

DEVELOPMENT OF MECHANICAL GASOLINE DIRECT INJECTION (GDI) ENGINES FOR 4 STROKE TWO WHEELERS

¹Mani, Kaushik*, ²Jain, Vineet*

¹ Manipal University, India, ² Manipal University, India

KEY WORDS- GDI, scavenging losses, variable injection timing, exhaust gas analysis, jerk type fuel injection pump

ABSTRACT- The general demand in the market today is for two wheelers with excellent fuel economy, superb power performance and cleaner & greener emissions. But the actual situation is somewhat contrary in the sense that the two wheeler generally bought by the public have characteristics which include very high levels of pollution caused by scavenging losses, uneconomical operation because of fresh charge losses, less scope for lean operation and no control on the engine once the valves have closed. Therefore the goal of this paper is to design an injection system to achieve optimum emission values and noise levels. In addition this paper looks at improving fuel consumption and drivability independent of the operating point, which is implemented by a mechanical variable injection timing system. For this, the effect of different head designs on the exhaust gas emissions is analyzed initially. Also a light weight and compact Aluminum housing is designed for the pump – follower junction. This is directly attached to the overhead camshaft.

A new jerk type fuel injection pump was designed based on the differences in the physio-chemical properties of diesel and petrol. The characterization of the engine is done in carburetor mode for reference purpose. A characterization of the fuel injection pump was also carried out.

INTRODUCTION

There are an estimated 70-80 million two wheelers in the Asian Market. Two wheelers are characterized with high emissions levels that are primarily caused by “scavenging losses” produced when the fresh air/fuel mixture is used to flush the exhaust gases from the previous stroke out of the engine; over 35% of the fuel is typically lost in the scavenging process. The application of direct in-cylinder fuel injection (or “direct injection” – DI) can be used to reduce HC and CO emissions by over 70%. There is also a reduction in fuel consumption.

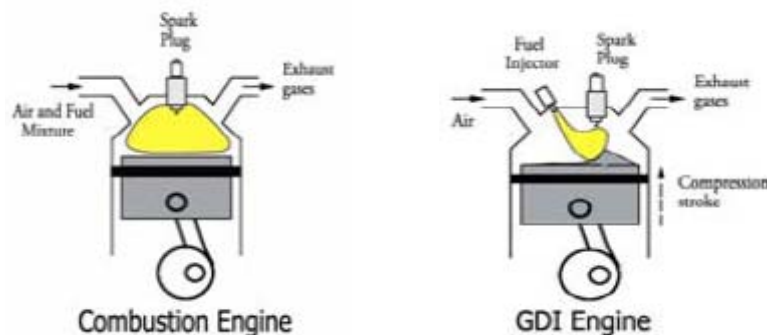


Figure 1 [1]

These are achieved through charge stratification under overall lean conditions, to increase volumetric efficiency and to reduce exhaust emissions. Charge Stratification leads to drastic reduction in throttling losses and reduction of wall heat losses. Compared to the Port Fuel Injection System we expect fuel savings of 15-20 % in GDI engines (Figure 2).

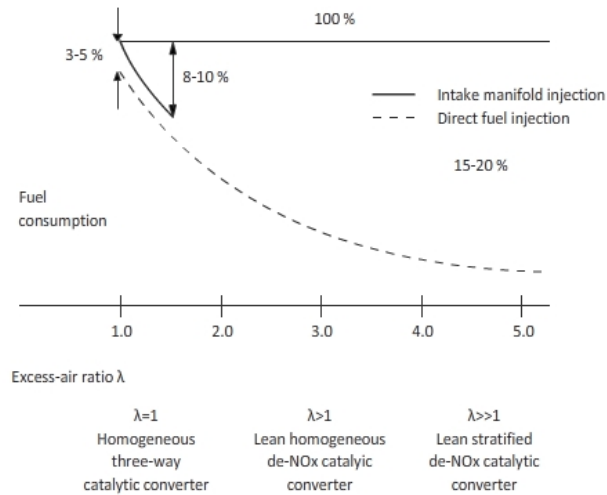


Figure 2: Fuel savings, Partial load operation [2]

Decreasing throttling in GDI engine reduces the charge cycle work by one-third in comparison to Port Fuel Injection. Minimizing wall heat loss in a DISI engine lowers the release of heat to the coolant water by approximately 60% because of lower process temperatures.

Several types of engine operations are possible with Direct Injection – Stratified Operation, Homogenous Operation and Dual Injection. Controlling Injection during the compression stroke prevents the mixture from being completely mixed in the combustion chamber before the moment of ignition resulting in the stratification of fresh charge. The homogeneous operation is used in the full load range & for lean operation in the partial load range.

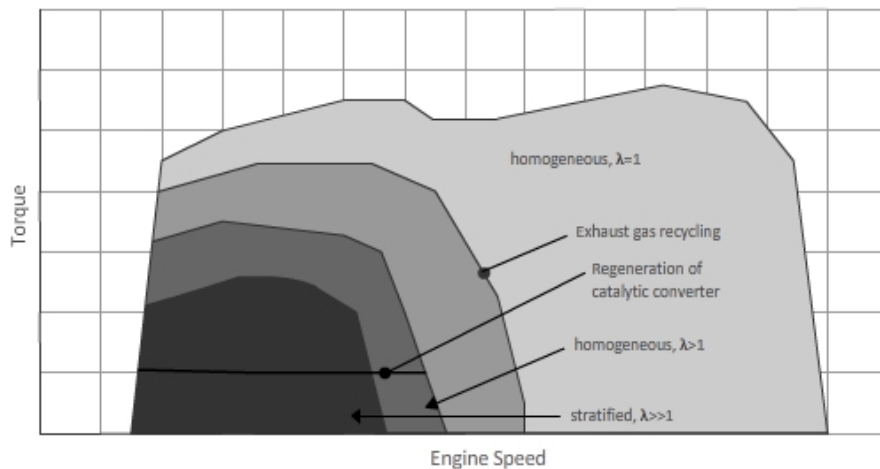


Figure 3: Strategies in direct gasoline injection [3]

Dual injection is the distribution of the injection event at two points in time. The injection timing could be distributed between intake compression & exhaust cycle. However the mixture is generally inhomogeneous. There are several feasible design configurations for GDI engines depending on relative position of injector to the spark plug & piston crown shapes, the injector timing and air motion and mixture preparation strategy. They are classified as air-directed combustion method, wall directed method and jet- directed methods.

EXPERIMENTAL SETUP AND INSTRUMENTATION

We started the development of 4 stroke SI engine based on GDI technology with mechanical fuel injection by testing and analyzing the performance of a two stroke engine with injection. This was followed up with the design part for GDI technology for a 4 stroke engine.

The experimental rig (figure 4) contains a Bajaj Champion scooter engine, Mico Bosch Fuel Injector, a 5 kilowatt fuel injection pump and an MS housing to support the cam shaft driving the fuel injection pump. The above mentioned camshaft takes its drive from the crankshaft of the engine and reduces the rotational speed to half. The weight of the housing was 5.52 Kg and the weight of the camshaft was 1.36 Kg.

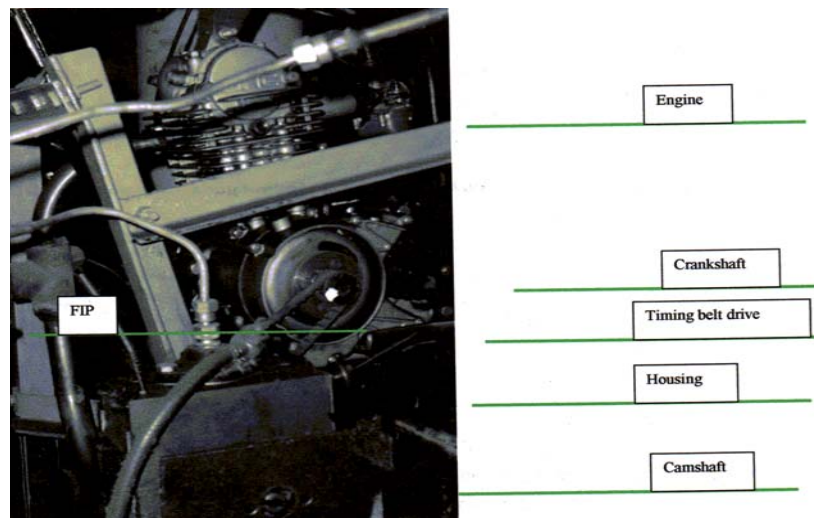


Figure 4: Experimental Rig

In this setup, the comparison of brake specific fuel consumption (bsfc), HC emissions, CO₂ emissions and NO_x emissions of piston heads having no cavity with piston heads having cylindrical, conical and spherical cavities was done using an exhaust gas analyzer. The objective of the experiment was to show the improvement in engine performance especially bsfc, with different heads. It is observed that the bsfc decreased with piston cavities, however CO₂ and NO_x emissions increased as expected. Ranking the piston cavities according to various performance parameters, the following qualitative results were obtained (Table 1).

Rank	Bsfc	Emissions			
		CO	HC	CO ₂	NO _x
1	Spherical	Conical	Conical	No cavity	No cavity
2	Conical	Spherical	Spherical	Cylindrical	Cylindrical
3	Cylindrical	Cylindrical	Cylindrical	Spherical	Conical
4	No cavity	No cavity	No cavity	Conical	Spherical

Table 1: Ranking the piston cavities according to various performance parameters

From the above data, we can see that there are no clear-cut winners. The spherical and conical profiles prove to be the best in terms of bsfc, but they lose out in terms of emissions. However, we attain our objective of experimentally verifying that different pistons head geometries significantly affect the bsfc.

PROBLEMS WITH THE ABOVE SETUP

After setting up the test rig and running the engine over several cycles of data collection, many major problems were observed. The self designed cam shaft lobes tend to wear out fast. The selected high pressure fuel injection pump was developing pressures higher than the limiting pressure of the injector. Further, it was observed that the injector sprayed fuel in excess to the required amount. High carbon deposition in the injector was observed. The housing being bulky, lead to a low power to weight ratio. The lubrication was observed to be improper. One of the objectives of developing the GDI engine is to have variable injection timing. However, in the present setup the variation of injection timing had limited flexibility. The lack of a fuel return line further compounded the excessively high pressure being developed at the inlet of the injector. All these problems lead to a poor load bearing capacity and erratic operation of the engine.

SOLUTIONS

Initially to achieve a better power to weight ratio while considering the size of the engine and the pump, keeping in mind the ergonomic considerations of an average bike, we chose a Fuel Injection Pump from single cylinder stationary Kirloskar Engine. In order to avoid the problem of the CAM wear out, the original overhead cam shaft of the 4 stroke Bajaj Champion Engine was used. However two extra lobes were removed to make the final cam shaft light. Also a new housing was designed based on functionality and this was attached to the cylinder head. Since the original cam shaft was used for transmission therefore there was no need to reduce the rotational speed of the camshaft - this lead to a reduction in the transmission losses. This further reduced the bulk of the setup. The isometric views of the housing are shown in figure 5.

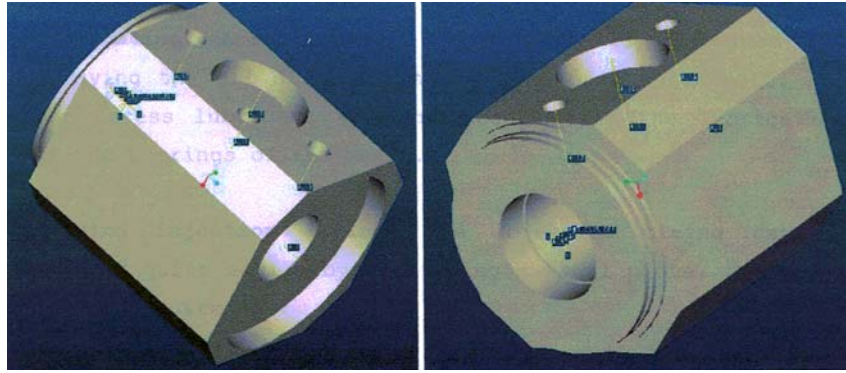


Figure 5: Isometric view of housing

The compact housing, made of Aluminium, protrudes only 50 mm outside the original system, making it light and commercially viable. The timing pulley and a newly designed overhead cover (OHC) provide the necessary arrangement for mechanically varying the injection timing. For smooth operation the injection timing is set to 55 degrees before top dead centre, under light to medium load conditions. The new OHC facilitates the variation of injection timing by 35 degrees on either side. The design of the new housing facilitates variation in injection pressure. The test rig facilitates fuel metering. A return valve was introduced in the fuel delivery pipe after the pump and just before the injector. Lubrication was provided by spraying the oil directly on the lobe of the camshaft. The excess lubricant compensates for the lubrication of the bearings of the shaft. The graph depicting the thermodynamic cycle of the engine is shown in figure 6.

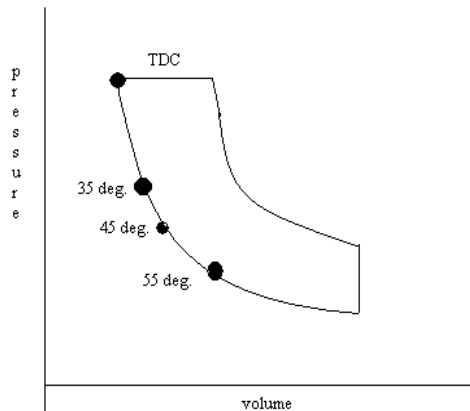


Figure 6: Ideal Engine Thermodynamic Cycle



Figure 7: Fuel Spray from an Orbital Air-Assisted Fuel Injector [3]

DESIGNING OF HIGH PRESSURE FUEL PUMP

The pump in use was creating more pressure than the engine required. It was also supplying more fuel to the engine which resulted in stopping of the engine. It was decided that a new pump had to be designed to suit our requirements which would develop optimum pressure as well as supply optimum fuel. It was also decided that the housing and principle of the present pump be used so that the trouble of changing the whole design can be evaded.

1. The pump was completely fragmented to parts and it was seen the whole fuel passage had dimensions more than required. The barrel hole, delivery valve orifice and the helical groove had to be reduced in dimensions.

2. The orthographic views of the delivery valve, barrel, plunger and the arrangement fitted in housing were made for further use and calculations.
3. Then a ratio of viscosity of petrol and diesel was calculated and it was multiplied to the present dimensions with some index as a reducing factor.
4. The dimensions were further reduced by calibrating it according to the required fuel supply and the rated fuel supply ratio.
5. Finally graphs were plotted - relating variables such as the engine speed, cam speed, mass flow rate, fuel supply rate, stroke length etc.
6. These graphs were now calibrated according to the standard behaviour of the engine.

The pump was characterized for optimum results by using following formulas

- 1) Mass flow Rate (\dot{m}) = $\rho A V = C_d A (\Delta P / \rho)^{1/2}$
- 2) Mass flow Rate (\dot{m}) = $-E_v \Delta V / V = -E_v A \cdot S / V$
- 3) $A_{\text{petrol}} / A_{\text{diesel}} = (\mu_{\text{petrol}} / \mu_{\text{diesel}})^n$

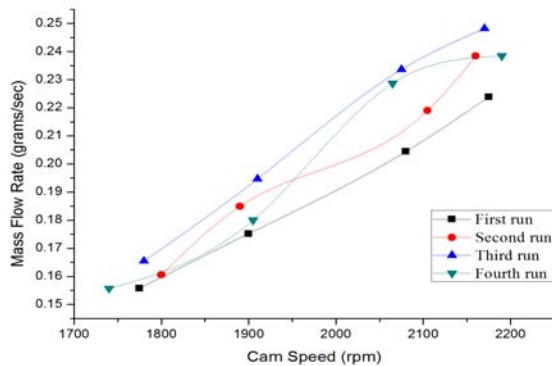


Figure 8: Cam Speed vs Mass Flow Rate

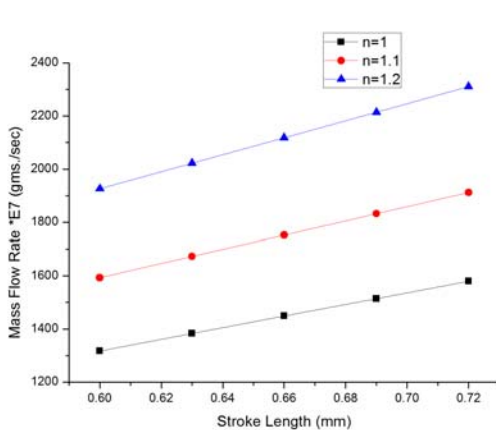


Figure 9: Stroke Length vs Mass Flow Rate

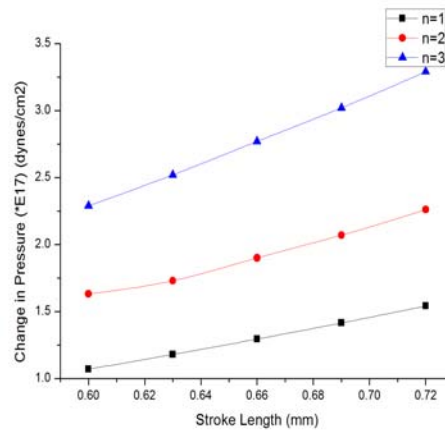


Figure 10: Stroke Length vs Change in Pressure

A new high pressure fuel pump was designed and fabricated according to the calculations. This was followed by the characterisation of the pump. The problem of overflow was now controlled, making it possible to run the engine smoothly and improving its load bearing capacity.

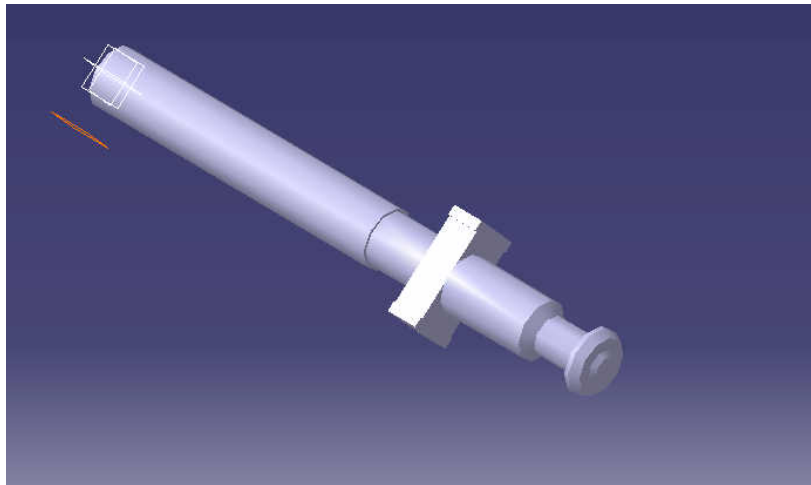


Figure 11: Isometric view of the plunger designed

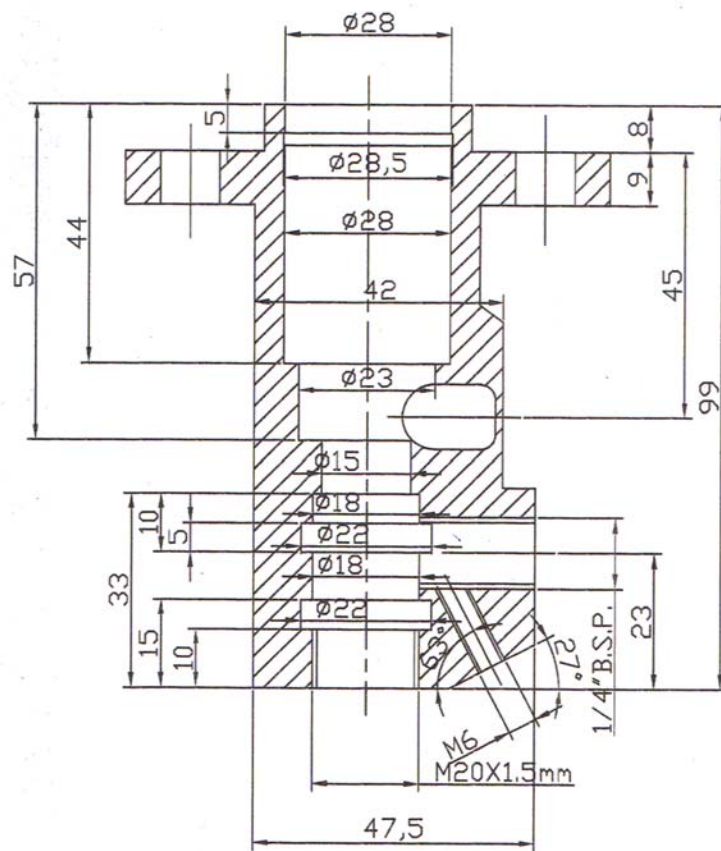


Figure 12: Elevation of pump casing

CONCLUSION

This GDI technology was successfully implemented in a 2 wheeler 4 stroke engines. The newly developed housing results in the reduction of weight and regulation of injector pressure. The high pressure fuel pump was designed and characterized for various performance parameters. Through this, the problem of overflow was controlled – thus making it possible to run the engine smoothly, continuously and economically. This improved the load bearing capacity and operational reliability.

The efficiency of the engine could be improved by using a suitable piston head that would concentrate the entire mass of incoming air in a given region of the cylinder. Also a suitable swirl type injector with appropriate flow characteristics should be used. The injector design should also be based on the size of the engine and the viscosity and density of the fuel. The injector should be used to take combustion heat. Further, the position of the spark plug and injector should be optimized in such a way that they get more close to the cylinder head and spark plug doesn't get wet with fuel spray. We would also have to deal with the demands of the exhaust gas treatment in stratified and lean operation. Observing the data from the several cycles of the test run, we concluded that we would have to minimize the cyclic variations in pressure of the engine. This would help in lowering the maximum cylinder pressures and increasing the efficiency and the detonation limit. For this to happen we would have to minimize cycle to cycle variations in combustion and/or maximize combustion rates.

The implementation of this technology for two wheelers in the Asian Market has the potential to drastically decrease pollution levels. Using the lean burn concept for the gasoline direct injection engines there would be a definite decrease in fuel consumption levels due to higher efficiency. Since less fuel is used there would be a subsequent decrease in fuel expenditure by the consumer.

REFERNCES

- [1] Gäfvert, M. et al. Control of GDI Engines Using Torque Feedback Exemplified By Simulations, 2002
- [2] Eichseder, H., W. Hübner, S. Rubbert, and M. Sallmann, Beurteilungskriterien für otto-motorische DI-Verbrennungskonzepte, Spicher, U.u.A.: Direkteinspritzung im Ottomotor, Expert Verlag, Renningen, 1998
- [3] Dr. Bryan Willson, Direct Injection as a Retrofit Strategy for Reducing Emissions from 2-Stroke Cycle Engines in Asia, 2002
- [4] Heywood and Vilchis, Combustion Science and Technology, v38, 1984
- [5] Richard van Basshuysen, Fred Schafer, Modern Engine Technology from A to Z, SAE International, 2006
- [6] Richard van Basshuysen, Fred Schafer, Internal Combustion Engine, SAE International, 2002
- [7] Translated by A. Troitsky, Motor Vehicle Engines, Mir Publishers, Moscow, 1971