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Development of Algorithms for Efficient Energy Management in the Industrial Common Rail Engine

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Abstract

In order to meet the recently enhanced emission standards at home and abroad, it is necessary to develop the CRDI ECU control algorithm that users can adjust fuel injection timing and amount in response to their needs. Therefore, this study developed the simulator for knocking analysis that enables knocking discrimination and engine balance correction applicable to the ECU exclusive to the industrial CRDI engine. The purpose of this study is to provide the driver-oriented diagnostic services that enable drivers to diagnose vehicles directly by developing diagnostic devices for vehicles with the use of the results of the developed simulator for knocking analysis according to the OBD II standards. For this purpose, this study aims to improve the fuel efficiency of vehicles by proposing the S/W design method of the OBD-II diagnosis device that can provide real-time communications with the use of wired system and bluetooth module as a wireless system to send and receive automobile fault diagnosis signal and sensor output signal, and to suggest an improvement for engine efficiency by minimizing the generation of harmful exhaust gas

Keywords: *CRDI (Common Rail Direct Injection), CMP (Camshaft Position Sensor: TDC), CKP (Crankshaft Position Sensor: CPS), Knocking, long tooth, OBD-II*

1. Introduction

The fuel efficiency of the conventional mechanical diesel engine is 30% higher than that of gasoline engine, and the amount of carbon monoxide and hydrocarbon in the exhaust gas is less than that of the gasoline engine, so that it helps prevention of global warming, whereas the noise is huge and the amount of nitrogen oxides and particular matters (DPM) is higher than that of the gasoline engine, as a result of it, air pollution can be getting worse, so that in the process of commercialization of both passenger cars and commercial vehicles, several difficulties have been naturally existed. To respond the more stricter regulations, in case of diesel engines, they achieved remarkable growth such as high power, high efficiency and low emission technology based on the development of high voltage fuel injection and electronic control technology representing the CRDI system, whereas in case of industrial engines, they does not have the CRDI system because of lower demands about that compared with road driving vehicles, so that currently exclusive-use-purpose ECUs for commercial-purpose CRDI engine are not being produced by both domestic and abroad enterprises. Currently, users can not change the timing and amount of the injection fuel because only manufacturers can change the parts of ECU's program and data, so that actually changing ECU algorithms such as the injection timing and amount is difficult, as a result of it, there exist many difficulties for CRDI engine control practitioners to research and develop them [1, 2].

The study uses the results of the knocking analysis simulator that was developed for developing a diagnostic program for vehicles by using the OBD-II standard so as to provide

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driver centric diagnostic services that allows drivers to directly diagnose their vehicle. To accomplish this, functions including automobile maintenance and diagnosis, and vehicle convenience device control which aim at providing more improved services to consumers from the limited services of existing diagnostors were added so that sensor information useful for informing the current state of the vehicle can offer a PC diagnostor that has been applied an easily knowable UI through customized mapping. Also in order to block abnormal phenomena beforehand by informing abnormalities of the electronic controller of the CRDI engine in real time, the diagnosis program which was created for the PC was developed into an android application that could be used on smart phones, which enables automobile diagnosis through the application

2. Theoretical Background

2.1 Input and output signals of CRDI ECU

As shown in Figure 1, the CRDI ECU analyses the information such as the engine speed, crank angle, fuel pressure and so on; it decides the injection amount and injection timing of the fuel to meet fuel injection at the optimal condition; and it controls the common rail system to improve the fuel mileage and minimize occurrence of the harmful exhaust gas [1, 2].

In this study, algorithms, which identify the CRDI ECU's knocking and correct the engine balance, are suggested by using CKP and CMP, which are two important input sensor values deciding the injection timing of the fuel at start-up among the ECU information.

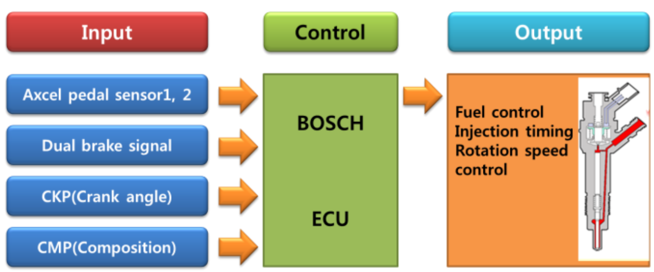

Figure 1. Input and output components of the electronic control system [3, 4]

1) Waveform analysis of CKP and CMP

In the 4-cycle engine, in order to calculate the ignition timing and fuel injection timing, each stroke's identification and specially knowing exactly when the compression TDC is coming on are important. If what degrees of BTDC (Before Top Dead Center) should be more efficient to ignite can be calculated in advance, the ignition at BTDC can be implemented. The ECU should know reference points (missing tooths) to calculate the exact TDCs (top-dead center) and BDCs (bottom-dead center). After occurring the CMP signal, number 1 TDC is the 19th tooths' position; based on the missing tooth, this point is before 114°, so that the ignition timing can be known by calculating degrees of the BTDC if the number of tooths from the missing tooth is calculated [1].

In case of 1-3-4-2's ignition order of the 4-stroke cycle engine, the positions of number 1 piston and number 4 piston are always the same. Number 4 is TDC whenever number 1 is TDC, and number 4 is exhaust TDC when number 1 is compression TDC. Therefore, in order to perform the ignition and fuel injection, when the piston is at the TDC, that the TDC is whether a compression TDC or an exhaust TDC should be identified; the existence of the TDC position is calculated by the sensor signal of the crankshaft through the CMP sensor.

The calculation principle of the TDC position is as follows: the CMP signal is changed; and then number 1 TDC is the 19th tooth's position from that point measured the long-tooth signal; number 3 TDC is the 30th tooth's position from number 1 TDC; number 4 TDC is the 30th tooth's position from number 3 TDC; and number 2 TDC is the next 30th tooth's position from number 4 TDC.

3. System Design and Implementation

3.1 System Configuration

In this study, algorithms, which can provide baselines to identify the car's knocking by collecting control sensor values from the simulator, are implemented. Figure 2 is a configuration diagram to receive control sensor values from the simulator. On the car or simulator mounted the CRDI engine, through the Encoder or CPS(Crankshaft Position/angle Sensor), to measure the knocking sensor and important engine control sensor, the sensor values are collected by using the DAQ board; the values are transmitted to a laptop via USB communications connected with it; and the values are analysed on it. By using these values, to customize the mapping for the improved. CRDI engine control, an algorithm for knocking identification and correction, which can provide the optimal Knocking identification baseline by analysing and processing the useful sensor information, is implemented.

As shown in Figure 2, data are collected by using NI USB-6529 and BNC-2110 Controller devices; the algorithm is developed based on NI Labview 2010 software with the collected data. Engine simulator device generating CPS and CMP signals of the car mounting a motor to the crankshaft and camshaft devices. To analyse the knocking's identification baseline, several tone wheels were made by putting different angles to the special projection portions and different positions to reference points on the tone wheel of the crankshaft.

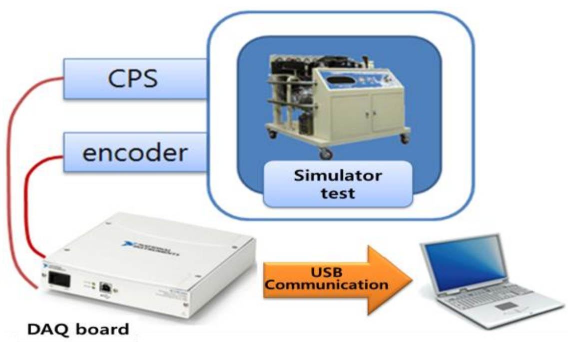

Figure 2. System Configuration

3.2 OBD-II protocol dianosis system design

The S/W used in the research analyzes through the OBD-II connector of the ON-Board a protocol that suits the car type, and after processing the collected vehicle information, the development of a window program more easily accessible to drivers may be developed.

If a personal vehicle diagnostor is installed, quicker action may be taken because it allows the driver to know the information in real time when an abnormality occurs to the vehicle. So the prevention of accidents resulting from vehicular abnormalities takes place, and because the OBD-II detects organs related to the exhaust through sensors, it can prevent atmospheric pollution such as excessive exhaust emissions or incomplete combustion gas emissions thereby contributing to the eco-industry which has recently been receiving prominence [5]. Also, the consumables replacement notice helps maintain the vehicle at its best condition.

Figure 3. Diagnosis schematic diagram using the Bluetooth network

1) **Bluetooth Mobile Application S/W for OBD-II Protocol Diagnosis**

The vehicular dianostor enables checking the information of the vehicle in real-time without other equipment through the development of a mobile application. The driver checks the vehicle information by using his smart phone which he always carries around, and can quickly respond when abnormalities occur to the vehicle.

3.3 Algorithm Development

The knocking of the vehicle can occur diesel knock when the ignition delay period is getting longer; to prevent this diesel knock, one of the methods is to control the injection timing. Therefore, if algorithms controlling the fuel injection timing and injection amount are implemented, the fuel injection timing can be controlled through the knocking identification.

1) **Knocking identification algorithm**

If the measured acceleration is greater than the previous acceleration compared with the acceleration of each CPS as shown in Equation (1), the fuel injection timing is controlled by identifying the knocking. Figure 4 is a flowchart of the algorithm determining the knocking.

$$\Delta t = \text{last timing} - \text{initialtiming} = t1 - t0 \qquad (1)$$

2) **Long-Tooth identification algorithm**

When the signal of the crank angle sensor is input, it is identified as the behavior of the engine; in order to match the timing of the fuel or ignition up to the exact timing and position, the input signal of number 1 cylinder TDC sensor(No.1 TDL = CMP) is used as the base. At this time, in order to determine the fuel injection and ignition timing, an algorithm should be needed to determine exactly whether the input value is Long-tooth or not. When the value of the measured current time is 1.75~4.25 times of that of the previous time, the value is determined as the Long-tooth, and it is used as the signal determining the fuel injection timing.

3) Engine Balance Correction algorithm

Diagnosing the cause of the engine structure is very important: the number of the cylinder's engine rotation can be detected by using the crank position sensor signal; the calculated data can be used to identify the injector's injection amount variation and the engine body (compression pressure, intake and exhaust valve devices, *etc.*), so that the total result of every each part can be identified. Almost every engine developed recently gets a crankshaft position sensor, so that the identification of the disparity cylinder is possible by using the speed difference when cranking with a scan tool. The ignition timing is 0° ~ 30° after the TDC; For each TDC, number 1 is 0°~30°, number 3 is 180°~210°, number 4 is 360°~390°, and number 2 is 540°~570°; therefore, whether the cylinder is defective or not can be identified by calculating the average speed of these 4 numbers. Figure 5 is a flowchart of the engine balance correction algorithm.

In order to measure the exact average speed, the cycle, the TDC's start and end angles are directly input to reduce the limit of error of the average speed, as a result of it, whether the cylinder is defective or not can be judged more exactly.

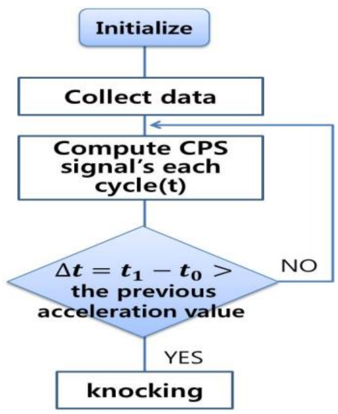

Figure 4. Flowchart of knocking identification algorithm

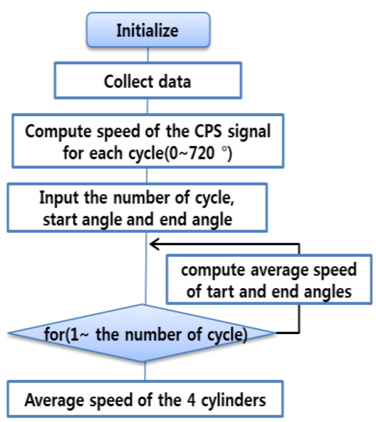

Figure 5. Flowchart of the engine balance correction algorithm

4. Experiments and Results

In this section, by using values of the sensors collected on the designed simulator, algorithms of knocking identification and engine balance correction are developed. Figure 6 is a screen of the program developed to collect data signals, and it shows waveforms of CPS and TDC signals collected at real-time on the simulator.

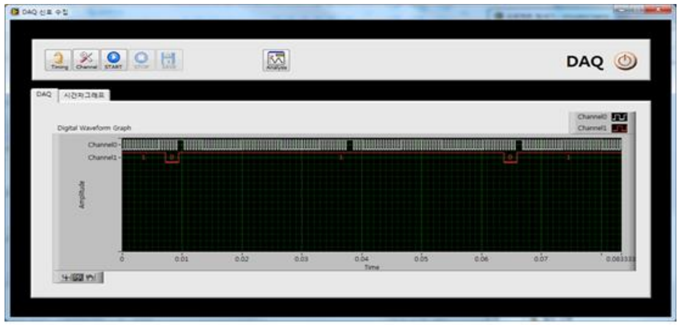

Figure 6. Screen of data signal collection program

Figure 7 shows the result of using the knocking identification algorithm calculating the acceleration difference between the current time and the previous time. The long waveform is a reference point(missing tooth); the short one, which is between one missing tooth and another missing tooth, is the position occurring knocking.

Figure 7. Result Screen of Knocking Identification algorithm

If the value of the current time is 1.75~4.25 times of that of the previous time, this value is identified as a Long-tooth; the 19th projection is then determined as number 1 compression TDC; from this base point, the next 30th projection becomes number 2 TDC; the next 30th projection is number 4 TDC, and finally the next 30th projection becomes number 2 TDC. Figure 8 shows the result of the Long-tooth identification control algorithm.

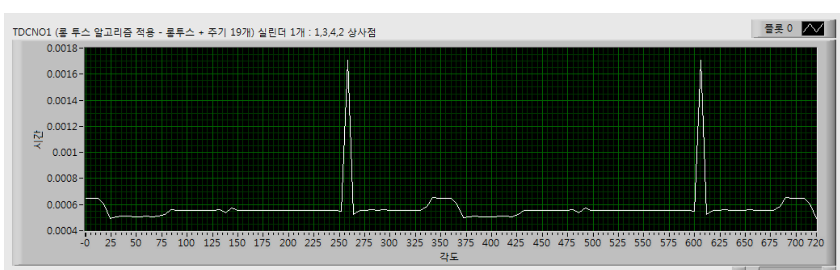

Figure 8. Result Screen of the Long-tooth identification algorithm

Figure 9 is the result of the engine balance correction algorithm performed. It shows a graph of the average speed up to 6°~36° for each TDC; in order to calculate the average speed exactly, the cycle, the start and end angles of the TDC were input; and then, the average speed was measured, as a result of it, whether the cylinder is defective or not was determined.

When checking the result, abnormalities were found from number 3 and number 4 of the cylinder.

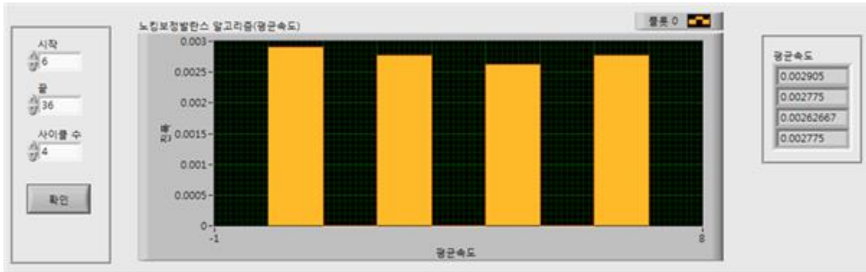

Figure 9. Result Screen of the engine balance algorithm

5. Conclusion

In this study, algorithms of Knocking Identification and Engine Balance Correction were developed by collecting sensor values of the simulator through a DAQ board. Knocking was identified by implementing the Knocking Identification algorithm; the fuel injection timing was able to control by implementing the Long-tooth Identification algorithm because the positions and the cylinder occurred knocking could be found; and the fuel injection amount was able to adjust by detecting whether the cylinder is defective or not by implementing the Engine Balance Correction algorithm. In addition by proposing a design plan for the OBD-II diagnosis system which can provide knocking analysis simulator data and vehicular malfunction diagnosis signals and sensor output signals by using the OBD-II diagnostor and by means of real-time communication through smart phones by using the bluetooth module, the future mileage of the vehicle as well as engine efficiency is improved by minimizing the emission of harmful gases.

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