Mahindra & Mahindra Ltd./ Supro 0.909 L

Experimental Set up

Twin-cylinder, four-stroke, naturally aspirated, water cooled, common rail direct-injection (CRDI) diesel engine (Mahindra Supro) was used as a test engine for experimental investigation. Test engine is shown in figure [1], is rated for the 19.2 kW (26 BHP) @3600 rpm. The engine has four valves per cylinder (two intake valves and two exhaust valve) operated by a double overhead camshaft (DOHC). The test engine is also equipped with the common rail direct injection (CRDI) fuel injection system with a high-pressure pump, which can deliver the fuel injection pressure up-to-1200 bar. However, lower injection pressure (in the order of 400 to 600 bar) for the injection of gasoline required compare to the diesel, which was controlled by using the open ECU.

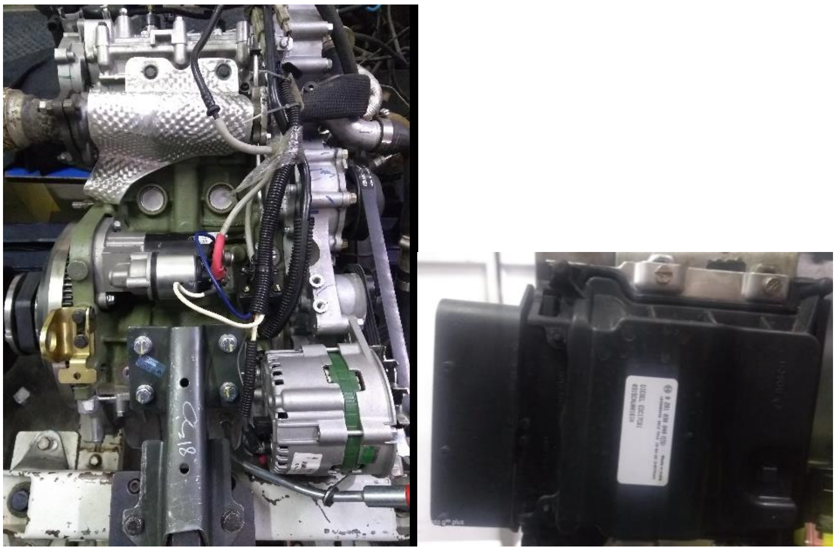

Figure 1: Test Engine and Closed ECU

A pump is connected to the fuel tank and deliver the high-pressure gasoline to the common rail system. Common rail system distributes the measured quantity of fuel to the injectors. The fuel injectors are solenoid type of injector with six-hole nozzle operated with the help of open ECU. Gasoline is more volatile as compared to diesel. The rate of evaporation of gasoline becomes higher with an increase in temperature. Therefore, an intercooler was used between the fuel pump and common rail system   to reduce the fuel temperature at high injection pressure without altering fuel mass flow rate significantly. Detailed technical specifications of the test engine are presented in Table 1.

Table 1: Detailed technical specifications of the test engine

Engine Parameters	Specifications
Company/Model	Mahindra & Mahindra Ltd./ Supro 0.909 L
Engine Type	Four strokes, Naturally Aspirated Diesel Engine
Fuel Injection system	Common Rail Direct injection (CRDe)
Number of cylinders	Twin cylinder
Bore × Stroke	83 × 84 mm
Connecting rod	140 mm
Engine displacement	909 cc
Compression ratio	16.5:1
Rated torque	55 Nm @ 2200 rpm
Rated power	19.2 kW (26 BHP) @3600 rpm
Valvetrain type	Double overhead camshaft (DOHC)
Engine management system	Open ECU controlled
Cooling system	Water cooled
Injector	Six holes Solenoid injector

The fuel supply line was also equipped with the fuel filter and water separator (sendimeter with the water sensor) for ensuring the good fuel quality supply by removing the particle and water from the test fuel. For experimental study, provision to recirculate engine exhaust gas (EGR) was made. By using the propositional integral derivative (PID) controlled EGR valve, the fraction of exhaust gases was supplied to the intake manifold. The EGR valve was monitored using pulse width modulated (PWM) signals sent by open ECU.

Dynamometer and Controller

The test engine was coupled with the eddy current dynamometer (figure 3.6), which was used for engine speed and load variation. The dynamometer was controlled by using the dynamometer control panel by using closed-loop control. This closed-loop control is providing the accuracy within ± 5 rpm. Dynomerk engine testing (DET) is a data acquisition and analysis software used for dynamometer control and working of control panel. The dynamometer control panel indicates load, speed, exhaust gas temperature, oil temperature, fuel temperature, and throttle position. Both external and internal commands can be given by user to control the engine dynamometer. Dynamometer controller and indicator display, as shown in figure 2.

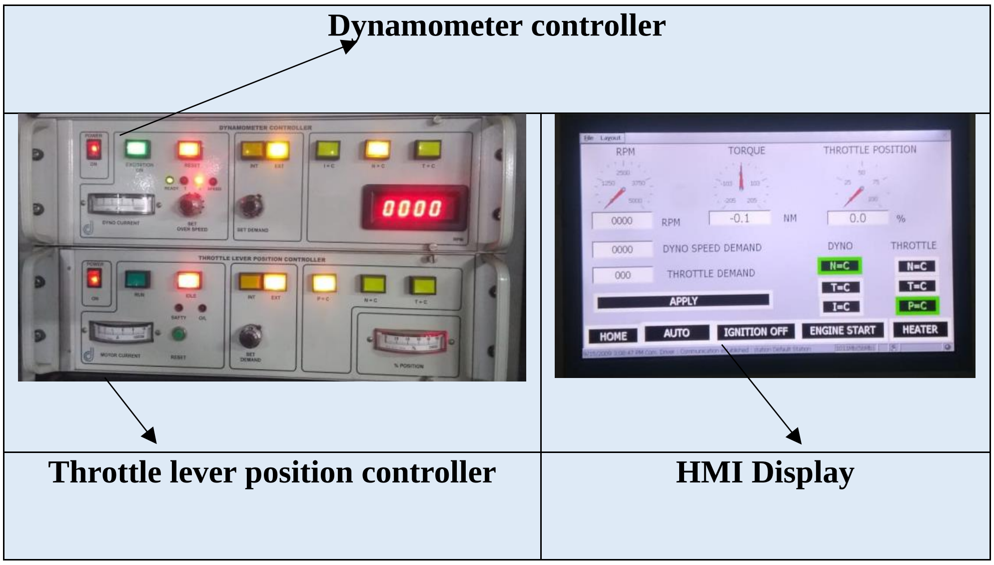

Figure 2: Dynamometer controller and throttle lever position controller with an HMI display

The eddy-current dynamometer works on the principle of the electromagnetic induction (Fleming's law of right hand). It has a notched disc (rotor), which is driven by the engine and magnetic coil (stator) are located around the rotor with a gap. When a current is run through the magnetic coils, the magnetic flux loop is formed around the coil through stator and rotor. The rotation of disc produces electromagnetic density difference, then eddy-current goes to the stator. The electromagnetic force applies in the opposite direction of the disc rotation by the product of this eddy-current and vector of magnetic flux. Such that dynamometer absorbs the torque and dissipates power generated by the engine. Engine speed and load conditions can be control by using the variation of excitation current.

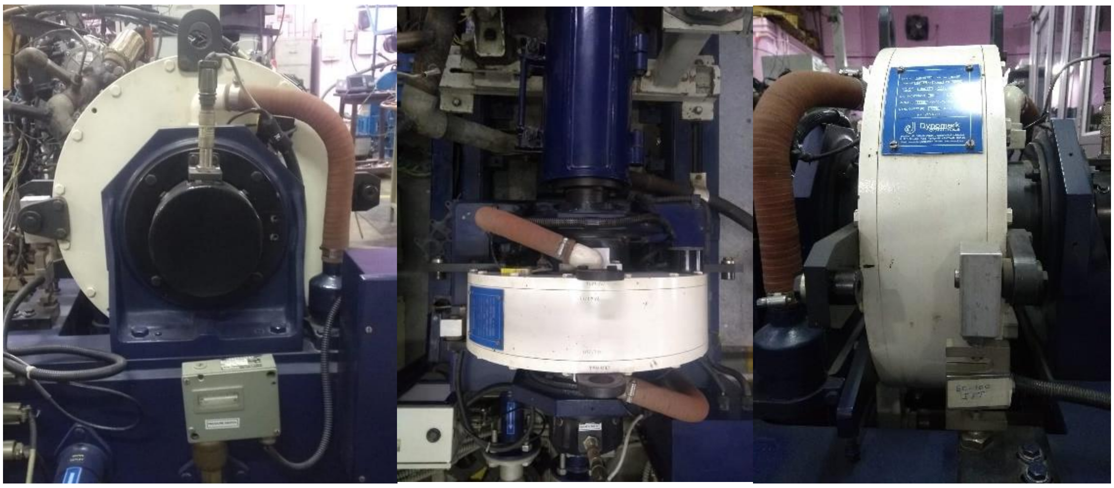

Figure 3: Eddy Current Dynamometer coupled with the test engine

A load cell is connected to the lever arm which senses the force acting on the lever arm and converted that force into the propositional torque output. An inductive proximity type sensor was fixed close to the dynamometer shaft to measure of the rotational speed of the dynamometer. Measured dynamometer torque and speed were displayed on the control panel. An eddy-current dynamometer cannot be used for motoring the engine. Other technical specifications of the eddy-current dynamometer are given in Table 2.

Table 2: Technical specifications of eddy current dynamometer

Characteristics	Specifications
Company/Model	Dynomerk Controls/ EC-100
Rated power	100 HP @ 3500 to 8000 rpm
Maximum speed	8000 rpm
Rated torque	205 Nm @ 1500 to 3500 rpm
Direction of rotation	Bi-directional
Maximum excitation current	6 A DC
Speed accuracy	±5 rpm

Electronic management system

Many parameters like injection pressure, injection timing & quantity, and EGR have to be control simultaneously with the engine load and speed. The automobile companies are using OEM's programmed ECU (closed ECU) for controlling above mentioned parameters. In present experimental study, the effect of injection pressure, injection timing & quantity, EGR on the combustion, performance, and emission characteristics of test engine were analyzed. For that purpose, OEM's engine management system (EMS) was replaced by the open ECU (Motec GPR Diesel, M-142), connected to the different sensors and actuators mounted on engine. Open ECU provides greater flexibility compared to the closed ECU to control various parameters of engine. Open ECU system is subcategorized into three parts; ECU unit, unterminated wiring looms & connectors, and M1 tune software. Detailed discussions on the roles of open ECU and its subcomponents are in described below.

Introduction to open ECU

Open ECU (*MoTeC* GPR Diesel-M142: Part#13142AF) was used in experiments as an engine management system to the control the various engine parameters. GPR Diesel-M142: Part#13142AF designed for the direct injection, common rail, turbo diesel engine, but can also be used for naturally aspirated engine. Multiple injections can be possible and controlled with the help of M-142 open ECU. This ECU system provides an interface to achieve the maximum performance of the engine by optimizing the various engine variables. It has a quick response time and precise control of the engine operating parameters of the sensors and actuators. M1 package is used for monitoring, programming the ECU, and tuning the data for optimum performance of the engine. Specifications of the GPR Diesel-M142 open ECU are listed in table 3.

Table 3: Specifications of the GPR Diesel-M142 open ECU

Characteristics	Specifications
Company/Model	MoTeC's M1 GPR Diesel Package
Max Boost Voltage	188 V
Max Peak Current	20 A
Max Hold Current	10 A
Number of connectors	04
Number of pins	68+52=120
Type	Open (configurable through PC)
Injector driver	Solenoid (8)
Communication	Ethernet

Components of open ECU

Open ECU is divided into three parts such as ECU unit, unterminated wiring looms & connectors, and M1 tune software, are shown in figure 3.8. OEM’s ECU is connected to the wiring connections coming from different sensors and actuators like exhaust gas temperature (EGT), manifold air pressure (MAP), fuel injection pressure (FIP), throttle, crank & camshaft sensor. Sensor & actuator signals were tapped for replacement of closed ECU with a programmed open ECU. Unterminated looms were directly connected to the sensors and actuators.

(a) (b)

Figure 4: Components of Open ECU (a) MoTeC M142 Aftermarket ECU (b) Unterminated looms

Tune software reads the data transfer by the ECU after receiving from the sensors and actuators. It also analyzed and transferred the data after processing. When the parameter values are out of the range, then ECU indicates it by the alarm.

The functioning of open ECU

Open ECU monitors injection timing & quantity, EGR, and injection pressure (FIP) as per mapping. Maps control output values from the open ECU based on the user defined operating parameters. Typically, these parameters are sensor outputs, such as engine speed, throttle position, manifold absolute pressure (MAP). These maps may be one, two or three dimensional based on the number of operating parameters. In a one-dimensional map, the output of ECU is a function of a single operating parameter, whereas a two-dimensional map uses two input signals of operating parameters, i.e. one on the x-axis and the other on the y-axis. Therefore, the output signal of ECU depends on both input signals.

Mappings for M1 tune software comprises of four main parameters: fuel, engine start, boost control, and rpm control. These parameters in-turn comprise of sub-parameters, which include maps for controlling output values from the open ECU (based on sensor values). For fuel parameter; sub-parameters include primary, injection control, and pressure control. These contain maps for controlling fuel quantity for the main injection, Start of Injection (SoI) timings, and amount for main/pilot injection and fuel injection pressure. Boost control parameter comprises of a closed loop sub-parameter, which include maps for controlling the EGR rate and start/stop of EGR. The rpm control parameter consists of a chart for controlling the idle speed of the engine.