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EXPERIMENTAL INVESTIGATION OF EMBEDDED CONTROLLED DIESEL ENGINE

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ABSTRACT

Diesel engines are widely used in Automobiles, Agriculture and Power generation sectors in a large scale. The modern techniques have contributed a lot in the saving of fuel in these diesel engines. However, from 1970 onwards the fuel consumption becomes a serious concern because of a manifold increase of automobiles and fast depletion of non renewable sources of energy. Since the fuel injection system plays a major role in the consumption of fuel in diesel engines, various control measures were tried in the past. The advancement in electronics and measurement technologies has led to substantial improvement of engine fuel-injection control systems, both in hardware configuration and in control methodology. This paper presents embedded control design and experimental results of the fuel injection control system of a single cylinder direct injection diesel engine. Here, the electronic fuel injector is controlled by PIC microcontroller using the signals received from air velocity sensor, load sensor, exhaust temperature sensor, crankshaft position sensor and speed sensor. The performance of the electronic fuel injection system is compared with that of a mechanical fuel injection system and fuel consumption characteristics are studied. The results show that the electronic injection system improves SFC, TFC, ME, ITE, and BTE substantially.

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Key Words: Diesel engine, Sensors, Fuel injector, Fuel pulse width, Electronic injection.
Nomenclature: ECU – electronic control unit, SFC – specific fuel consumption, TFC-total fuel consumption, ME-Mechanical efficiency, ITE-indicated thermal efficiency, BTE-brake thermal efficiency.

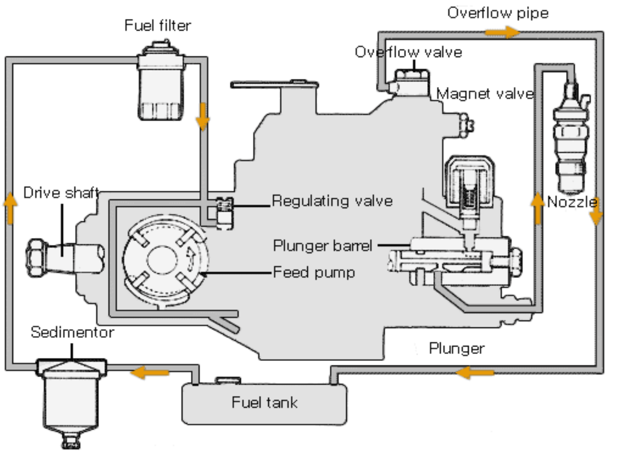
INTRODUCTION

Internal Combustion (IC) engines are used in a variety of stationary applications ranging from power generation to inert gas production and in automobiles. Both spark ignition and compression ignition engines can be found. Depending on the application, stationary IC engines range in size from relatively small (5 HP) for agricultural irrigation purposes to thousands of horsepower for power generation. The major issue with the usage of IC engines is fuel consumption. For this purpose, electronically controlled fuel injection systems are tried in multi cylinder diesel engines instead of mechanically controlled fuel injection systems. However due to cost and space requirements, usage of embedded control systems are not implemented in single cylinder diesel engines. But for automobiles, agriculture pumping, and standby power generator sets, large quantum of single cylinder diesel engines are utilized. By providing electronically controlled fuel injection systems in these single cylinder diesel engines, sizable quantum of fuel will be saved and the performance will be improved. With this in mind, a 6 HP single cylinder diesel engine is tested both with mechanically controlled fuel injection system and electronically controlled fuel injection system.

MECHANICAL FUEL INJECTION SYSTEM

The construction of fuel injection system of mechanical type is shown in Fig 1. The injection pump drive shaft is turned by the engine's timing belt (or gear) and fuel is drawn by the feed pump of the injection pump through the sedimentor and fuel filter to the injection pump's fuel inlet. The fuel filter acts to filter the fuel, and the sedimentor is located in the lower portion of the fuel filter to remove moisture from the fuel system. With drive shaft rotation, the fuel drawn into the feed pump is pressurized and filtered in the injection pump chamber. The fuel pressure is proportional to drive shaft speed. When it exceeds a specified pressure, excess fuel return to the inlet side through a regulating valve located at the feed pump's fuel outlet. The fuel in the injection pump chamber flows through the distributor head inlet into the pressure chamber, where plunger rotation and reciprocating motion increase its pressure. The fuel is then delivered through the injection pipe to the nozzle and nozzle holder. An overflow valve located at the top of the injection pump functions to maintain a constant fuel pressure in the pump chamber by returning excess fuel to the fuel tank.

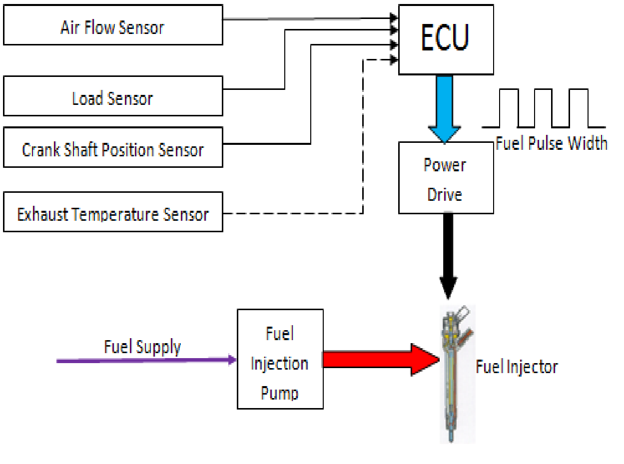
Fig-1. Fuel System of Mechanical Type



ELECTRONIC FUEL INJECTION SYSTEM

The construction of fuel injection system of electronic type is shown in Fig 2. An embedded system is a computer system designed to perform one or a few dedicated functions with real-time computing constraints. It is embedded as part of a complete device including hardware and mechanical parts. Embedded systems control many devices in common use today. The IC engine embedded system is known as Engine Management System. An engine management system is a type of electronic control unit that determines the amount of fuel, injection timing and other parameters an internal combustion engine needs to keep running. It does this by reading values from multidimensional performance maps, using input values (e.g. Engine speed) calculated from signals coming from sensor devices monitoring the engine. Before ECU's, air/fuel mixture, is directly controlled by mechanical and pneumatic sensors and actuators.

Fig-2. Fuel System of Electronic Type



VARIOUS DEVELOPMENTS

The various developments for past years in the automotive engine are discussed here. Various Zirconia air fuel sensors are used in diesel engines (Jong-Heun Lee, 2003). Stoichiometric λ sensor/the limiting current-type sensor/the wide range air-fuel sensor is used in the automobile engine based on the the necessity, structure, operation principle, long-term stability, and the algorithm for catalyst monitoring. The miniaturization and simplification of a sensor design using co-firing and planar processing technology will be an effective approach to improve the performance and cost-effectiveness of the sensor.

The influence of geometry on the internal flow and macroscopic behavior of the spray in Diesel nozzles are examined (Raul Payri, 2004). In this investigation, two bi-orifice are employed, one cylindrical and one conical. Analytical models of Computational fluid dynamics are developed and experimental validation is done through tests. The conclusion from this work is that cavitation leads to an increment of the spray cone angle and hole velocity increases when cavitation appears.

Two models for the common rail injection system, control-oriented model and a nonlinear control design are used in diesel injection (Paolo Lino 2007). A model is developed in a virtual simulation environment representing the injection system in details in a reliable replication of reality. The model is validated by a virtual detailed simulation environment. The prediction capability and control efficiency are clearly shown.

Non-linear engine simulator called virtual engine is developed for diesel engines (Garcia-Nieto, 2008). This simulator provides possibilities of testing complex and innovative algorithms. A suitable controller for the engine is implemented. The results are compared with standard predictive control.

The electronic inline pump is developed for diesel engines (Fan Li-Yun et al., 2008). It can be used in marine diesel engines and commercial vehicles. A numerical model is built into the AMESIM software environment. The model is used to predict key injection characteristics under different operating conditions, such as injection pressure, injection rate, and injection duration. The results are validated by experimental tests. Different fuel pulse width at different operating conditions is presented. It is found that injection pressure and injection quantities are almost independent of injection timing variation due to the application of a constant cam velocity profile.

Diagnostic tool which implemented the physical connection and level translation between personal computer and electronic control unit is designed for diesel engine (Junxi Wang et al., 2009). The various tests scheduled in this module are compressing test, fuel shut-off test, run up test, fuel leakage test, and electrical system test. The system developed for the functions of communication, diagnostic trouble code management, measuring and programming data. Visual C++ and LabVIEW languages are used for designing the system.

The essentials required to establish a high-quality diesel engine research laboratory is described (Usman Asad et al., 2011). A single cylinder diesel engine is taken as the fundamental building block and the requirements for all essential subsystems including fuel, intake, exhaust, and coolant is laid out. Data acquisition requirements and the uses of different sensors in measurements are explained in detail.

Common rail system's injection timing and rail pressure on the diesel engine fuel economy and emission are studied (Tan Xu-Guang et al., 2012). The results show that fuel economy and emission are improving with the rail pressure increase. With injection timing delayed No_x emission is improved but economy and smoke are augmenting. At different load and speed conditions, the tests are conducted.

The evolution of diesel engine and its growth, from conventional engine to electronic engine are reviewed (Shrinivasa, 2012). Various subsystems of the diesel engine are explained. The importance of Electronic Control Unit (ECU) is also explained. Supercharging and turbo-charging are also explained. The various maps of the diesel engine are drawn.

Four states in electronic control of diesel engine i.e., Starting, idleness, normal and after a run are discussed (Jinhu Wang et al., 2012). Engine speed and load are taken as inputs to electronic control of diesel engines. A simulation model is derived and validated by experimental research. Control effect is conveniently obtained in this paper.

Impact of Low cost embedded control system using manifold absolute pressure sensor and crankshaft position sensor is discussed (R.Govindaraju and K.R.Govindan, 2012). The result shows decrease in fuel consumption and a reduction in emission after introducing embedded control.

From the above discussions, the various outcomes of the engine control methods are summarized as follows.

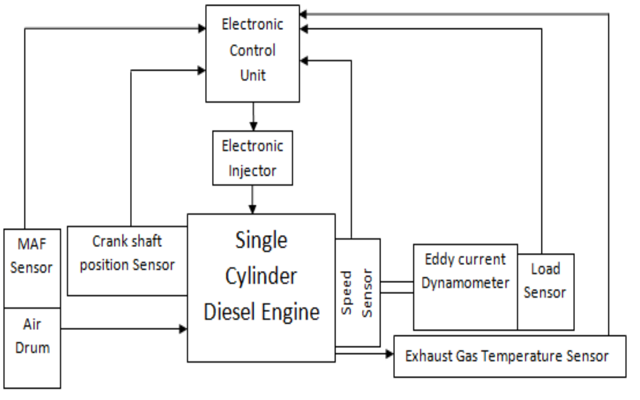
- Embedded controls are needed for increasing efficiency of the engines.
- Electronic control of engine components is available.
- Wide varieties of sensors are used in engine control.
- A precision instrumentation system for engine research is needed.
- Fuel injection pressure and injection timing are important in electronic injection.
- Engine diagnostic trouble code management systems are developed, and
- Selection of nozzle geometry is important in electronic engine management.

In this paper, a suitable embedded controlled single cylinder diesel engine is designed and tested.

EXPERIMENTAL SETUP

The conversion of mechanical injection system into the electronic injection system is discussed here. The engine specification, different sensor details, fuel injector details and microcontroller details are also presented.

Fig-3. Block diagram of Experimental Setup



METHODOLOGY

Hardware block of the experimental setup is shown in Fig 3. In this experiment, mechanical controlled engine is converted into electronic controlled engine. From the mechanical controlled engine, the injection quantity is calculated for different loads and speeds. This injection quantity calculation is stored in the memory of Electronic Control Unit in the form of lookup table. In electronic fuel injection system, air flow sensor, crankshaft position sensor, speed sensor, exhaust gas temperature and load sensor are used to give input to the Electronic Control Unit. The ECU will calculate the load and speed calculations from inputs from the sensors. Then the ECU will calculate the fuel pulse width from lookup table using this load and speed. This fuel pulse width is given to the electronic fuel injector through driver circuit. Electronic fuel injector injects the fuel according to the operational requirement of the engine. Fig 4 and Fig 5 show the experimental setup with various sensors.

ENGINE SPECIFICATION

The engine specification taken for this experiment is given as follows:

Make	:	Kirloskar
Power	:	6 HP
Speed	:	1500 RPM
Cooling type	:	Air – Cooled
Start	:	Hand start
Loading type	:	Eddy current brake

Fig-4. Experimental Setup

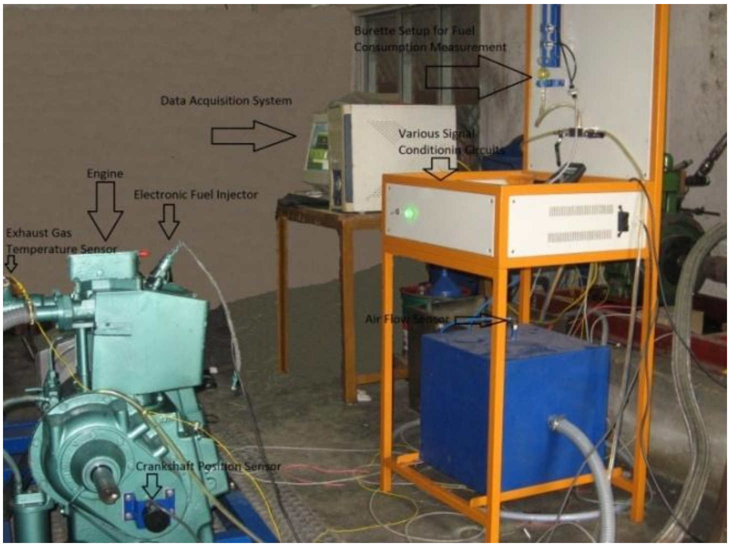


Fig-5. Various Sensors

SENSOR DETAILS

The sensors used in this electronic fuel injection system are airflow sensor, crankshaft position sensor, load sensor, exhaust temperature sensor. Some of the sensors require signal conditioning because of weak signal strength, noises, etc., Various signal conditioning boards are used for the crankshaft position sensor, speed sensor, and air flow sensor and are shown in Fig 6. Sensors are fitted at different places of the engine. Load sensor is fitted at the dynamometer to get the engine load condition.

Fig-6. Various Signal Conditioning Boards

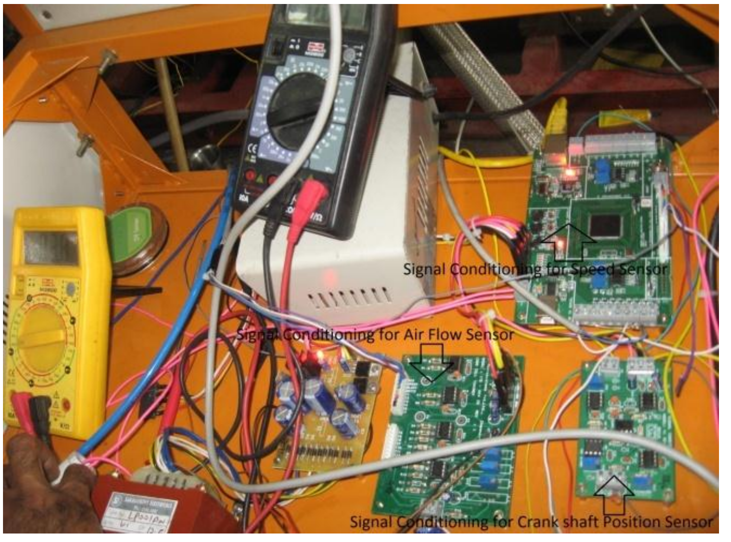


Fig-7. Electronic Control Unit arrangement

AIR FLOW SENSOR

In order to achieve optimum idle mileage control for an electronically controlled fuel injection system, accurate measurement of intake air is required. Air Flow Sensor (AFS) measures intake rate of air that is filtered by air cleaner, and one of the most important components of EMS. Therefore , AFS shall have accurate response characteristic over a wide air rate range, immediate response characteristic against rapid change of air flow rate and easier processing of signals. AFS is fitted in the air drum of the experimental setup.

CRANK SHAFT POSITION SENSOR

The crankshaft position sensor sends the information of the piston position to find the timing of the injection and it is fitted at the extreme end of the crank shaft. The sensor consists of sensor part that includes magnets and soft iron core winded by coil and toothed wheel that is designed to rotate in linkage with the crankshaft. Toothed wheel has 58 teeth and two tooth gaps that are used for identifying the cylinder position. The revolution of toothed wheel makes the crank angle sensor to generate 58 signals. From which the exact timing at which the start of the delivery of fuel is arrived.

SPEED SENSOR

The Speed sensor is fitted at the coupling between the engine and the dynamometer. It is used to find the engine speed. Speed sensor generates 4 pulse signals per a revolution of the output gear. Then ECM receives the pulse signal that will be used for idling speed adjustment. Speed sensor finds whether the engine is at idling or running. When current flows it receives 0.5V, when the sensor does not operate and it receives a 12V signal, to detect engine speed.

LOAD SENSOR

Load cell is attached to the dynamometer. Load cell calculates the mechanical load acting on a dynamometer. This value is given to the ECU to calculate the load acting on the engine through the dynamometer. Fuel injection quantity is fixed based on the engine load at the ECU.

EXHAUST GAS TEMPERATURE SENSOR

The exhaust gas temperature sensor is attached to exhaust manifold of the engine. The Exhaust gas temperature sensor uses a temperature sensitive semiconductor called a thermistor. The sensor is typically connected as a varying resistance across a fixed reference voltage. As the temperature increases, the output voltage decreases.

FUEL INJECTOR DETAILS

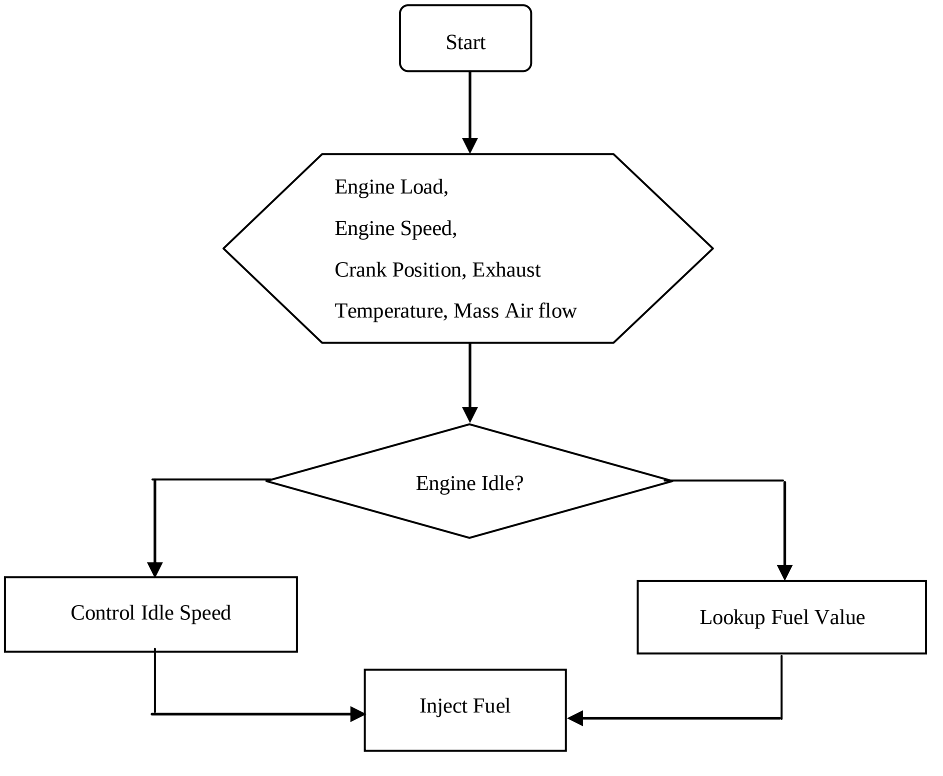
It is the injector's job to inject into the combustion chamber exactly the correct amount of fuel at precisely the right time. To do so, the injector is triggered by signals from the ECM. The injector has an electromagnetic servo-valve. It is a high-precision component which has been manufactured to extremely tight tolerances. The valve, the nozzle, and the electromagnet are located in the injector body. Fuel flows from the high-pressure connection though an input throttle into the valve control chamber. There is the same pressure inside the injector as there is in the pump, and the fuel is injected through the nozzle into the combustion chamber. Excess fuel flows back to the tank through the return line. Maximum RPM & fuel cut off on overrun is achieved by controlling injectors, via ECU. ECU is shown in the Fig 7.

The mechanical fuel injection system is replaced by electronic fuel injection in this experiment. The advent of electronic control over the diesel injection pump has allowed many advances over the purely mechanical system. The production of high pressure and injection is, however, still mechanical with all current systems. The advantages of the electronic injection system improve performance, increased comfort, reduced smoke at acceleration, more precise control of fuel quantity injected, better control of the start of injection, idle speed control, drive by wire system and output to data acquisition systems etc.

MICROCONTROLLER

The configuration of microcontroller is chosen for the experiment is PIC micro controller; CISC CPU, 8MHz; Wide range of integrated peripherals; Analog to digital converter – min 8 channels; 8-10 bit; Pulse width modulator – 3, 8bit channels; Timer processing unit – 8, 16bit channels, inputs or outputs, each with separate compare register and individually configurable for interrupt generation; Serial interfaces – 2, 8 bit RS-232 compatible, 1 dedicated debugging port for ITP; and Parallel Interface / Bus – 8/16 bit with corresponding control signals.

Fig-8. Flow chart for the Microcontroller



The microcontroller programming is done with the aid of c language and it is converted into hex code from the Code warrior software. Then, it is fused on the chip. The lookup value is stored in the microcontroller. Fig 8 shows the flowchart logic followed in the microcontroller programming.

TESTING

In this experiment, fuel consumption and the performance test are done on a 6 HP single cylinder diesel engine. The tests are conducted both before and after modification on the same engine i.e., first with mechanical injection system and then with embedded controlled injection system. For the first test on fuel consumption, the time taken to consume 10 cc of fuel is noted using burette setup. Total fuel consumption and Specific Fuel Consumption are found. Similarly for the second test on performance, measurements are taken using the data acquisition software for finding brake power, brake thermal efficiency, indicated thermal efficiency and mechanical efficiency. The following formulas used to calculate the Brake Power, Total Fuel Consumption, Specific Fuel Consumption, Brake Thermal Efficiency, Indicated Thermal Efficiency and Mechanical Efficiency.

a. Brake Power,

$$BP = \frac{2\Pi NT}{60X\ 1000} \text{ kJ/sec or kW}$$

N = Speed of the engine in RPM

T = Torque applied to the engine in Nm

b. Total Fuel Consumption,

$$TFC = \frac{10}{t} \text{ X } \frac{\text{Specific Gravity of Diesel}}{1000} \text{ X } 3600 \text{ kg/hr}$$

Specific Gravity of Diesel = 0.83

t = Time Taken for 10 cc fuel consumption

c. Specific Fuel Consumption,

$$SFC = \frac{TFC}{BP} \text{ kg / kW-hr}$$

d. Brake Thermal Efficiency,

$$BTE = \frac{BP\ x\ 3600}{Qs}\ x\ 100$$

e. Indicated Thermal Efficiency,

$$ITE = \frac{IP\ x\ 3600}{Qs}\ x\ 100$$

f. Mechanical Efficiency,

$$ME = \frac{BP}{IP}\ x\ 100$$

RESULTS AND ANALYSIS

Performance tests are conducted for both mechanical and electronic fuel injection systems using eddy current dynamometer loading. Fig 9 shows that the Total Fuel Consumption (kg/hr) in Electronic Fuel Injection System is significantly reduced due to accuracy in the delivery of diesel. Fig 10 shows that the Specific Fuel Consumption (kg/kW-hr) is almost same in both types of fuel injection. Fig 11 shows that in an electronic fuel injection system, the brake thermal efficiency (available at the crankshaft) is comparatively high due to increase in the amount of heat conversion. Similarly Fig 12 shows that in an electronic fuel injection system, the indicated thermal efficiency (available at the piston) is higher due to increase in the amount of heat conversion. Fig 13 shows that mechanical efficiency for both electronic and mechanical fuel injection systems are same. From these experimental investigations, it is found that the fuel consumption (liter per hour) is reduced in the electronic fuel injection system than that of the mechanical fuel injection system for the same 6 HP single cylinder diesel engine. Also, it is found that both brake thermal efficiency and indicated thermal efficiency are on the higher side in the case electronic fuel injection system (i.e., the conversion heat into work is more). Since the fuel consumption for producing 1 HP of power is same, the specific fuel consumption of both the systems are identical. Similarly, the mechanical efficiency is same in both the cases since similar mechanical transformation takes place.

CONCLUSION

Diesel engine is the most efficient energy source in the areas of Transportation, Agriculture, and Power Generation. Mechanical fuel control is most widely used in all these areas of applications. However to ensure reduction in fuel consumption, embedded controlled fuel injection system for a single cylinder diesel engine is designed and tested. Performance and fuel consumption tests are conducted for both mechanical and electronic controlled fuel injection systems. Load sensor, Air flow sensor, Speed sensor, Exhaust gas temperature sensor and crankshaft position sensor are used to give the load, speed and piston position of the engine to the ECU in electronic controlled fuel injection system. Based upon these inputs, the ECU determines the fuel injection requirements and corresponding fuel pulse widths are generated. This in-turn regulates the fuel supply to the injector through driver circuit. The results show that an improvement in Total Fuel Consumption, Brake Thermal efficiency and Indicated Thermal Efficiency. Specific Fuel Consumption and Mechanical Efficiency remain same for both Mechanical and Electronic Injection System. Hence by using embedded controlled fuel injection system in a single cylinder diesel engine, saving in fuel is ensured.

Fig-9. TFC versus BP

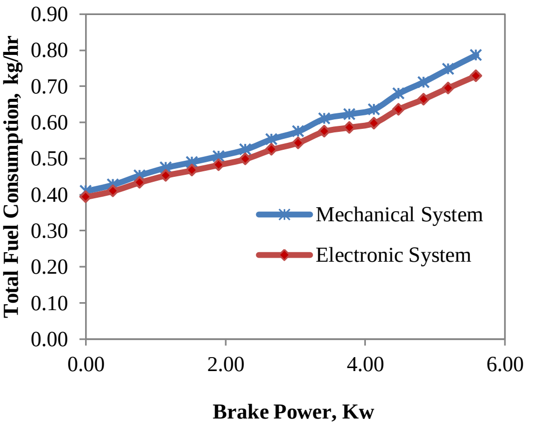


Fig-10. SFC versus BP

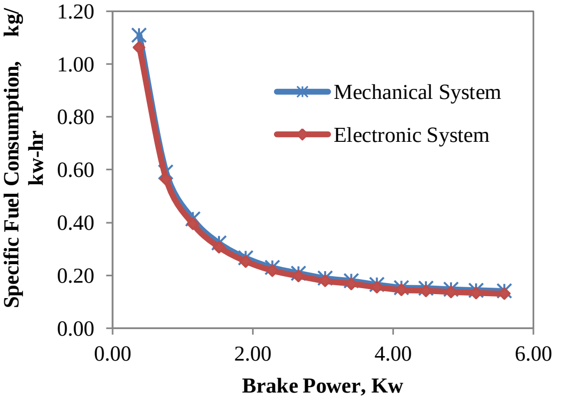


Fig-11. BTE versus BP

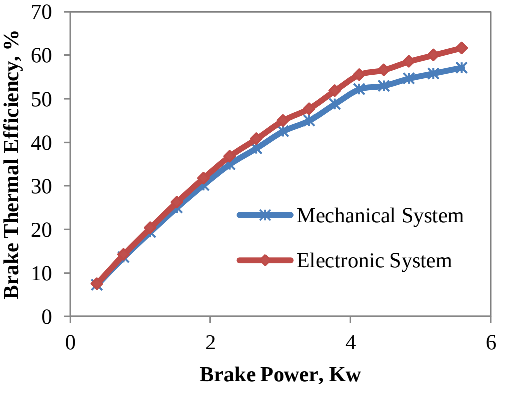


Fig-12. ITE versus BP

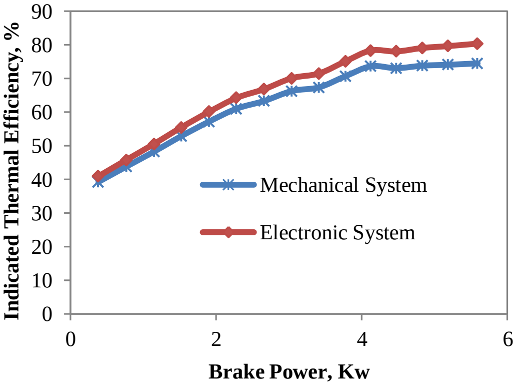
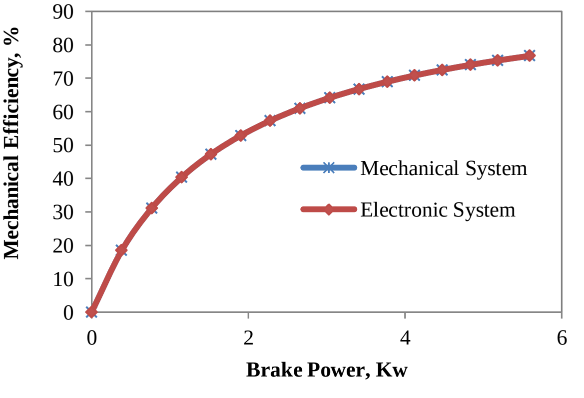


Fig-13. ME versus BP



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