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Performance Calculation & Development of Turbocharged Gasoline Direct Injection 125cc Motorcycle Engine

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ABSTRACT

It's my aim to design low fuel consumption and innovative engine concept for the future demands and many more features for such type of engine I made Gasoline Direct Injection turbocharged engine for 2-wheeler. The design and installation of GDI turbocharger engine in a single cylinder is available in this paper. The developed and fabricated a prototype of the GDI turbocharger system in Two- wheeler, In which I try to improve the efficiency of the Engine, more torque and horsepower for 125cc engine. It will be First Motorcycle 125cc engine with Turbocharged Gasoline Direct Injection.

Keywords: 125cc Engine, Fuel pump (Low & High Pressure Pump), Fuel Injector, Intake Manifold, Turbocharger, Fuel Filter, Spark plug

I. INTRODUCTION

It's my primary ambition to design, perform & fabricate Gasoline Direct Injection System with Turbocharger in Motorcycle engine. For this work I selected a straight engine of motorcycle (Honda Stunner 125 cc) to attain the goals of improving power output, low exhaust emission, high fuel economy for better performance & to lower down the exhaust emission. For this I have changes all the engine design and modified i.e. the removal of carburettor system, new design of cylinder head, ignition timing, and assembly with fuel injector, turbocharger.

Turbocharged GDI technology for motorcycle come through, the motorcycle launched with fuel injection (FI) technology in two-wheelers under the brand name Hero Honda Glamour FI.

Before installation of GDI system, I remove carburettor system from bike. Because the GDI System creates the Air-Fuel mixture inside the combustion chamber which result in higher compression & thus improving efficiency & also ignition level reduces.

1.1 Basic of GDI with Turbocharged

To supply fuel I need electronic fuel pump & the fuel is compress by high compressor pump. High pressure injector sprays fuel inside the combustion chamber. Intake of air is supplied every works internal.

Air-fuel needs ignition spark, for this ignition spark generates 30000 volts.

Turbocharger enables the superior air mass into the combustion chamber.

In GDI Engine the Inlet & Exhaust valve open instantaneously. Input of fresh air intake the combustion & blushes exhaust gasses inside the chamber.

1.2 About GDI & Turbocharger

GDI- Gasoline Direct Injection (GDI) is surely not new. The first known application of this technology was introduced in 1925 in a Hesselman engine for airplanes. Cars starting using it in the 50's with the Mercedes Benz Gullwing (1953) having this technology.

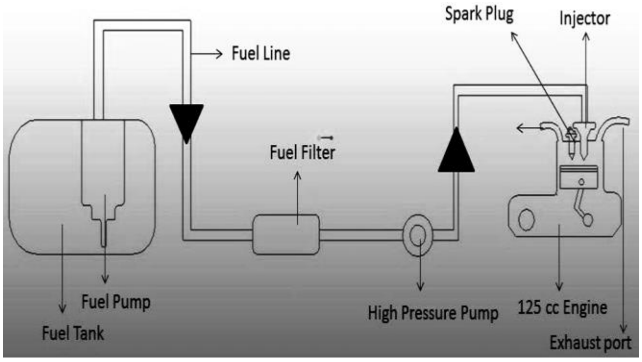

Figure 1.1. Layout of GDI System

Gasoline Direct Injection (GDI) also known as Petrol Direct Injection (PDI) or Direct Petrol Injection, Spark Ignition Direct Injection (SIDI), Fuel Stratified Injection (FSI) it a variant of fuel injection system which use in two or four stroke Gasoline engine.

Figure 1.2. GDI Function Inside Combustion Chamber.

Turbocharger- Basically turbochargers are called forced induction system. It is use to compress the air flowing into the Engine. The benefit of compressing the air inside the cylinder is that we get more power. A turbocharger delivers more power as compare to the same engine without charging.

A turbocharger acquires the power from the exhaust stream, the exhaust runs through a turbine, which in turn spins the compressor. The major parts of turbocharger are turbine wheel, turbine housing, turbo shaft, compressor wheel, compressor housing & bearing housing.

Figure 1.3. Turbocharger Connection with Bike Silencer

1.3 Why GDI Turbocharged Engine For 2-Wheeler

The summary of GDI Turbocharged was to decrease fuel consumption and exhaust gas emissions such as hydrocarbons (HC), nitrogen oxides (NOx).

In combination with turbocharger the Co2 reduced 30% & proper scavenging process is done because the input of fresh air inside the combustion chamber blushes the burnt gases through exhaust. & intake and exhaust valve open simultaneously.

By the installation of GDI turbocharged in single cylinder engine I improved volumetric efficiency of engine, compression ratio, reduction pumping losses, more torque & horsepower is produce for small engine and noise is decreased.

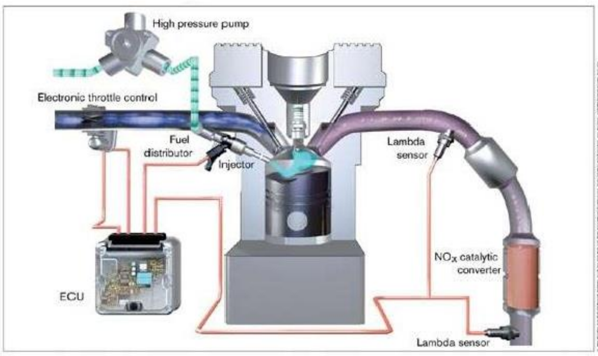

Figure 1.4. Gasoline Direct Injection

II. DESIGN PRINCIPLES & FUEL INDUCTION SYSTEM

The tasks of the fuel induction systems are;

1. To present right amount of fuel at specified schedule.
2. This schedule must be in arrangement with permissible heat release rate and period of combustion.
3. To prepare a mixture that satisfies the requirement of the engine using ambient air and fuel.
4. This preparation is to be passed out over entire engine operating system.

In principle, the optimal air-fuel ratio for an engine is that which give the required power output with the lowest fuel consumption. It should also confirm smooth and dependable operation.

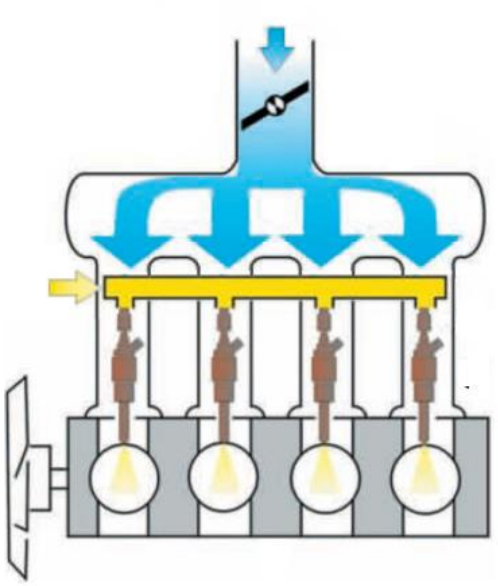

Figure 2.1. Fuel Induction Method In GDI

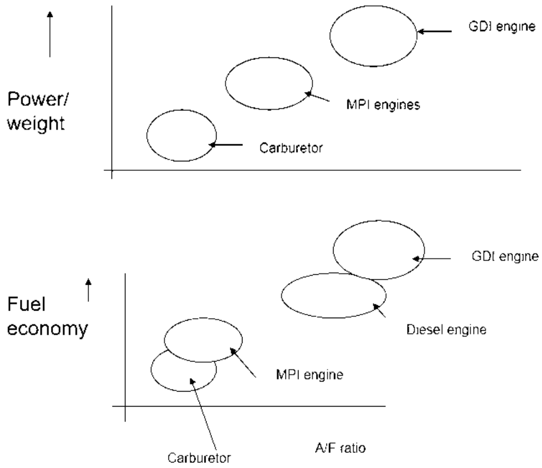

Figure 2.2. Comparission regarding Power Weight & Fuel Economy

2.1 Predictable Good Side Effects in GDI Engine

High Compression ratio as related with Carburettor engine. Accurate control over Air/Fuel distribution inside the combustion chamber improved volumetric efficiency. Generation of Optimal GDI configurations.

Effect of Geometrical and Spray Parameters

a. Injector location,
b. Spray orientation,
c. Injection timing,
d. Droplet diameter,
e. Spray cone angle,
f. Type of spray,
g. Fuel temperature

2.2 Experimental Development

- A four stroke 125cc engine of Honda Stunner 2 wheeler is modified to work as turbocharged GDI engine.
- An electronic driven petrol injector is placed in the cylinder head.
- Pistons with a number of geometries of cavities (Cylindrical, Conical & Spherical) are tested using a compression ratio of 9:2:1at several speeds.

Specification: - Single Cylinder 125cc Engine

Bore	: - 52.4mm
Stroke	: - 57.8 mm
Displacement	: - 124.7 cc or 125 cc

Maximum Power : - 11 Bhp @ 8000 rpm
Maximum Torque : - 11 Nm @ 6500 rpm
Compression ratio : - 9:2:1
Connecting rod length : - 96 mm
No. of Cylinder : - 1
No. of Valve : - 2
Ignition Type : - Spark
Cooling System : - Air cooled

2.3 Engine Intake Process: Uniform-State, Uniform-Flow Process

Any direct during intake, the equation of state for in cylinder ideal gas is expressed as:

$$p_{cyl}V_{cyl} = m_{mix-cyl}R_{mix}T_{cyl}$$

Rate of change of in cylinder gas properties:

$$\frac{d\left(p_{mix-cyl}V_{cyl}\right)}{d\theta} = \frac{d\left(m_{mix-cyl}R_{mix}T_{mixcyl}\right)}{d\theta}$$

$$p_{mix-cyl}\frac{dV_{cyl}}{d\theta} + V_{cyl}\frac{dp_{mix-cyl}}{d\theta} =$$

$$\left(R_{mix}T_{mix-cyl}\right)\frac{dm_{mix-cyl}}{d\theta} + \left(m_{mix-cyl}R_{mix}\right)\frac{dT_{mix-cyl}}{d\theta} + \left(m_{mix-cyl}T_{mix-cyl}\right)\frac{dR_{mix}}{d\theta}$$

$$V_{cyl}(\theta) = V_{cyl-TDC}\left(1 + \frac{r-1}{2}\left[R + (1-\cos\theta) - \sqrt{R^2 - \sin^2\theta}\right]\right)$$

According to 1st law of USUF

$$\dot{Q} + \dot{E}_{in} = \frac{dE_{CV}}{dt} + \dot{E}_{out} + \dot{W}$$

$$\dot{Q} + \dot{E}_{in} = \frac{dU_{CV}}{dt} + \dot{W}$$

2.3 Air Flow through Intake Valves: No Fuel Injection

The air flow rate is connected to the intake manifold stagnation pressure p0, in and stagnation temperature T0, in, Static pressure just downstream of the valve and a reference area AR.

AR is a characteristic of the valve design.

The real gas flow effects are included by means of an experimentally determined discharge coefficient CD.

$$\dot{m}_{air-in}(\theta) = \frac{C_D A_R p_{0,in}}{\left(RT_{0,in}\right)^{1/2}}\left(\frac{p_{mix-cyl}}{p_{0,in}}\right)^{1/\gamma}\left\{\frac{2\gamma}{\gamma-1}\left[1 - \frac{p_{mix-cyl}}{p_{0,in}}\right]\right\}^{1/2}$$

$$\frac{dm_{mix-cyl}}{d\theta} = \dot{m}_{air-in}$$

With No Fuel Injection

$$\dot{Q} + \dot{m}_{air-in}h_{air} = \frac{dU_{CV}}{dt} + \dot{W}$$

2.4 Air Flow through Intake Valves: with Fuel Injection

Engine Analysis with GDI Turbo

$$\frac{dm_{mix-cyl}}{d\theta} = \dot{m}_{air-in} + \dot{m}_{fuel-in}$$

With Fuel Injection

$$\dot{Q} + \dot{m}_{air-in}h_{air} + \dot{m}_{fule-in}h_{fuel} = \frac{dU_{CV}}{dt} + \dot{W}$$

III. FUEL INJECTION SYSTEM IN GDI ENGINES

Presently the most extensively used injector for GDI applications, is the single-fluid, swirl-type unit.

This uses an inwardly opening pentile, a single exit orifice and a fuel pressure, in the range of 70-100 bar. The liquid arises from the single discharge orifice as an annular sheet that spreads centrifugally outward to form an originally hollow-cone spray.

Pressure energy is changed into rotational momentum that improves atomization.

The initial spray angle ranges between 25°-150° and the

Saunter Mean Diameter (SMD) varies from 14-23 μm. Surface roughness may, though, produce streams of fuel in the fuel sheet, resulting in development of pockets of locally rich mixture.

The spray has a important edge that penetrates away from the nozzle tip for about 50mm in less than 20ms.

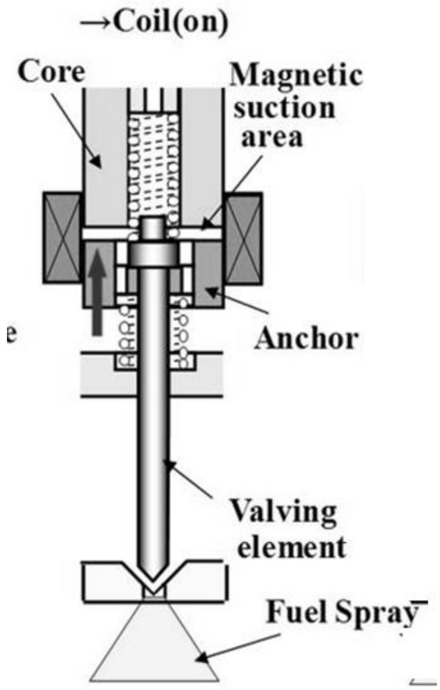

Figure 3.1. Fuel Injector Used

Figure 3.2. Location of Fuel Injector & Spark Plug

IV. ENGINE ANALYSIS

- ✓ Engine Ideal RPM: - 1500 RPM
- ✓ Maximum Engine RPM: - 8000 RPM
- ✓ Turbocharger RPM: - 20000 RPM
- ✓ Average Increased: - 14 Km*

(Under Specific Conditions)

- ✓ Specific Conditions Engine RPM = 3000 RPM
- ✓ Turbocharger RPM = 18000 RPM
- ✓ Weight on Bike = 45 kgs
- ✓ Vehicle Speed = 48 Kmph

Tested in Vacuum & Frictionless Surface.

4.1 Turbocharger Analysis

Matching of Turbocharger with Engine

I.C. Engines are semi-control volumes. Can receive or deliver flow across the boundary intermittently. Turbocharger is a combination of two unpolluted control volumes. They need to continuously accept and deliver flow across boundary. Demands a special engineering art called as tuning. An art of tuning CVs with CM Fluid Dynamic Turning and Thermodynamic Tuning

4.2 Compressor Sizing

- A compressor is sized based on two sections of information, boost pressure and airflow.
- The preferred boost pressure is selected based on the performance purposes.
- The minimum boost pressure desirable to achieve the performance purposes is to be evaluated.
- The airflow is straight related to the engine speed and is thus calculated based on what part of the speed range is chosen to experience a power increase.
- Once the boost pressure and airflow are known, they are used to size the compressor.
- A compressor works best at a particular combination of airflow and boost pressure.

Work consumed by A compressor = Increase in Stagnation Enthalpy of gas

$$P_{act} = \dot{m}\,\omega\left(V_{w2,i}r_2 - V_{w1}r_1\right) = \dot{m}\left(h_{02} - h_{01}\right) = \dot{m}\,c_p\left(T_{02} - T_{01}\right)$$

$$T_{02} \geq T_{02s}$$

$$\frac{p_{02}}{p_{01}} = \left(\frac{T_{02s}}{T_{01}}\right)^{\left\{\frac{\gamma}{\gamma-1}\right\}} = \left(1 + \frac{T_{02s} - T_{01}}{T_{01}}\right)^{\left\{\frac{\gamma}{\gamma-1}\right\}}$$

Define, Adiabatic Efficiency of A Compressor:

$$\eta_{comp} = \frac{T_{02s} - T_{01}}{T_{02} - T_{01}}$$

$$\frac{p_{02}}{p_{01}}=\left(1+\frac{\eta_{comp}(T_{02}-T_{01})}{T_{01}}\right)^{\left\{\frac{\gamma}{\gamma-1}\right\}}$$

$$P_{act}=\psi\,\dot{m}\,\omega(V_{w2i}r_{2i}-V_{w1}r_{1})=\dot{m}\,c_{p}(T_{02}-T_{01})$$

$$\sigma=\frac{U}{V_{w2i}}$$

$$\frac{\psi\omega(\sigma Ur_{2i}-V_{w1}r_{1})}{c_{p}}=(T_{02}-T_{01})$$

$$\frac{p_{02}}{p_{01}}=\left(1+\frac{\eta_{comp}\psi\omega(\sigma Ur_{2i}-V_{w1}r_{1})}{c_{p}T_{01}}\right)^{\left\{\frac{\gamma}{\gamma-1}\right\}}$$

$$\rho_{ivc}\leq\rho_{02}=\frac{p_{02}}{RT_{02}}$$

For an irreversible compression of given pressure rise, the actual temperature rise is more than isentropic temperature rise.

The size of the compressor/turbine can be described either by its exducer bore.

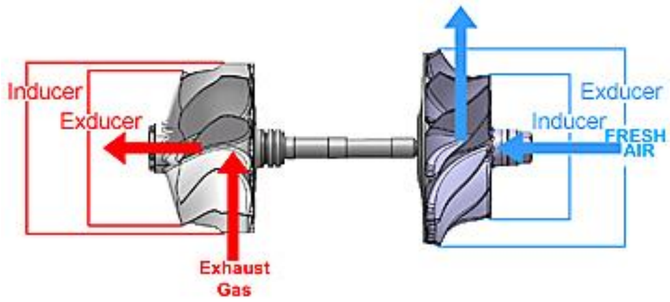

Figure 4.1. Geometrical Detail

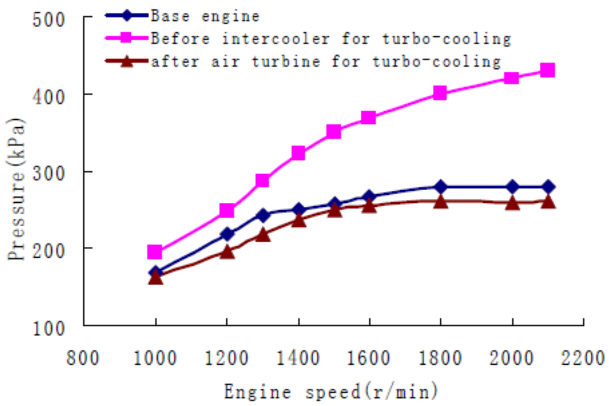

Figure 4.2. Cold Air for Better performance

4.3 Turbine Sizing

- The selection of the turbine size is a while simpler than the sizing of the compressor.
- The fact is that the turbine size effects boost beginning, turbo lag and fuel consumption.
- There are no complex maps or processes used to select the turbine size. It is essentially just a balancing act.
- Smaller turbines will provide lower boost thresholds and better turbo response but only be able to create limited airflow through the compressor and will generate a loss of back pressure and heat in the exhaust manifold.
- Larger turbines, conversely, allow much more airflow through the compressor and reduce back pressure and heat in the exhaust manifold at the expense of higher boost thresholds and larger turbo lag.

4.4 Irreversible Adiabatic Flow through Turbine

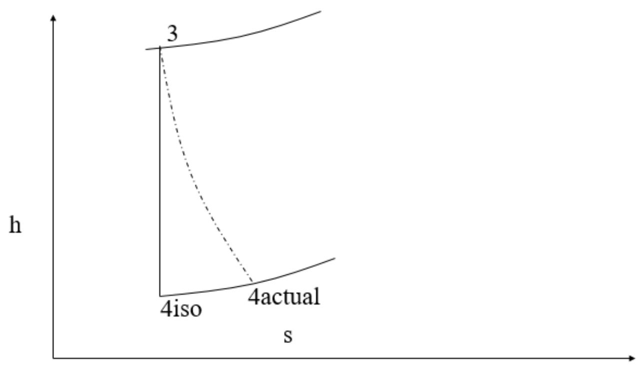

Figure 4.3. Irreversible adiabatic process

$$h_{3}+\frac{V_{3}^{2}}{2}=h_{4}+\frac{V_{4}^{2}}{2}+w_{act}$$

$$h_{03}=h_{04}+w_{act}$$

Ideal work $w_{iso}=h_{03}-h_{04iso}$

Actual work $w_{act}=h_{03}-h_{04act}$

Internal Efficiency of a turbine

$$\eta_{iso,turbine}=\frac{h_{03}-h_{04,act}}{h_{03}-h_{04,iso}}$$

$$\eta_{iso,turbine} = \frac{T_{03} - T_{04,act}}{T_{03} - T_{04,iso}}$$

Thermodynamics of Turbine Sizing

$$T_{04,iso} = T_{03}\left[\frac{p_{04}}{p_{03}}\right]^{\gamma-1/\gamma}$$

$$T_{04,act} = T_{03}\left(1 - \eta_{iso,turbne} \times \left\{1 - \left[\frac{p_{04}}{p_{03}}\right]^{\gamma-1/\gamma}\right\}\right)$$

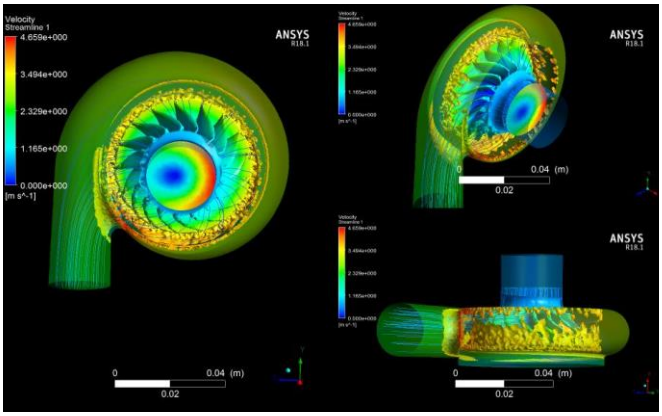

Figure 4.4. Effect on turbine

4.5 Tuning of Compressor, Turbine & Engine

- ✓ The airflow through the compressor is straight connected to the boost pressure the compressor creates.
- ✓ Therefore larger airflow through the compressor means advanced boost pressures.

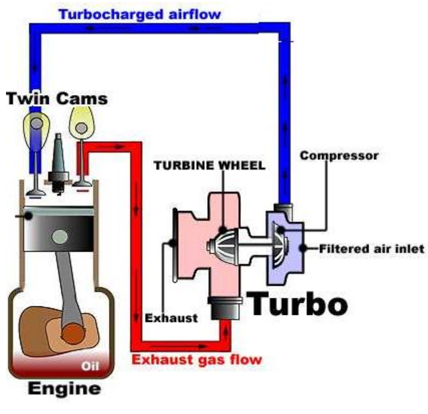

Figure 4.5. Primary Tuning

Back pressure in the exhaust manifold can lead to return, which is when the pressure is so high in the exhaust manifold that exhaust gases are forced back into the cylinder when the exhaust port opens during the exhaust stroke.

This clearly not good and damages engine power. These opposite concerns must thus be balanced against each other.

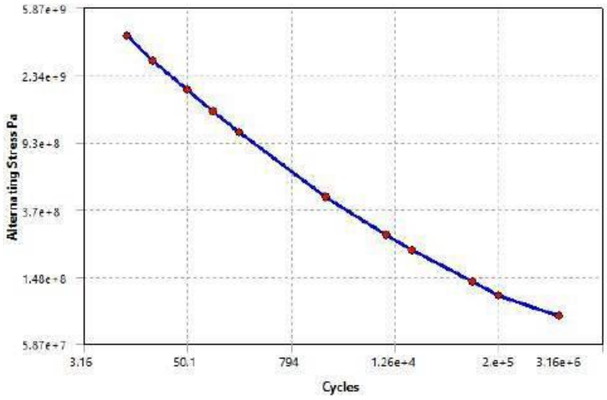

Figure 4.6. Stress on turbine

Table 1. Technical Analysis Data

Maximum Engine RPM	20000 RPM
Mass flow of gas	1.56314e-006 [kg s^-1]
Torque generated	2.16399e-006 [N m]
Turbocharger RPM	1800.03 RPM
Exhaust Temperature	486°C.

4.6 Air inlet & exhaust pressure

- ✓ Air inlet pressure into air cleaner & in engine = 0.4 bar (Normal Condition)
- ✓ Air inlet pressure into air cleaner & in engine = 0.3 bar (Turbocharged Condition)
- ✓ For our analysis it is 0.35 bar or 35000.0 Pa
- ✓ Engine exhaust gas pressure = 4 bar or 400000.0 Pa
- ✓ Air inlet through Air filter = .35 Atm or 35000.0 Pa

V. GDI SYSTEM

The more engine performance is happens after the GDI Turbo Engine. The compression ratio is to increase the power output and to reduce the fuel consumption. GDI engine run with lean mixture, this operation provide developments in fuel economy. In GDI engine, fuel is injected into cylinder before spark plug ignites. The knock does not take place because only air is compressed at low and medium loads. To decrease CO2 produced from vehicles, it is compulsory to decrease fuel consumption.
GDI Turbocharged engines have showed great possible to meet the opposing targets of lower fuel consumption as well as high torque and power output.

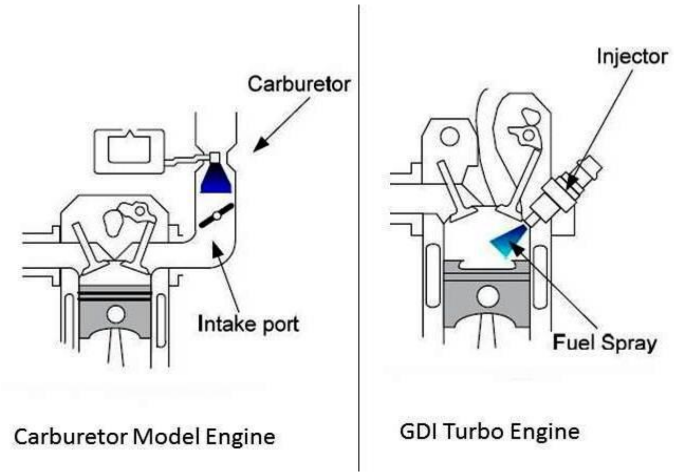

Figure 5.1. Show the Difference between Carburettor & GDI engine

Injection location	Direct in-cylinder
Type of mixture	Stratified-charge
Injector pressure	High

5.1 Problem faced

The first main problems occur is that after the installation of GDI & turbocharger in engine the turbo lag occur & problem in Valve timing setting. This occurs after the engine start when I open full throttle or when we accelerate.
Careful timing is necessary to avoid turbo lagging at a wrong time for a racing application. This can create problem in vehicle cornering and vehicle controlling.

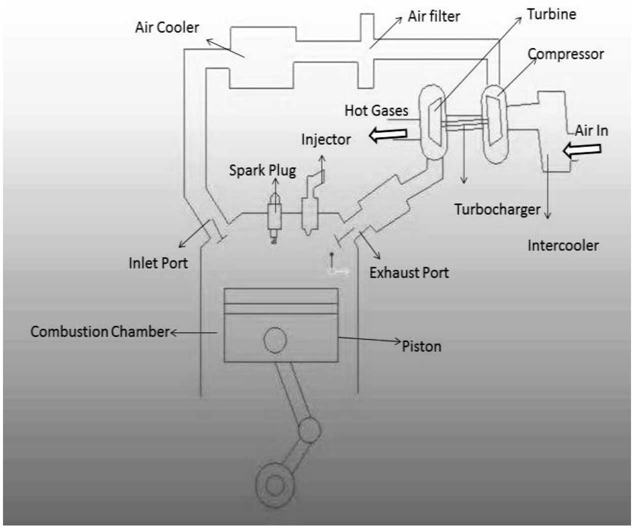

Figure 5.2. Layout of GDI & Turbo

A layout design of turbocharged gasoline direct injection has been shown in figure.

5.2 Changes in Engine System

In GDI turbo Engine first I remove the carburettor system so that I convert this system into GDI. Then the changes in Valve timing setting & also changes in engine cylinder head so that I can properly fix the injector. In this system the inlet & exhaust valve open simultaneously.

Changes in Ignition Coiling System also done to generate more Spark ignition level.
Changes in Air induction system with modified air-filter for better performance.

5.3 Connection of turbo system

- Attach the turbo turbine portion with the engine exhaust port.
- Then I Connect air-filter with turbo compressor port i.e. air inlet in turbo.
- Connect the silencer with turbo waste gate port.

 (a)  (b)

 (c)

Figure 5.3. (a,b,c) Installed System

VI. SCOPE OF ANALYSIS

6.1 Advantages

- Produce more power using less fuel.
- Tolerate extremely lean fuel mixtures under light load
- 15 to 20 % better fuel economy compared to carburetor and fuel injection systems of motorcycle.
- No throttling losses
- GDI engines can switch higher static compression ratios
- Volumetric efficiency increased
- Advance combustion efficiency and power.
- More torque & Horsepower for small engine
- Low Co2 emission

6.2 Disadvantages

Cost will Increase for the installation of GDI & Turbocharged function.

Installation is difficult for 1st time.

VII. CONCLUSION

This work was started from 2013 and still it is in continuous processes but a research of 4 years after the installation of GDI turbocharger there is changes in engine efficiency, its volumetric efficiency improved. Motorcycle 25 to 30% power increased. Motorcycle mileage increased up to 14 km as compare to without turbocharging & GDI system

After GDI turbocharging in engine I observe that there is low engine heating & pollutant agent like Carbon monoxide & Hydrocarbon emission were decreased.

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