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Ignition Timing and Fuel Injection Timing Control using Arduino and Control Drivers

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Abstract. To meet the regular global emission norms, the transition of fuel development stages was incorporated in petrol/gasoline engines from Carburetor type to Throttle fuel injection/Single point petrol injection and throttle injection to Port/Manifold fuel injection. To achieve advanced emission norms, conventional or manifold fuel injection (MPFI) engines are replaced by Gasoline Direct Injection (GDI) engines. To attain efficient range of fuel economy, power output and controlled concentration of emissions coming out of an engine exhaust, the control of ignition timing and fuel injection timing are much important. In this work, the electronic hardware part includes controller/Arduino with ignition control and fuel injection drivers were used for controlling both ignition timing and fuel injection timings. In order to control these timings, the position of piston with respect TDC was measured with the help of crank and cam position sensors. Software required for ignition and fuel injection timings with crank and cam position are developed for controlling an engine with arduino and drivers.

Keywords: Ignition, Arduino, Fuel Injection, Sensor

1. Introduction

The ignition timing, fuel injection timing and injection duration are the major engine control parameters to achieve efficient range of fuel economy, power output and reduced emissions from an engine exhaust. The ignition advance angle adopts different strategies according to different working conditions, each working conditions calculate the current basic ignition advance angle and correct according to the different conditions of the outside world. After threshold processing the ignition advance angle is the final ignition advance angle [1].

The temperature distribution on the combustion chamber surface of diesel engine was measured using thermocouples. In engines, the NOx formation is because of high temperature regions in the combustion chamber volume and it is necessary to measure the temperature ranges inside the combustion chamber volume. K type compression fitting thermocouples are used for the measurement of temperature values on the combustion chamber surface [2]. Ignition timing, fuel injection timing and fuel injection duration are the major sources responsible for the temperature ranges developed inside an engine cylinder. Also with these measured temperature values on the combustion chamber surface, the heat transfer correlated terms are calculated [3].

A pressure sensor system was developed for the determination of combustion parameters and ignition control on a Ford 1600cm^3 four-cylinder engine fuelled with natural gas. Several tests were carried out in optimizing the pressure detection system. The results obtained provide important information compatible with intelligent control of the engine using fuzzy logic technology [4].

Rostami B et al. investigated the effect of fuel injection timing on the performance of a diesel engine, experimentally and analytically using diesel-biodiesel blends. Different experiments were carried out on the diesel engine at engine speeds of 1200, 1600, 2000 and 2400 rpm. The injection timing was regulated for 10, 15 and 20 degree crank angle before top dead centre. The experimental results of engine torque, brake specific fuel consumption (BSFC), cylinder pressure, and exhaust gas temperature for fuel blends of B20, B40, and B100 at different engine speeds and injection timings were recorded. The results showed that advancing the fuel injection timing for fuel blends of B20, B40, and B100 increased engine torque by approximately 2.1%, 2.9% and 6.3%, respectively, and decreased maximum BSFC by approximately 2.7%, 3.3% and 6.6%, respectively [5]. The effect of injection timing, load and speed on BSFC, Brake Thermal Efficiency, peak pressure, Heat Release Rate, CO, HC, NO and smoke were investigated. Advanced injection timing results in reduced BSFC, CO, HC, smoke and increased BTE, P_{max}, HRR_{max} and NO for Jatropha biodiesel[6].

Retarding the injection timing results is increase of in-cylinder pressure, temperature, heat release rate, cumulative heat release and NOx emissions. Decreasing trend is observed by advancing the injection timing. In case of soot emission, the increasing trend is observed up to certain crank angle then reverse trend is observed. The supercharged with inter-cooled cases show lower peak heat release rate and maximum cumulative heat release, shorter ignition delay, higher NOx and lower soot emissions [7]. With the advance of injection timing compared to baseline, the amount of CO and HC in biodiesel fuel reduces to 83.88% and 64.87%, respectively, and the lowest NOx emission with the retardation of starting injection, to decane fuel is awarded [8].

The effects of EGR and ignition timing on engine emissions and combustion were studied through an experiment carried out on an air-guided GDI engine. The test results showed that the ignition timing significantly affected the GDI engine emissions, that the NOx emissions significantly reduced when the ignition timing was retarded, and that NOx emissions decreased with the EGR level increasement. A higher EGR rate could reduce CO emissions while the CO emissions were less affected by the ignition timing [9].

The Mercedes-Benz OM660 engine, used in the Smart Fortwo model 450, was chosen for its common rail injection system, all aluminum construction, and small size. The Common Rail fuel injection system allows flexible control of combustion and torque parameters under all operating conditions, and the custom control system exposes as much of this flexibility as possible to the calibrator [10].

Arduino Uno board is used as a microcontroller to control both ignition timing and fuel injection timing with the help of crank and cam interrupt signals through triggered wheels mounted on the crank shaft and cam shafts respectively. The Arduino controller controls the timings of ignition and fuel injection with engine TDC position as reference captured by cam position sensor. The interrupt signals from the controller board are sent to ignition driver and fuel injection drivers to control both ignition timing and fuel injection timing respectively.

2. Diesel and GDI Engines

2.1. GDI Engine

The GDI engine is working with the principle operation of charge mode which defined as the distribution of fuel into a combustion chamber in which the fuel is injected either during a suction or compression (or) during both the stokes. The charge mode is split into two terms namely Homogeneous charge mode and Heterogeneous charge mode.

2.1.1. Homogeneous charge mode

Homogeneous charge mode is that the engine operates on a homogeneous air-fuel mixture which means that there is an almost chemically correct mixture of fuel and air in the cylinder. The fuel is injected directly into an engine cylinder at the very beginning of the intake stroke in order to provide injected fuel the most time to mix with the air, so that a homogeneous air/fuel mixture is formed throughout the cylinder volume.

2.1.2. Stratified charge mode

Stratified charge mode creates a small region of fuel/air mixture around the spark plug tip, which is surrounded by air in the rest of the cylinder volume. This results in less fuel being injected into the cylinder with compressed air during compression stroke, leading to very high overall air-fuel ratio within the cylinder volume.

2.2. Fuel Injection Modes

Injection modes are the common techniques for creating the desired distribution of fuel throughout the combustion chamber volume, which is classified into Spray-guided, Air-guided, or Wall-guided injection modes.

2.2.1. Spray Guided Direct Injection

In spray-guided direct injection, the distance between spark plug and injection nozzle is relatively low. Both the injection nozzle and spark plug are located almost centre of combustion chamber in order to maintain equal flame travel distance throughout the combustion chamber volume. The fuel is injected during the end stages of compression stroke, causing very quick mixture formation. This results in large fuel stratification gradients, meaning that there is a cloud of fuel with a very low air ratio in its centre, and a very high air ratio at its edges. The fuel can only be ignited in between these two air ratios. Ignition takes place almost immediately after injection to increase engine efficiency. The spark plug must be placed exactly in the zone where the mixture is ignitable.

2.2.2. Air Guided Direct Injection

In engines with air-guided injection, the distance between spark plug and injection nozzle is relatively high. However, unlike in wall-guided injection engines, the fuel does not get in contact with cold engine parts such as cylinder wall and piston. Instead of spraying the fuel against a swirl cavity, in air-guided injection engines the fuel is guided towards the spark plug solely by the intake air. The intake air must therefore have a special swirl or tumble movement in order to direct the fuel towards the spark plug tip to initiate the combustion of fuel air mixture. This swirl or tumble movement must be retained for a relatively long period of time, so that all of the fuel is getting pushed towards the spark plug but it will reduce the engine charge efficiency and output.

2.2.3. Wall Guided Direct Injection

In wall-guided direct injection, the distance between spark plug and injection nozzle is relatively high. In order to get the fuel close to the spark plug, it is sprayed against a swirl cavity on top of the piston which guides the fuel towards the spark plug tip to initiate the combustion of air fuel mixture. Special swirl or tumble air intake ports aid this process. The injection timing depends upon the piston speed, therefore, at higher piston speeds, the injection timing, and ignition timing need to be advanced very precisely. At low engine temperatures, some parts of the fuel on the relatively cold piston cool down so much, that they cannot combust properly. When switching from low engine load to medium engine load, some parts of the fuel can end up getting injected behind the swirl cavity, also resulting in incomplete combustion.

GDI engine provides wider air fuel control range, which makes they are more fuel efficient and are easier to control GDI is the next step in evolution for multi-point fuel injection GDI offers another degree of emission control by eliminating the fuel portion being introduced. Along the intake manifold the directly injecting fuel is forced into compression chamber. The cylinder and Piston are cooled thereby allowing higher compression ratio which gives more ignition timing and power output. The GDI is to inject fuel on top of the cylinder and be able to control injection event. So that the system can be programmed with multiple injection at different times during compression cycle, during intake the ECM command for very lean injection allowing air to mix with fuel very well which make the mixture evenly distributed. The main advantage to halt the injection event or introduction of rich mixture has late as possible to prevent knocking.GDI engine provides more aggressive ignition timing curve. No throttle losses in engine without a throttle plate.

The disadvantages for GDI in system are very few but it can be catastrophic if they are not closely monitored. The efficiency loss due to deposition on the piston crown surface and also more deposit on the intake ports and valves. This disadvantage needs regular maintenance to keep it minimum.

In petrol engine, the ignition timing, fuel injection timing and injection duration were important in order to improve fuel economy, increase power output and reduce emissions from engine exhaust.

2.3. Diesel Engine

In diesel engine, the fuel is injected directly into an engine cylinder at the end of compression stroke. Ignition delay is the major diesel engine variable because the time required for the diesel fuel to ignite includes both physical delay and chemical delay. Physical delay covers the time required for fuel atomization, fuel droplets split up with turbulent air, vaporization of fuel after absorbing heat from combustion chamber and mixing of fuel vapor with fuel. Chemical delay covers time required for oxidation of fuel with air. In diesel engine, the fuel injection timing and injection duration were important in order to improve fuel economy, increase power output and reduce emissions from engine exhaust.

3. Work Methodology

In this work, the cam position sensor was used to trigger the TDC position of an engine and the timings/positions of crank were triggered using crank position sensor. The Arduino coding for interrupt signals from cam and crank sensors was developed using Arduino IDE software. The triggered signals from controller/Arduino Uno through cam position and crank position sensors sent to Fuel Injection cum Fuel Pump control and Ignition control drivers.

The below mentioned steps were followed to develop the complete circuit for the control ignition and fuel injection timings with Arduino controller.

Schematic circuit of ignition timing control driver,
Development of Ignition timing control driver,
Selection of Fuel injection driver suitable for GDI engines,
Connecting Arduino Uno controller with ignition control and fuel injection control drivers,
Adjusting/controlling the timings using interrupt signals with controller and drivers.

4. Experimental Work

The developed control circuit unit will be using for MPFI and GDI engines to control/adjust both ignition and fuel injection timings & for Diesel engines to control fuel injection timing with pump control.

The trigger wheels on both crank and cam shafts are installed as shown in figure 1. Also the cam and crank position sensors were installed with proper clamping over the cam and crank triggered wheels by keeping 0.8 mm to 1.5 mm clearance between sensors and teeth. For crank position, 60-2 teeth triggered wheel was used to maintain proper control timings of ignition and fuel injection. For cam position, TDC target wheel was used to define the top dead centre position of piston with the help of cam position sensor. To capture both cam and crank positions, the Hall Effect type sensors were used.

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a). Trigger wheel with Crank Sensor b). TDC Target wheel with Cam Sensor
Figure 1. Installation of Trigger wheels on Crank and Cam shafts.

5. Results and Discussion

In this controller, the pins 2 and 3 used for interrupt signals from crank and cam position sensors respectively. Pins 8 and 13 are used for LEDs to check interrupt signals from cam and crank position sensors. The digital PWM pins were used to get signals for controlling ignition and fuel injection timings. Figure 2 shows Arduino Uno board used as controller to control the timings of ignition and fuel injection in petrol engines and only fuel injection in diesel engines.

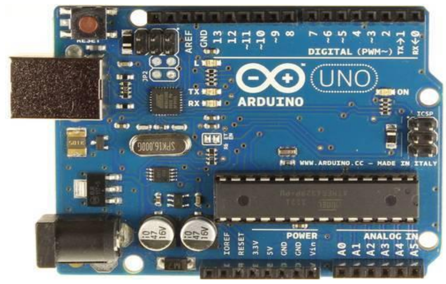

Figure 2 Arduino Uno as Controller

Figure 3 shows the schematic diagram of ignition driver consists of TC4427 timer and IRG4BC40U NPN Bipolar Junction Transistor. The generated interrupt PWM signal from Arduino controller was input to the timer with 12v supply and ground. The output signal voltage from the timer was connected to base of the IGBT. The COP (coil on plug) type ignition coil acts as step up transformer which receives the signal from IGBT and it boosts the voltage upto 38,000 volts.

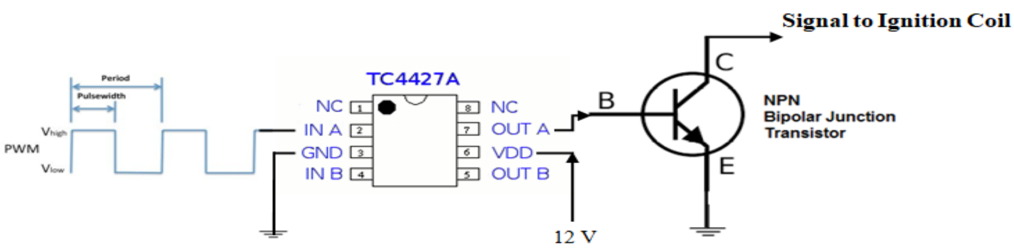

Figure 3 Schematic of Ignition Driver

The TC4427 timer IC, IRG4BC40U NPN Bipolar Transistor (IGBT), capacitors and the required connectors were soldered on the PCB for developing ignition control driver as shown in figure 4

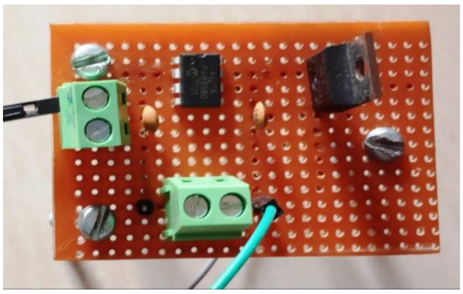

Figure 4 Ignition Driver Circuit

Other than ignition timing, the fuel injection timing is important factor for the efficient operation of MPFI and GDI engines. Figure 5 shows the NXP developed fuel injection and fuel pump driver KIT33816. With this driver, it is possible to control 4 number of fuel injectors with 2 number of fuel pumps. This driver used for both diesel injection and petrol injection applications. It generated injection pulse boost voltage upto 72 volts with the interrupt signal received from Arduino controller.

With this KIT33816 driver, the KL25Z controller board replacing Arduino Uno controller board for the control of fuel injection timing and injection duration. The interrupt crank angle signals from Arduino Uno controller was sent to fuel injection driver for the control of injection timing.

Figure 5 Fuel Injection with Fuel Pump Driver Circuit

The assembled Arduino Uno controller with ignition timing and fuel injection timing control drivers register address were used for the development of coding to control the respective timings. The LED pin 13 was used to check the trigged interrupt signal from cam position sensor which defines the TDC position of an engine. Similarly, the LED pin 8 was used to check the triggered interrupt signals with time delay from Crank position sensor and define the timings of fuel injection timing with duration as well as ignition timings.

The NXP KIT33816 board can be used to control 4 fuel injectors and 2 fuel pumps but in this work, one injector and one pump was controlled/actuated. The output signals from fuel injection driver and ignition driver were checked with the help of multimeter. The output voltage of 45 volts at fuel pump terminal point and 72 volts at injector terminal point were recorded from NXP board.

From ignition driver board, the voltage of 15 volts at the output of timer, 580 volts at the output of IGBT transistor and 38 kilo volts at the output of COP (Coil on Plug) type ignition coil were recorded using voltmeter.

6. Conclusion

The Arduino controller with cam and crank position sensors are used for generating interrupt signals to control both ignition and fuel injection timings. The cam and crank position sensors define the TDC position of piston and crank positions of an engine respectively. The coding was developed for Arduino Uno controller with developed Ignition control driver and selected Injection Timing control driver. With the help of LEDs ON and OFF signals through interrupt toggle and time delays, both ignition timing and fuel injection timing were adjusted using cam and crank position sensors & developed control unit.

Future Work: The Arduino Uno controller with Ignition and Fuel injection drivers control unit will be using to control MPFI and GDI engines.

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