocharger is used. It implies that a Turbocharged engine requires less fuel for developing 1 KW power in 1hr than a naturally aspirated engine.

Emission analysis

The Emission Test Setup consists of an Auto Exhaust Analyzer and a Pollution Testing Gun. The exhaust emissions of the engine, with and without Turbocharger for CO and HC emissions were monitored using an Auto Exhaust Analyzer, using a Pollution Testing Gun.=

Variations in CO and HC Emissions of the engine, with and without Turbocharger for the maximum possible load conditions are provided at the Table below:

Sl. No	Without Turbocharger		With Turbocharger	
	CO (%vol)	HC (ppm)	CO (%vol)	HC (ppm)
1	0.98	851	0.89	721
2	0.99	893	0.89	750
3	0.98	890	0.93	787
4	1.2	921	0.95	811
5	1.3	935	0.95	840

Table.3 Emission Observations with and without Turbocharger

Results and discussions

The engine performance results, with and without Turbocharger are as follows:

- For the same engine the brake power increased with the installation of a turbocharger.
- IMEP increases for the same engine, by using a Turbocharger, further leading to a boost in the power.
- A decrease in SFC occur for the same engine, when turbocharger is used. It implies that a turbocharged engine requires less fuel for developing 1 KW power in 1hr than a naturally aspirated engine.
- Mechanical efficiency is higher for a Turbocharged engine.

Engine emission results

The engine emission results, with and without Turbocharger are as follows:

- With the installation of a turbocharger, the CO emission level significantly reduced.
- HC emission level get greatly reduced with the implementation of a turbocharger.

Conclusion and scope for future work

This work is an attempt to reduce our dependency on foreign oil and reduce the tailpipe emission from automobiles. This is also an attempt to design and implement this new technology that will drive us into the future. The use of turbo charger will reduce smog-forming pollutants over the current national average.

Turbocharger is implemented in a 180cc single cylinder engine and its performance and emission characteristics are studied and analysed. It is found that the Brake Power is increased by 12.3% and the Mechanical Efficiency of the engine is increased by 3.25%. This concludes that with the installation and implementation of Turbocharger in the single cylinder SI engine, the performance of the engine gets readily boosted up without any sacrifice in the efficiency of the engine.

CO emissions get reduced by 0.09% and the HC emissions get reduced by 15.2%. With the use of the turbocharged engine, the exhaust emissions gets greatly reduced, significantly reducing the Engine Exhaust Pollution Rate.

In future, this Turbocharging technique can be implemented in a real wide scenario. To ensure the maximum efficiency and performance of a turbocharged engine, a well tuned and performing carburetor can be introduced and implemented.

REFERENCE

1. Petitjean D, Bernardini L., Middlemass C. and Shahed S.M (2004).Advanced gasoline engine turbocharging technology for fuel economy improvements. SAE Technical Paper Series, 2010 - 01-0988
2. A. Kusztelan, Y.F. Yao*, D.R. Marchant, Y. Wang (2011), "A Review of Novel Turbocharger Concepts for Enhancements in Energy Efficiency", Int. J. of Thermal & Environmental Engineering Volume 2, No. 2 (2011) 75-82.
3. Mohd Muqeem, "Turbocharging With Air Conditioner Assisted Intercooler", IOSR Journal of Mechanical and Civil Engineering (IOSRJMCE) ISSN: 2278-1684 Volume 2, Issue 3 (Sep- Oct 2012), PP 38-44
4. J. Cheong, Sunghwan Ch, Changho Kim, "Effect of Variable Geometry Turbocharger on HSDI Diesel Engine", Seoul 2000 FISITA World Automotive Congress June 12-15, 2000, Seoul, Korea.
5. C.D. Rakopoulos, E.G. Giakoumis, "Availability analysis of a turbocharged DI diesel engine operating under transient load conditions" Energy 29 (2011) 1085–1104, www.elsevier.com/locate/energy.

6. Naser B. Lajqi, Bashkim I. Baxhaku and Shpetim B. Lajqi, "Effect of Intercooler on Turbocharged Diesel Engine Performance" 13th International Research/Expert Conference, Trends in the Development of Machinery and Associated Technology" TMT 2009, Hammamet, Tunisia, October 2012.
7. Eyub Canli, Selcuk Darici and Muammer Ozgoren "Intercooler Effect on Conventional Supercharging Systems" International Scientific Conference, 19-20 November, 2010, Gabrovo.
8. Mitsubishi Heavy Industries, Ltd. Technical Review Vol. 43 No. 1 (Jan. 2006)