SETTING UP A DATA ACQUISITION SYSTEM FOR SPARK ENGINES

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Abstract:

Measuring dynamic parameters on an engine is very important to diagnose and analysis the faulty problems and the quality of it. To achieve such measurements, it requires expensive data acquisition system (DAS) capable of measuring these parameters. The problem arises when there is a need to build such a system from scratch with a very limited budget and depending on your experience. This paper is dedicated to transfer experience and technology to mechanical engineers who have a little experience in setting up their dynamic test rigs and they do not have enough budgets to buy an expensive DAS [1].

The proposed system is intended to set up a low cost and configurable DAS consisting of sensors, analog to digital card A/D and software package for acquisition and processing.

The sensors are used to measure cylinder pressure, vibration of the cylinder block on 3D, different types of temperature (oil, inlet and outlet water temperature), crank angle and engine’s RPM. The processing includes cycle separation to prepare the acquired data for heat release analysis. The Fast Fourier Transformation (FFT) is also used to analyze the data for fault diagnosis using vibration analysis. The developed system saves about 75% of the price of a similar on the shelve system.

Key Words: Data Acquisition System, Frequency Domain, Spark Ignition, Time Domain

Introduction

Data acquisition technology has taken giant leaps forward over the last 30 to 40 years [2]. Vehicle data acquisition covers a wide range of applications. This may be a simple data acquisition system in the form of a test process, testing the engine temperature of a new automobile design. However, vehicle data acquisition does not mean automobiles alone, but can include, race cars, buses, trucks, motorcycles, aircraft, boats, and other transportation. Vehicle data acquisition is not only measurement of gas or diesel engine parameters but, with using proper sensors and signal conditioning, it could be extend to display, report and control any other vehicle parameters.

The vibratory and acoustic behavior of the internal combustion engine is a highly complex one, consisting of many components that are subject to loads that vary greatly in magnitude and which operate at a wide range of speeds.

The acquisition of the cylinder pressure and its evaluation is one of the most powerful means for experimental optimization of internal combustion engines [3]. Behavior of engine working cycle may be investigated using this technique. Conditions influencing mechanical and thermal load of engine part may be determined as well. The quantification of engine running roughness is also a very useful result of evaluation of in-cylinder pressure records. The use of in-cylinder pressure record is extremely powerful tool as far as experimental data are confronted with results of mathematical model of engine working cycle. For production, testing or even prototype evaluation of vehicles (cars, trucks, etc.) the data acquisition requirements can be very demanding. This is made obvious from the fact that the types of parameters that would need to be measured include: Temperature (water, oil, transmission fluid, brakes, interior cooling system, and exhaust), Pressure (engine compression, tire, cooling system, and oil), Vibration (chassis, engine, doors, hood, trunk, and interior), Voltage (battery, lamps, relays, electric motors, fans, pumps, and instrument panel), Flow (water, oil, transmission fluid, coolant, and air). A vehicle data acquisition system might include hundreds of data points

Basic Operation

The four steps of data acquisition are:

- Measure
- Record
- Access
- Analysis

Different types of Sensors represent the main key to achieve the measuring step, in which it measures the different aspect of parameters such as electronic signal, temperature, pressure, acceleration, linear movement, frequency and ON/OFF switch position which recorded by the data acquisition unit [4].

Recording is achieved throughout converting the sensor measurements into digital signal by A/D converter prior to logging. The sampled rates refer to the number of times per second the data is recorded i.e. 100Hz = 100 samples per second.

Access of the number of monitored channels and the sampling rate determine how long it takes to full or overwrite the data log memory, the download time and the amount of time to analyze the logged data. A higher hertz (Hz) rate creates more data. Once the data has been recorded it then needs to be accessed for analyzing and archiving.

Analysis, a software analysis program is used to process the data and prepare it in the required form. Finally one has to keep in mind that not all signals need to be recorded at a fast rate;

Data acquisition construction

A typical data acquisition system consists of these components, as shown in figure 1.

The data acquisition includes 3 phases as follows:

Input Phase

a) Physical Phenomenon (Pressure, Vibration etc..)

b) Sensors: A transducer is a device that converts input energy of one form into output energy of another form. For example, a microphone is a sensor that converts sound energy (in the form of pressure) into electrical energy, while a loudspeaker is an actuator that converts electrical energy into sound energy.

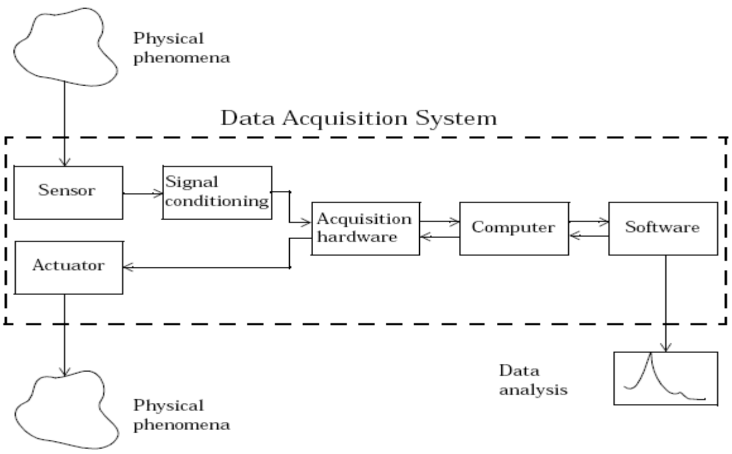

Figure 1: The data acquisition components

c) Signal Conditioning : Sensor signals are often incompatible with data acquisition hardware. To overcome this incompatibility, the signal must be conditioned. For example, you may need to condition an input signal by amplifying it or by removing unwanted frequency components. Output signals may need conditioning as well [5].

d) A/D Card: At the heart of any data acquisition system lays the data acquisition hardware. The main function of this hardware is to convert analog signals to digital signals, and to convert digital signals to analog signals.

e) Screw terminal (to connect wires)

Processing Phase

a) Computer

b) Software: Data acquisition software allows you to exchange information between the computer and the hardware. For example, typical software allows you to configure the sampling rate of your board, and acquire a predefined amount of data.

Output Phase

a) Actuators (if there is a control system)

b) Monitor

c) Printed report

Hardware

Channel Types

- Analog - Any input that continuously changes within a specified range. This type of input would traditionally have been displayed with a needle gauge.
- Digital - Any input or output which can only be in two states. e.g. ON or OFF, true or false, above or below.
- Frequency - Any input that is pulsed or oscillating. The rate at which the input is pulsing or oscillating is measured.
- Serial - Any device or sensor which is semi-intelligent and is capable of communicating via RS-232 serial communication.

Sensor Types

Table 1 Show various types of sensors' output

Analog	Digital	Frequency	RS232
Temperature	Switches	RPM	**Gas analyzer**
Pressure	in/out	Speed	
Flow	Status	Rotary encoder	
Current	Counter		
Volts	on/off		

What do you need to know?

- Resolution and range (4.1 & 4.2).
- How fast to sample (4.3).
- How many times to sample.
- Device and configuration (what is the maximum number).
- Connecting the signals the right way.
- What channels to sample.
- How to deal with the data.
- Data bus (type of slot inside computer e.g. PCI or external such as USB [6].

Analog-to-Digital Conversion

- The A/D converter (ADC) converts an analog voltage into a binary number through the process of quantization.
- The ADC will have a full-scale voltage range over which it can operate.
- The number of bits will dictate how many discrete levels will be used to represent measured voltages. For example, an 8-bit converter with a full-scale voltage of 10 V will give you a resolution of 10V/256 which is 39.1 mV. Figure 2 shows a comparison between 16 bit card resolution and 3 bit. [7]

Signals' Resolution

$$\Delta = \frac{V_{FS}}{2^n}\begin{cases} \dfrac{10V}{2^3} = 1.25V \\ \dfrac{10V}{2^{16}} = 0.15mV \end{cases}$$

Where V_{FS} is the full scale of the input signal

N is the card's resolution (12, 14 or 16 etc.)

□ is the signal's resolution

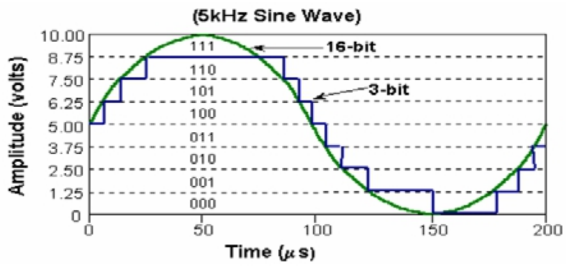

Figure 2 shows a comparison between 16 bit card resolution and 3 bit

Choosing a sampling or scan rate (scans/sec, or Hz)

The ADC samples according to a scan rate. How fast you sample should satisfy the Nyquist sampling theorem. The sampling frequency should be at least two times the highest frequency present in the signal. If Nyquist criterion is not satisfying there will be implications in how the signal is 'reconstructed'. Depending on your objective, you might choose **scan rate** to satisfy Nyquist criterion but, you might also want to have accuracy in **time** measurements. Can you see how you have to balance how fast you sample, how many samples you get, etc.?

Types of Measurement Systems:

1. Differential measurement system
2. Referenced single-ended (**RSE**)
3. Non-referenced single-ended (**NRSE**)

You may see these connection options on A/D hardware.

What Hidden things you have to take care about? [8],[9]

Sensors

When choosing the best analog sensor to use, you must match the characteristics of the physical variable you are measuring with the characteristics of the sensor. The two most important sensor characteristics are sensor's output & bandwidth

Sensor Output

The output from a sensor can be an analog signal or a digital signal, and the output variable is usually a voltage although some sensors output current.

Current Signals

Current is often used to transmit signals in noisy environments because it is much less affected by environmental noise. The full scale range of the current signal is often either 4-20mA or 0-20mA. A 4-20 mA signal has the advantage that even at minimum signal value, there should be a detectable current flowing. The absence of this indicates a wiring problem. You need to use this type if your measuring system is far from your control room.

Voltage Signals

The most commonly interfaced signal is a voltage signal. For example, thermocouples, strain gauges, and accelerometers all produce voltage signals. There are three major aspects of a voltage signal that you need to consider:

Amplitude

If the signal is smaller than a few millivolts, you may need to amplify it

Frequency

Whenever you acquire data, you should decide the highest frequency you want to measure. The highest frequency component of the signal determines how often you should sample the input. If you have more than one input, but only one analog input subsystem, then the overall sampling rate goes up in proportion to the number of inputs. Higher frequencies may be present as noise, which you can remove by filtering the signal before it is digitized. If you sample the input signal at least twice as fast as the highest frequency component, then that signal will be uniquely characterized. However, this rate may not mimic the waveform very closely.

Duration

How long do you want to sample the signal for? Data stored in ASCII format takes more space than data stored in binary format.

Sensor Bandwidth

In a real-world data acquisition experiment, the physical phenomena you are measuring have some limitation. The bandwidth is given by the range of frequencies present in the signal being measured. You can also think of bandwidth as being related to the rate of change of the signal. A slowly varying signal has a low bandwidth, while a rapidly varying signal has a high bandwidth. To properly measure the physical phenomena of interest, the sensor bandwidth must be compatible with the measurement bandwidth. You may want to use sensors with the widest possible bandwidth when making any physical measurement. This is the one way to ensure that the basic measurement system is capable of responding linearly over the full range of interest. However, the wider the bandwidth of the sensor, the more you must be concerned with eliminating sensor response to unwanted frequency components [4].

Signal Conditioning

Sensor signals are often incompatible with data acquisition hardware. To overcome this incompatibility, the sensor signal must be conditioned. The type of signal conditioning required depends on the sensor you are using. For example, a signal may have small amplitude and require amplification, or it may contain unwanted frequency components and require filtering. Common ways to condition signals include: Amplification, Filtering, Electrical Isolation, Multiplexing, and source Excitation [7].

Current DAS Application

The measuring system consists of many sensors and actuator which are shown in the figures (3-13). The sensors are RPM sensor, Oil pressure sensor, Cylinder head temperature sensor, Lambda (Oxygen) sensor, Inlet radiator temperature, Outlet radiator temperature, Dynamometer manual load, Cylinder pressure, Rotary Encoder (crank angle), and Vibration. The whole system is shown in figure 14.

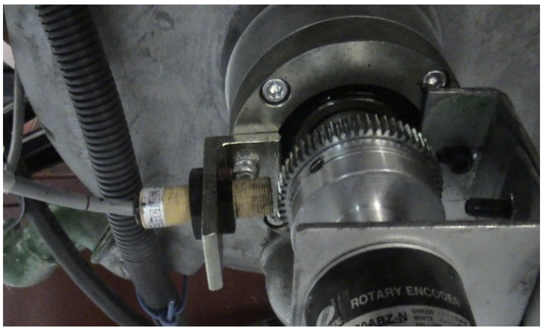

Figure 3: RPM Sensor

Figure 4: Oil Pressure Sensor

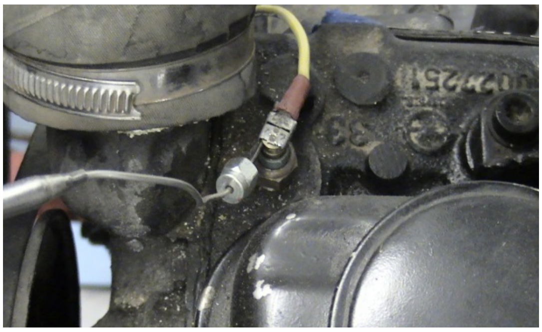

Figure 5: Cylinder Head Temperature Sensor

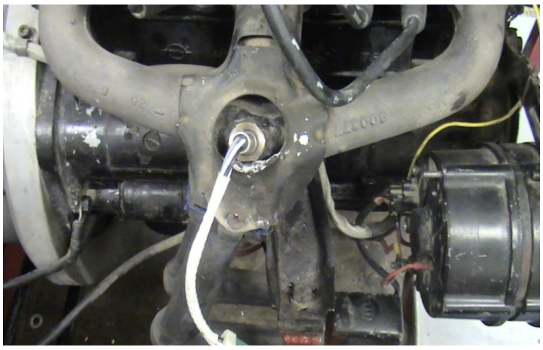

Figure 6: Oxygen Sensor

Software

The data acquisition software is developed using “TestPoint” [10].

TestPoint: It’s a software package that supports acquisition from A/D boards and RS232 devices, and combines this with analysis and display capability. It provides object-oriented graphic style of creating custom test, measurement, and data acquisition programs.

By dragging and dropping ***objects***, which are icons representing related tasks, to an ***action list*** in the desired order of execution, it is easy to create applications quickly without any complicated programming figure 15.

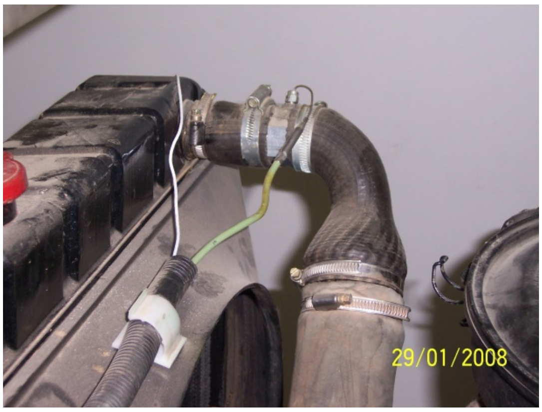

Figure 7: Inlet Radiator Temperature sensor

Figure 8: Outlet Radiator Temperature Sensor

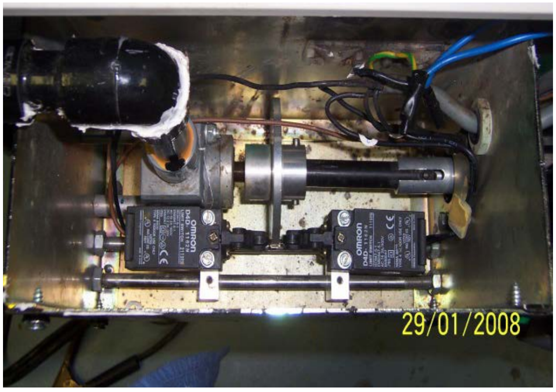

Figure 9: Manual load control actuator

Figure 10: Cylinder pressure sensor

Figure 11: Rotary encoder (Crank Angle) Sensor and Dynamometer

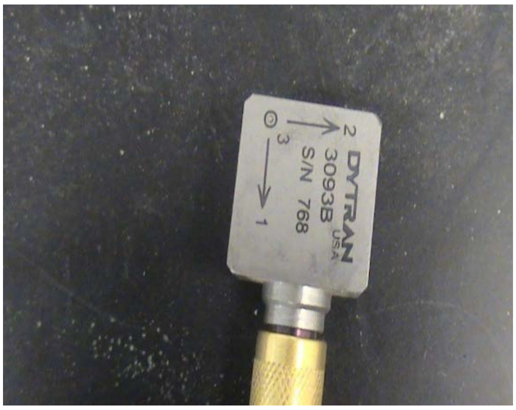

Figure 12: 3D vibration Sensor

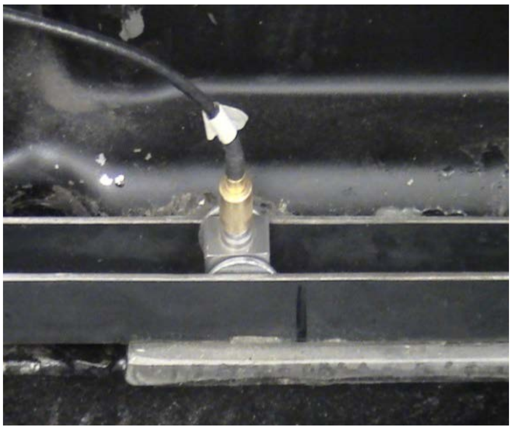

Figure 13: Installation of the Vibration Sensor

Figure 14: The whole system

Professional looking applications are created by simply placing the input, output, display, and control-button objects where you want them on the display window. Libraries for many popular instruments including Hewlett Packard oscilloscopes, spectrum analyzers etc. are supported. Data acquisition boards and GPIB cards are accessed through the same drag and drop action. During application development or test, a handy demo mode is available, allowing application development without the actual presence of hardware. Software package is necessary to process the acquired data [11]. A/D card without software is useless. A/D card with poor software is almost useless. A/D uses driver software which is the layer between the operating system and the hardware. It directly controls the registers of the A/D card, managing its operation and its integration with the computer resources, such as processor interrupts, Direct Memory Access DMA, and random memory [12].

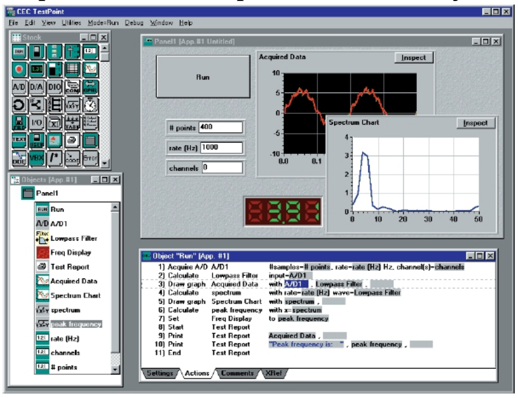

Figure 15: Interface architecture of the Software package

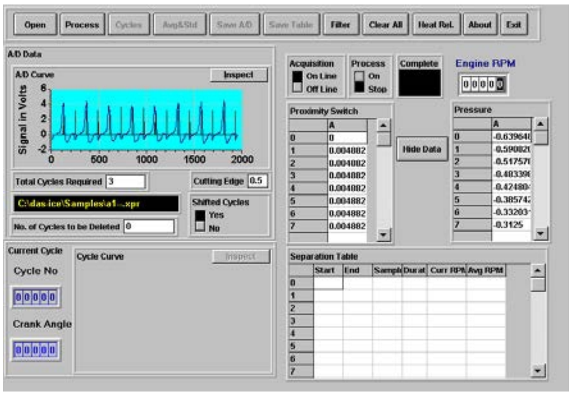

Figure 16: A typical DAS-ICE display showing the main menu system

Features of the developed package

Data Acquisition System for Internal Combustion Engine (DAS-ICE) provides an extensive set of data analysis tools, graphics, control and application interface development capabilities as well as the ability to acquire data from A/D. It runs in windows environment to provide the ability to tightly control timing and perform multi-tasking functions. Multitasking allows different parts of an application to run in parallel without complicated managers or disk-swapping methods. The synchronization of the acquired data (trigger) is very important (Top dead center of the acquired cylinder) [13]. The main interface of the application is shown in figure 16.

Measurement

Figures (17-18) illustrate a sample of the measurement results for the ignition cycles and the processed data to get average cycle. Multiply the magnitude of pressure by the sensor factor to get the physical real value in Pascal. Figures (19-20) illustrate a sample of processing the vibration signals in the frequency domain.

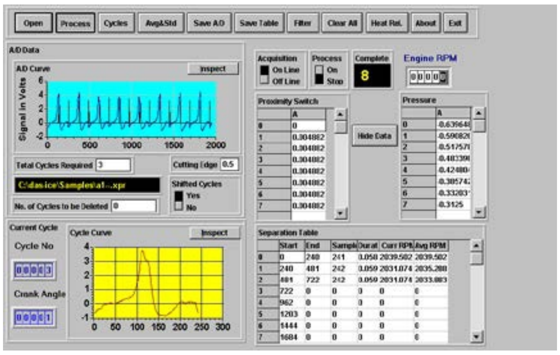

Figure 17: Acquiring 8 complete ignition cycles according to user request

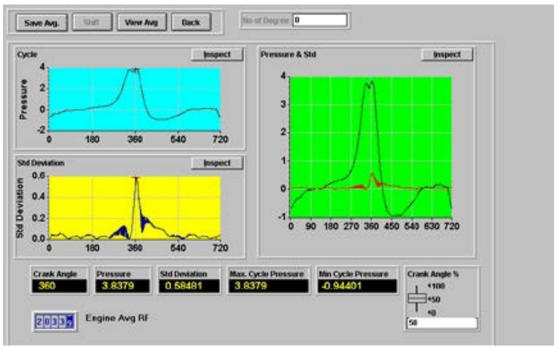

Figure 18: Processing the acquired data to get the average cycle

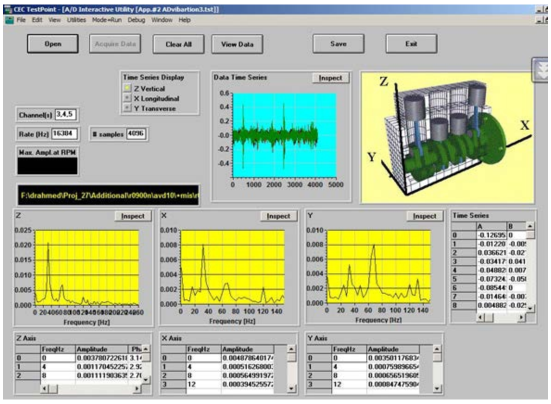

Figure 19: Acquiring vibration signals On the engine & Performing FFT

Figure 20: Processing the acquired data of the vibration signals

Conclusion

A configurable data acquisition system is built to acquire data from internal combustion engines. The system describes the basic steps for mechanical engineers who need to design their dynamic measuring system. The system is operational and capable of acting as a test bed for a wide variety of experimental investigation on Petrol engine.

The system takes into account different types of signals such as cylinder pressure, vibration in 3D, Oil pressure, crank angle, and engine RPM. Inlet water temperature to radiator, outlet temperature from radiator, oil temperature, and cylinder head temperature are also captured.

The system processes the acquired data to prepare the average cycle during the 4 strokes as a function of a synchronized crank angle. The vibration signals in time domain are converted into frequency domain using FFT. Beside online mode, the system can also process the data using offline mode. A digital filter is included in the system to filter the signals from noise. The developed system saves about 75% of the cost of a similar on the shelve system.

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