Chapter 4.0
CHAPTER 4.0 DEVELOPMENT OF VIRTUAL INSTRUMENTATION PROGRAM FOR ENGINE INPUT/OUTPUT CONTROL

4.1.0 INTRODUCTION

With the revolutionary changes in PC technology, the instrumentation design is undergoing rapid changes in both the hardware as well as software. The decreasing cost of PC makes economically viable to have a computer based system in which changes in the software could be made easily which in turn change the entire functioning of the instrument. The concept of Virtual Instrumentation (VI) is fast emerging to replace the traditional instruments. The use of PCs in instrumentation systems has many important advantages. The size, weight and power consumption are reduced substantially and such instruments are flexible and easy to use.

The traditional instrument is typically a stand alone box with fixed I/O capabilities, and few interface features. The unit may contain specialized circuitry, including A/D converter, signal conditioning microprocessor, memory and an internal bus that converts real time signal, analyse them and present the results to the user. Here, all the instrument functionality is mostly defined by the hardware and hence reconfiguration of the functionality involves major change in the hardware. On the other hand, the virtual instrument takes advantage of the open architecture of the PCs to provide the proceeding, memory and display capability as shown in Figure 4.1. In this case, by simply changing the software program, different instrument functionality can be defined. The comparison between conventional and virtual instruments are illustrated in Table 4.1

4.2.0 HARDWARE

A number of sensors are employed for the measurement of various parameters depending upon the concerned test requirements. The sensor interface unit provides a physical means of feeding the output signals to the various sensors and to the data acquisition card through the signal conditioning modules. The data acquisition
module is a 6035 E-series card which provides 8 analog channels 24 digital I/O lines, 2 counters and consists of 12 bit A/D and D/A converters with configurable range 0-10V and +5V. The data acquisition module digitizes the signals obtained from various sensors either directly or through signal conditioning modules and transmit the digital data to PC through RS 232 port. This provides programmable channel sampling, conversion modes and software selectable gains for each channel.

Table 4.1 Comparison of Conventional and Virtual Instruments

<table>
<thead>
<tr>
<th>Traditional Instruments</th>
<th>Virtual Instruments</th>
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<tbody>
<tr>
<td>Vendor -defined</td>
<td>User -defined</td>
</tr>
<tr>
<td>Functions specific, stand alone with limited connectivity</td>
<td>Application oriented system with connectivity to networks, peripherals and applications</td>
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<tr>
<td>Hardware is the key</td>
<td>Software is the key</td>
</tr>
<tr>
<td>Closed, fixed functional functionality</td>
<td>Open, flexible functionality</td>
</tr>
<tr>
<td>Slow turn on technology</td>
<td>Fast turn on technology</td>
</tr>
<tr>
<td>High development and maintenance cost</td>
<td>Software minimizes development and maintenance cost</td>
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Figure 4.1 Concept of Virtual Instrumentation
The front end signal conditioning system used is the SCXI system. This offers a selection from a wide variety of analog inputs to exactly match as per specific application needs. The system includes a 32 channel multiplexer amplifier, 8 channel isolation amplifier, and 8 channel simultaneous sampling differential amplifier. These modules are housed in a 4-slot DC powered chassis. These modules can easily interface to a wide variety of inputs including RTDs, thermocouples, strain gauges, current and voltage sources. It also provides further flexibility in configuration of individual channels and transducer types. The analog signals are conditioned and multiplexed onto single channel of the DAQ card for acquisition directly into PC memory. The CPU is Pentium based 133MHz, 128 MB RAM and other standard interfaces such as RS232 serial port etc. It can withstand extreme environmental conditions such as temperature, shock and vibration.
4.3.0 SOFTWARE

In a virtual instrumentation system, the software plays an important role in the data acquisition, analysis, display/presentation and report generation. The system software is essentially an integrated virtual instrumentation environment that features all the necessary user friendly interfaces combined with a strong programming environment. The software is developed under the MS Windows 97 environment. The software used is the LabVIEW 6.1 graphical programming language. It is highly modular and flexible and is based upon the object-oriented technique. It provides integration of all the system hardware and supports all three functional elements such as data acquisition, analysis and presentation. The system software resides on the top as shown in Figure 4.2, supported by the application software environment and its add on. The device driver software occupies hierarchically the lowest level in the architecture. It provides the foundation level for the system software architecture and is meant for the spanning and controlling the data acquisition and signal conditioning hardware. The application software environment sits on the top of the driver software, which provides the programming tools necessary for development of the application software. The software used in the system is the LabVIEW 6.1 in two development environments. On the front panel, man-machine interface is built for control and data visualisation. On the block diagram, the actual graphical program [4.1] is built. The features of the programming methodology are as follows:

- The tests are categorized into groups depending upon the nature of test. The test to be conducted is invoked from the specific group.
- The system software provides the user friendly front panel on the visual display unit similar to the controls in a conventional instrument.
- The test is configured for the desired parameters and initialization is carried out.
- The test can be started, aborted or stopped by invoking START/ABORT/STOP command buttons.
- The data is acquired during the test run and displayed on the front panel.
At the end of the test, the system performs the necessary analysis and computations and a display panel appears on the screen, which gives the complete test report.

A hard copy of the complete test report can be obtained by invoking the PRINT command button on the test panel.

Figure 4.3 Schematic of Assembly Configuration

4.4.0 ASSEMBLY CONFIGURATION

The schematic assembly configuration is shown in Figures 4.3 and 4.4. The system involves the use of various sensors [4.2] and hence it is important to take into consideration their mounting and interface configurations. Some of the assembly design features are as follows:
Figure 4.4 Assembly Configuration
Sensor interface units are different for different tests and are sensor dependent.

- Signal conditioning unit is employed for only those tests which require multi-channel signal conditioning and data logging. Otherwise, the sensor interface unit is compact providing only a means of connectivity of sensors to the data acquisition modules.
- For convenience, all similar types of connectors are grouped together.

### 4.5.0 MAINTAINABILITY AND RELIABILITY

All major elements of the system are designed with great care, keeping in view the maintainability and reliability requirements. Following are some of those features incorporated in the system to meet the above requirements.

- Minimum element configuration is employed in the system for enhancing reliability and ease of maintenance.
- All components having well established history and high reliability are employed.
- Reasonable levels of safety factors are followed in selection of different components.
- All major components like PC, signal conditioning and data acquisition modules are put to burn-in tests to eliminate early failures.
- The system is thoroughly tested under conditions of elevated temperatures up to $50^\circ$ C and vibrations up to 2g and shock of 10g.
4.6.0 DEVELOPMENT OF ELECTRONIC FUEL INJECTION SYSTEM

Over the years, various methods have been suggested to improve the power output and to reduce the exhaust emission from two-stroke petrol engines. Among the methods such as coating of piston and cylinder head using non-noble metal catalysts, use of catalytic converter, charge stratification, fuel injection system etc., the fuel injection system proves to be the most effective. Subsequently, the development of electronic controlled fuel injection system for a two-stroke SI engine using virtual instrumentation tool is discussed. The objectives for this research are as follows:

- To design a flexible fuel injection control system for use on a crankcase injected and port injected engine.
- To map the engine requirements and sensitivity of those requirements for air-fuel ratio at constant speed.
- To adaptively seek those operating conditions with several optimization strategies.

At present, the modern vehicles are embedded with Electronic Fuel Injection (EFI) system for better fuel economy and reduced emission. But the automation software used in this system is not user friendly because of preset program based on µP control. To overcome these difficulties, in the present work, it has been proposed for an interactive Electronic Fuel Injection (EFI) system for Spark Ignition (SI) engines. It replaces µP based software and hardware structures with a modern client/server solution. On the client side, the virtual instrumentation software program is used for data acquisition and signal processing. In a lean burn engine, the air-fuel ratio is extremely critical. The engine operation near the lean mixture limit is necessary to obtain the lowest possible emission and the best fuel economy. However, near the lean limit, a slight error in air-fuel ratio can drive the engine to misfire. This condition causes dramatic increase in exhaust emission, engine roughness and poor throttle response. Reliable maps require precise control and measurement of injection timing and fueling [4.3,4.4]. A PC based fuel injection system was designed and built in
order to control the engine for the map making and also for the evaluation of control strategies. The PC based virtual instrumentation tool sets the timing and pulse width for port fuel injectors and the start of fuel injection signal.

![Schematic of Experimental Setup](image)

**Figure 4.5 Schematic of Experimental Setup**

### 4.6.1.0 PC Based Control System

The fuel injection control is essentially a speed density system. The fuel injection into the intake port occurs once per cycle. In the current implementation, the pulse width is a linear function of Manifold Absolute Pressure (MAP). In addition to MAP, Throttle Position Sensor (TPS) and speed sensor (Proximity sensor) is also used to achieve the various operating conditions of the engine. The start of injection can be controlled for any point in the cycle. This may be useful when studying the effects of the air-fuel mixture stratification.
4.6.1.1 Sensors and Components

The schematic sketch of an experimental setup is shown in Figure 4.5. A standard MAP sensor is used to sense Manifold Absolute Pressure (MAP). It requires a 5 V dc supply and sends out a 0 to 5 V signal proportional to manifold pressure. Similarly, the Throttle Position Sensor (TPS) is used to sense the position of the throttle valve. A Crank Angle Degree marker (CDM) is used to measure the position of the piston with reference to TDC of the cylinder so that injection starting angle can be regulated. The solenoid controlled fuel injectors are used with 12 V input dc supply.

4.6.2.0 MAIN PROGRAM

The main program for electronic fuel injection is developed using software LabVIEW 6.1 and executed in a PC. The RS 232 port is used as an interface to the input/output device. The control panel is used to control the main program to meet out the engine requirements. In the control panel, MAP signal is varied for a fixed TPS to vary the fuel consumption and hence the air-fuel ratio to suit the different load conditions of the engine. This may be repeated for the various TPS position i.e. for various engine speeds.

4.6.2.1 Methodology

In the carburetor mode, the engine is tested to generate the base line data. The fuel mapping [4.5] is generated using data such as engine speed, MAP position with the help of visualization tool as shown in Figure 4.6. Similarly, the time mapping is generated using the data such as speed and MAP position as shown in Figure 4.7. This mapping is part of a program to develop fully adaptive timing and air-fuel ratio control strategies. It is important to know the optimum and the shape of the fuel surface and time surface from Figures 4.6 and 4.7 to optimize the response of a control algorithm. In addition, modeling the system to evaluate control algorithm requires an accurate knowledge of the surfaces. The control strategies being currently evaluated are described briefly in the results.
Figure 4.6 Fuel Map.

Figure 4.7 Time Map

4.11
4.6.2.2 Program Description

In the developed program for the electronic fuel injection of two stroke SI engine, the proximity signal is read through the DAQ card (6035E) interface via RS 232 port. The signal is compared with the threshold voltage to prevent any noise signal as shown in Figure 4.8. The panel as shown in Figure 4.9 is used to control the main program as per the operating requirements of the engine. The signal is read only if the signal voltage is higher than the threshold voltage. If the signal is not read through the DAQ, then the noise signal is suppressed by means of filter element. Then the program logic enables the signal initialization circuit for reading the signals. The counter reads the signal on time basis when the clock is set ON. The signals are buffered for further processing and hence reduce the signal transit time. The engine speed (RPM) is calculated using the moving average SUBVI. Here the average signals are carried out rather than single signal through moving average window. The signals are read frame by frame of estimated sample size depending upon operating system speed.

The output voltage from the DAQ card is only 5 V. But the injector solenoid requires 12 V for the energisation which is obtained by sending signal through switching (amplification) circuit as shown in Figure 4.10. The injection pulse width is calculated for the input signals of MAP and RPM. The pulse width varies with the engine speed, MAP and TPS. The injection signal commences during the rising index of the proximity signal and proceeds till the pulse width duration as calculated by the SUBVI as shown in Figure 4.11. The injection signal is used for triggering the solenoid coil of the fuel injector. The injector triggering time may be varied through the proximity position location. The program hierarchy is illustrated as shown in Figure 4.12. The program is executed for the various engine operations such as starting, idling and normal running. The engine load may be varied by varying the MAP at constant engine speed.
Figure 4.8 Block Diagram
Electrical Fuel Injection - Real Time I/O Signal

Injection signal

Proximity Signal

Figure 4.9 Control Panel
Figure 4.10 Switching Circuit

Figure 4.11 Pulse Width Calculation SUBVI

4.15
Figure 4.12 Hierarchy of VI Program
4.6.2.3 Pulse Width Variation

The main program developed using virtual instrumentation tool is executed using the control panel. At 2000 rpm, the fuel injection pulse width varies as shown in Figure 4.13 due to MAP variation.

Figure 4.13 Fuel injection pulse width variation for a speed of 2000 rpm and varied MAP and injection starting angle

Figure 4.14 Fuel injection pulse width variation for a speed of 3000 rpm and varied MAP and injection starting angle
This may be useful for varying the load at different air-fuel mixture of engine operation. The program is executed in the interactive method at different injection angle such as 260°, 270° and 280° from TDC. Figure 4.14 shows that the higher injection period for the engine speed of 3000 rpm than at a speed of 2000 rpm. This is due to increase in fuel requirements for the increase in load and speed of the engine [4.6,4.7]. The engine operation is not stable in the speed range from 4500 rpm to 5000 rpm possibly due to very high fluctuation in the injector needle lift.
4.7.0 FUEL INJECTOR CALIBRATION TEST BENCH

A small fuel injector calibration test bench for an experimental two stroke gasoline engine is developed as shown in Figure 4.15. A dc variable speed drive along with the speed sensor (proximity) is used to achieve the desired engine speed so that the fuel injector calibration can be carried out. The MAP sensor and TPS is interfaced with PC based Virtual Instrumentation (VI) program through 6035E Data Acquisition (DAQ) card. The VI program [4.6] is flexible, user-friendly and can be interactive during the calibration of injection system. A Crank angle Degree Marker (CDM) is used to measure the position of the piston with reference to TDC of the cylinder so that injection starting angle can be regulated during engine operation.

The solenoid controlled fuel injector [4.7] is used with 12V input dc supply. The fuel injector is connected to 12V dc electrical fuel pump and pressure regulator, providing fuel pressure up to 2 bar. The injector is calibrated to suit the minimum and maximum fuel requirements of the engine. The fuel metering is based on the load signal from MAP, TPS signal and speed sensor signal. The control system synthesises the injection timing during the calibration of the injector. The entire test bench along with VI program and connector block are shown in Figures 4.16 and 4.17. In this concept, the fuel quantity and injection timing are controlled by varying the width and timing of voltage pulses applied to the solenoid valve of the injector. Here the fuel injection takes place in a collection jar and not into the engine. The fuel injection spray is shown in Figure 4.18.

4.8.0 INJECTOR CALIBRATION

The fuel injector calibration is to trace the fuel injected quantity for various operating speeds of the engine and for the different parametric variations of the engine. The dynamic flow characteristics of the injector forms the most important aspect of tests. It is difficult to directly measure the flow rate for a single injection. This is because of the high speed at which injectors open and close as well as for the flow rate for each opening. The calibration results are generated for integrating flow.
Figure 4.15 Fuel Injector Calibration Test Bench
Figure 4.16 Calibration Test Bench

Figure 4.17 VI Program for Injector Calibration
Figure 4.18 Injector Assembly with Fuel Spray
of 2000, 2500, 3000, 3500 and 4000 injections per minute. A typical test series consists of the following sequence of operation. At first, the dc variable speed drive is started and the required speed is attained. After that, the Virtual Instrumentation program is executed for the appropriate pulse width according to the MAP, TPS and speed sensor signals.

The quantity of fuel injected is measured using electronic balance for the appropriate number of injections per minute. This procedure is repeated for the various operating conditions and a number of data points are evolved. The injector response characteristic is a very crucial factor for engine operation. It is extremely essential to know when exactly the injector opens and when the flow starts. In connection with the injector used in the present investigation, it is important that the response time of the injector depends on several factors including the physical size of the solenoid, the power output, the drive circuitry, the mass and travel of the armature and the fuel injection pressure [4.8]. The supply voltage is fixed at 12V. The result of the difference in opening and closing timing is due to the injector having to work against both the closed spring and the fuel pressure.

4.9.0 CALIBRATION RESULTS

Figure 4.19 shows the variation of fuel delivery quantity at various pulse width of the injector. This calibration test is used to regulate the engine operation for the various air fuel mixtures. This procedure can be repeated for the various speeds of the engine operation. The results show that higher injection period for the full load operation of the engine attributed by the increase in manifold vacuum pressure than at part load conditions. This is due to the increase in fuel requirements for the increase in load and speed of the engine as shown in Figure 4. 20. The injected fuel quantity increases with increase in fuel pump injection pressure. This increase in fuel quantity is more in the case of high speed of engine operation as shown in Figure 4. 21.
Figure 4.19 Fuel Delivery against pulse width for various engine speeds

Figure 4.20 Manifold pressure variation with pulse width

Figure 4.21 Injection pressure variation with pulse width
4.10.0 CONCLUSIONS

- The engine control system that is designed and implemented is flexible, reliable and easily programmed.
- The precise online control of fuel injected per cycle and the air-fuel ratio for any particular load (MAP) and speed using the mapping techniques can be achieved.
- The engine operation is not stable in the speed range from 4500 rpm to 5000 rpm possibly due to fluttering of the fuel injector.
- This system has been successfully used on single cylinder engines.
- Electromagnetic means of controlling fuel quantity and injection timing using virtual instrumentation enabled engine cycle to respond for the changes in control signal needed to satisfy the engine transient performance requirements.
- The calibration system using VI is flexible, user friendly and less expensive.

REFERENCES


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