Comparative investigation of electronic fuel injection in two-wheeler applications: A Review

K Venkata Mohan Krishna Reddy, B Manideep Reddy, K Chandra Sekhar Reddy, P Kartheek, T Sai Adarsh

1Department of Mechanical Engineering, Lovely Professional University, Punjab, Phagwara.

kesarivenkatamohankrishna@gmail.com

Abstract: This paper depicts about electronic fuel injection system for two-wheeler applications which have emerged in recent years and are commercially available. Electronic fuel injection system utilizes both electronic and electrical devices to observe and control engine process. An EFI system is a replacement for carburetor which mixes the air-fuel. EFI injects the fuel directly into an engine’s manifold or in a cylinder with the electronic controls. The types of EFI are: Throttle body injection system in which an injector (throttle-body injector) delivers fuel into the center point inside an intake manifold of the engine, Multipoint injection (also known as PFI (port fuel injection)), injects the fuel into the entry ports at upstream of every chamber's entry valve, instead of a main issue inside an admission. Direct fuel injection system in which it delivers fuel directly into a single combustion chamber formed in the cylinder space. An electronic fuel injection system provides an opportunity to mix the air-fuel ratio for every cylinder in an accurate manner and simultaneously by controlling the air mass flow rate, by injecting the suitable fuel mixtures, fuel delivery is being controlled from each cylinder. Furthermore, the ignition and injection timings are optimized as well.

1. Introduction

As of late, there has been a fast expansion in utilization of non-renewable energy sources. There are various considers, for example, increment energy utilization in agricultural nations, expanded modern speculations and so forth. In this way, the future accessibility of petroleum derivatives and worldwide environmental change has given a re-established interest in elective fills for transportation and modern utilization in a continued way.[13] Looking for these other options, a huge number of potential fills, for example, Bio-diesel, hydrogen, alcohols and so forth have been investigated each having their own preferences and disservices.[1] These elective powers, were discovered to be the most reasonable energizes for an assortment of vehicles including bikes, light-obligation vehicles (LDVs) and Heavy-obligation vehicles. [11] The worldwide market for small engine applications speaks to around 100 million new engines produced yearly; including minimal effort 2 and 3 wheeled vehicle applications and utility applications, for example, generators, pumps and nursery applications. With roughly 9 million new two-wheeled vehicles enrolled in India alone yearly.[14] This small engine market represents up to 80% of new vehicle enlistments in a considerable lot of Asian nations.Most of these
engines have been furnished with carburetors [12]. Be that as it may, presently because of environmental issues and pressures, emissions standards and end-client demand of the several companies are working on the low-cost fuel injection techniques and the engine management systems for small motorcycles and utility engines [5]. Since the electronic explosion in automotive field, Electronic arrangements have demonstrated to be solid over the long run. Gadgets progressively crawled into the control gadgets taking care of fuel injection and flash start timing. An Electronic fuel injection (EFI) that are replaced with carburetors back as the favored strategy for providing air and fuel to motors.[6] The fundamental distinction is that, a carburetor utilizes the vacuum consumption and a compel drop into the venturi to pump fuel from the carburetor to the engine, though fuel injection utilizes strain to shower fuel directly into the engine. Electronic fuel injection system uses both electrical and electronic gadgets that monitor and controls the engine activity.[18]

2. Sections of an electronic fuel injection system

2.1. Sensors

Sensors are installed at multiple points in an engine and their function is to drive out the information to the ECU. The following sensors are

a. Engine Temperature sensor.
b. Intake Temperature sensor.
c. Exhaust Temperature sensor.
d. Engine speed sensor.
e. Throttle Position sensor.
f. Cam shaft or crankshaft position: Hall Effect sensor.

2.2. Electronic Control Unit (ECU)

The ECU is vital to an EFI framework. ECU, is a PC, in an IC engine that collects data from the sensors that are placed in the engine and it uses to manage that data of the injection and begin frameworks of engine, bringing about more prominent eco-friendliness, better force and responsiveness, and much lower contamination levels contrasted with the past motors. Current ECU's are utilizing a microprocessor which can deal with the contributions from the engine sensors continuously.[16]

2.3. Fuel Injectors

The fuel injector will open up when driven by control unit and splashes out the pressurized fuel into the motor. The injector opening time corresponds to the measure of fuel conveyed. Contingent upon the framework plan, the circumstances of when injector opens is either relative to every chamber, or injectors to multiple chambers might be motioned to open simultaneously. The relative extents of air and fuel fluctuate as indicated by the sort of fuel utilized and the exhibition prerequisites.

3. Types of injection systems

3.1. Single Point Fuel Injection System

The first and basic sort of fuel infusion is the Single Port fuel infusion framework. Here the carburetor is replaced by a couple of fuel injector nozzle found halfway on the admission complex, directly over the choke plates. Fuel is showered into the top focal point of the choke body and afterward atomized with the approaching separated air. This air-fuel blend, is then conveyed to every one of the engine’s cylinders uniformly. Since the fuel is splashed over the choke plates, it experiences certain weight, so the weight drops over the injector is consistently the same value. In these injection systems, the focal
injector is typically set off on each ignition pulse. Be that as it may if there are two injectors, alternate triggering may be used.

3.2. Multi Point Fuel Injection System

Multipoint fuel injection (also known as called PFI, port fuel injection), injects the fuel into the entry ports only upstream of every chamber's entry valve, instead of a main issue inside an admission complex. MPI frameworks can be successive, in which injection time is matched with every chamber's admission stroke; clustered, where the fuel is injected to the chambers, without exact synchronization to a specific chamber's admission stroke; or synchronous, in which fuel is infused simultaneously to all the chambers. The admission is just marginally wet, and common fuel pressure runs between 40-60 psi. Numerous cutting edge EFI frameworks use consecutive MPI; nonetheless, is more up to date gas motors, direct infusion frameworks are starting to supply successive ones.

3.3. Direct Fuel Injection System

In a direct injection engine, fuel is injected directly into the combustion chamber rather than injecting before the admission valve (petroleum engine) or a varied pre-ignition chamber, making several advantages.[19] Initially DFI gives the most exact and exact fuel metering of any EFI framework yet created. Second it permits higher pressure proportions, for more force and cleaner emanations. The fuel is injected at an incredibly high weight in the scope of 500 to 3000 psi. There is a subsequent high weight fuel pump, typically situated on the engine right close to the fuel rail to convey these high weights at spot on schedule. [3].

4. Results and discussion

4.1. Brake Thermal Efficiency

Figure 1. Illustrates about the dissimilarities in brake thermal efficiency with respect to air-fuel ratio, where we can observe that the BTE is quite high for fuel injector as compared to a carburetor which implies that fuel injector is more efficient at brake thermal efficiency as the air fuel mixture is increasing.

4.2. Speed and Power

Figure 2. Illustrates between the speed and power that has been produced as the speed increases, we can observe that the Fuel Injector performs better compared to car benzine producing high power output. A better composition blend in which fuel atomization is high that permits betterment in engine power.[4]

4.2. Specific Fuel Emissions

Figure 3. Illustrates that, SFC is reducing gradually as we enrich air to fuel ratio, for carburetor it is more compared to fuel injector, implies carburetor is consuming more fuel compared to fuel injector. Air fuel ratio remains constant when we use fuel injection as the ratio varies in case of carburetor.[15]
Table.1 Summary of Literature highlighting the work by various researchers of various fuel injection systems in two-wheeler applications

| Reference                  | Title                                                                 | Technology                                                                 | Engine and Objective                                                                 | Design considerations & conditions                                                                 | Abstract parameters                  | Advantages                                                                 |
|-----------------------------|-----------------------------------------------------------------------|---------------------------------------------------------------------------|--------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------|---------------------------------------|---------------------------------------------------------------------------|
| Todd L. Rachel et al. [7]   | Design Considerations for automotive electronic fuel injection.       | Electronic Fuel Injection.                                                | To perform controlled functions within the automotive environment using the electronic fuel injection system | Designing for value: 1) There is a reduction in Better fuel control than carburetor. 2) In high volume, the design is cost competitive with carburetor system. Vibrations: This concept is mainly used while we are talking about the sensors that were mounted on engine. | EFI Subassemblies: 1) ECU. 2) Map Sensor. 3) Temperature Sensor. 4) Fuel Pump. 5) Fuel pressure Trigger. 6) Oxygen Sensor. 7) Injectors. 8) Throttle position switch. | 1) Better fuel control than carburetor. 2) In high volume, the design is cost competitive with carburetor system. |
| Mr. Saurabh Muralidhar Chaudhary et al. [8] | Smart Electronic Fuel Injection System with the use of Magnetic Fuel Vaporizer. | Electronic Fuel Injection. Electronic Mileage booster with Magnetic Fuel Vaporizer | The Honda GX35. To design and develop the fuel injection systems with a prototype used in cars that increases fuel adaptiveness of an IC engine. | 1) Fuel Efficiency. 2) Ease of implementation. 3) Precise tuning. 4) Reliability. 5) Maintenance and Cost. | Features: 1) Starting of engine is very quick even in cold environments. 2) Higher power and torque compared to that of carbureted vehicle. 3) High fuel efficiency with a reduction in CO emissions. | 1) Considerable reduction in global fuel. 2) Increase in vehicle mileage. 3) Improved fuel efficiency. 4) To reduce greenhouse gas emissions. |
| Rohit Patil et al. [20]     | Electronic Fuel Injection.                                             | Electronic Fuel Injection.                                                | NA                                                                                   | Sub-systems of EFI: 1) Fuel supply system. 2) Air Induction System. 3) Electronic Control System | Sensors: An Air Charge Temperature (ACT) sensor, Manifold Absolute Pressure sensor (MAP), Throttle Position Sensor (TPS), the Idle Speed Control Valve (ISCV). | 1) The Air-Fuel ratio is accurate in overall engine operating conditions. 2) Uniform Air-Fuel Mixture Distribution. 3) Excellent fuel Economy with improved Emission Control. 4) Elevated throttle response and power. Uniform Air-Fuel Mixture Distribution. Good fuel economy with increased control of emissions. Accurate Air-Fuel ratio is high. Higher throttle response. High power. |
| Ram Kumar Kunjam et al. [21] | Advanced EFI System.                                                   | An electronic fuel injection (Air induction system, Air inlet system).     | NA                                                                                   | When an injector is switched on, a valve gets opened and sprays atomized fuel in the inlet valve. The accurate quantity of fuel that is supplied to engine is a function done by an ECU. The control unit explains the basic injection amount in engine and engine rpm. | Sensors: An Air Charge Temperature (ACT) sensor, Manifold Absolute Pressure sensor (MAP), Throttle Position Sensor (TPS), the Idle Speed Control Valve (ISCV). | 1) The Air-Fuel ratio is accurate in overall engine operating conditions. 2) Uniform Air-Fuel Mixture Distribution. 3) Excellent fuel Economy with improved Emission Control. 4) Elevated throttle response and power. Uniform Air-Fuel Mixture Distribution. Good fuel economy with increased control of emissions. Accurate Air-Fuel ratio is high. Higher throttle response. High power. |
| Authors | Key Points |
|---------|------------|
| Brian J. Birch et al. [9] | Improving an electronic fuel injection system for air-cooled motorcycles. Electronic fuel injection (ECU). V-Twin engine |
| TEOH Say Lai et al. [10] | Developing an EFI Retrofit system for small motorcycles. Electronic Fuel Injection. Set 2009 engine, Carburetor, 4 Stroke, SOHC. Number of cylinders-1 with the throttle position sensor. |
| Giriraj et al. [22] | Electronic Fuel Injection. Fuel Injection System. Power Output, fuel efficiency, Emission performance, initial cost, maintenance cost. |
| Hansjorg Manger et al. [23] | Electronic Fuel Injection. L-Jetronic Multi-Point fuel injection system. NA |

**ECU, the parameters which were recorded during the experimentation includes:** engine rpm, manifold weight, TPS, required air-fuel proportion – both sides for 2 chamber motor, air-fuel proportion input from oxygen sensor – both sides of 2 chamber motor, volumetric efficiency, air mass stream dependent on alpha-N, close-circle amendment, ignition timing.

**ECU Calibration and Testing:**

1. Lower engine and also tailpipe emissions.
2. Modified and increased fuel efficiency
3. Modified and increased engine performance.
4. Improved cold starting of engines.

There is reduction fuel consumption by 10%, HC emissions by 55%, CO emissions by 96% while increasing NOx emissions and same carbureted system’s power.
1. Improvements of volumetric efficiency of the engine.
2. Atomization of fuel is independent of crank speed hence good atomization even at low speeds.
3. Variation of air fuel ratio is almost negligible results in good engine performance.

With the use of electronic fuel injection system, it is very easy to meet the required/desired engine parameters with respect to engine power and emissions and also the fuel economy.

**L-JETRONIC System:**

1. Injector: The fuel injector is using a spring-loaded with solenoid operated pintle for measuring the fuel.
2. Electronic Fuel Pump: The fuel pump is an electrically operated roller-cell pump.
3. Air Flow Meter: Vane type air flow meter in which electrical output signal has a standard and more accurate relation to the measured air flow.

**Types of Injection Systems:**

Single point and Multi point injection systems.
4.4. Carbon Monoxide Emissions

Figure 4. Illustrates the variation between CO emissions as we increase speed, and it is observed that the CO emissions are way higher for a carburetor as compared to fuel injector, which implies that the FI’s are more efficient at harmful emissions as it uses most of its fuel. The CO emissions gets steadily decreased with increasing in air fuel ratio up to lean misfiring limit. This is because the time required for mixture formation and better combustion is high.[2]

4.5. Brake Specific Fuel Consumption

Figure 5. Explains us about the brake specific fuel consumption with respect to the variation in rpm, as the rpm increases BSFC tends to decreases significantly and it is found that for carburetor is significantly more as compared to fuel injection and hence fuel injectors are most efficient compared to a carburetor system. As BSFC is more for carburetor, the engine performance is less in this case and it is vice versa in case of fuel injection.[17]
4.6. Hydro Carbon Emissions

Figure 6. Illustrates the variation in HC emissions as we increase speed, it can be seen that the HC emissions are way more for a carburetor as compared to fuel injector as we increase the speed gradually from 1000 rpm to 3500 rpm.[4]

4.7. Brake Mean Effective Pressure

Figure 7. Explains us the difference in variation between brake mean effective pressure and the air-fuel ratio, as we can observe that the BMEP is comparatively more for fuel injector to carburetor as the air-fuel mixture gets richer.
5. Conclusion

- Carburetors are generally used for two-wheeler gasoline engines. However, it is always difficult to monitor the intake of air-fuel mixture into the cylinder chamber which is the reason why there has been more exhaust emissions even though we get better performance results and the device cannot last long.

- Fuel injection systems became more popular and good alternatives for carburetor, the only reason is because of the accurate measurement of intake air-fuel mixture and the lower exhaust emissions keeping the engine performance constant.

- Placement of fuel injection can tell the differences between a port injection and direct injection, the latter is more efficient in terms of combustion, increases fuel economy and lowers emissions, but the only problem with GDI is that it forms oil/dirt particles that will be blown in a reverse direction from the crankcase ventilation and deposits onto the walls of the inlet port and back of the valve.

- A Single-point injection system is a developed version for a carburetor which not only reduces exhaust emissions but also increases the driving performance for the customer.

- A Multi-point injection system is developed, so that the air-fuel mixture is injected accurately at a desired point inside the cylinder chamber which increases the efficient usage of fuel without wasting any, and thus, by further reducing the emissions as compared to single-point injection.

- EFI is viable and provides the control flexibility required for optimum overall engine performance. EFI gives better pollution control. The use of an EFI system improves the atomization which leads to significant combustion of fuel.

- PCI can be manufactured at significantly lower costs than conventional PWM (Pulse Width Modulated) systems.

- Pulse Count Injection (PCI) technology can be applied to both fuel injection and lubrication oil metering on a 2 Stroke engine.

References

[1] Sakthivel P, Subramanian KA, Mathai Reji., Fuel 2020. Experimental study on unregulated Emission characteristics of a two-wheeler with ethanol-gasoline blends (E0 to E50); 262.

[2] Sakthivel P, Subramanian KA, Mathai R., 2019.Comparative studies on combustion, performance and emission characteristics of a two-wheeler with gasoline and 30% ethanol-gasoline blend using chassis dynamometer. Appl Therm Eng; 146:726–37.

[3] Kalwar, Ankur, Akhilendra Pratap Singh, and Avinash Kumar Agarwal., 2020. “Utilization of primary alcohols in dual-fuel injection mode in a gasoline direct injection engine”. Fuel 276: 118068.

[4] Wani, Mohammad Marouf, MK Gajendra Babu, and T. S. Bhatti., 2005. Design of a Digital Electronic Fuel Injection System for Gasoline Direct Injection in a Two Stroke Cycle Spark Ignition Engine. No. 2005-26-359. SAE Technical Paper.

[5] Allen, J., et al., (2011). "Low-cost electronic fuel injection for 2 and 3 wheeled motorcycles." Innovations in Fuel Economy and Sustainable Road Transport; 177.

[6] Manivel, R., and S. Dhandapani., 2001. “Development of an Electronic Fuel Injection System for Two Stroke SI Engine Using Virtual Instrumentation.” No. 2001-28-0058. SAE Technical Paper.

[7] Rachel, Todd L., (1974). "Automotive electronic fuel injection—Essential design considerations." IEEE Transactions on Vehicular Technology 23.2;25-33.

[8] Mr. Chaudhary, S. M. and Mr. Salvi, M. H., 2015. "Smart Electronic Fuel Injection System using Magnetic Fuel Vaporizer. International Journal of Mechanical Engineering and Technology," 6(11), pp. 33-42.

[9] Birch, Brian J., and Manfred Amann., 2004. "Electronic fuel system development for air-cooled motorcycles." SAE transactions: 1877-1885.

[10] Lai, TEOH Say, and Horizon GITANO-BRIGGS., 2009. Development of a Small Motorcycle EFI Retrofit System. No. 2009-32-0034. SAE Technical Paper.
[11] Heffel, James W., Michael N. Mcclanahan, and Joseph M. Norbeck., (1998). “Electronic fuel injection for hydrogen fueled internal combustion engines.” SAE transactions: 837-845.

[12] Muslim, Mohd Taufiq, and et al., 2014. “A review on retrofit fuel injection technology for small carburetted motorcycle engines towards lower fuel consumption and cleaner exhaust emission.” Renewable and Sustainable Energy Reviews 35: 279-284.

[13] Agarwal, Tushar, Akhilendra Pratap Singh, and Avinash Kumar Agarwal., 2020 ”Development of port fuel injected methanol (M85)-fuelled two-wheeler for sustainable transport.” Journal of Traffic and Transportation Engineering (English Edition).

[14] Salvi BL, Subramanian KA., 2016. Experimental investigation on effects of compression ratio and exhaust gas recirculation on backfire, performance and emission characteristics in a hydrogen fuelled spark ignition engine. Int J Hydrogen Energy; 41(13):5842–55.

[15] Bawase, M., Saraf, M., 2017. Systematic evaluation of 20% ethanol gasoline blend (E20) as a potential alternate fuel. SAE Technical Paper 2017-26-0072.

[16] Andre R, Richer J, Robert L., 2013. A new calibration system for ECU development. In: Proceedings of the SAE paper 2003-01-0131.

[17] Costa, R.C., Sodré, J.R., 2011. Compression ratio effects on an ethanol/gasoline fuelled Engine performance. Appl. Therm. Eng. 31, 278–283.

[18] Barkhimer, R.L., and Wong, H., 1995. Application of Digital, Pulse-Width-Modulated Sonic Flow Injectors for Gaseous Fuels, SAE Technical Paper 951912, also in Gaseous-Fuel Engine Technology, SAE Technical Book SP-1104.

[19] Tan YH, Gitano-Briggs H., 2012. Design of retrofit kit for LPG driven direct injection Two-stroke engines. In: Proceedings of the SAE Paper 2012-32-0117; 2012.

[20] Rohit Patil.et.al., 2015. “Electronic fuel injection system”.

[21] Kunjam, R. K., P. K. Sen, and G. Sahu., 2015. "A Study on advance electronic fuel injection system." Int. J. Sci. Research and Mgmt 3.10: 1-6.

[22] Giriraj.et.al., 2014. ”Report on electronic fuel injection”.

[23] Manger, Hansjörg. 1982. Electronic Fuel Injection SAE Technical Paper. No. 820903.

ACKNOWLEDGEMENT

The work is carried at the School of Mechanical Engineering, Lovely Professional University. The Author would like to thank the guiding efforts of all faculties and staff in contributing towards this work.