LABVIEW-BASED DATA ANALYSIS FOR AUTOMOTIVE SINGLE-CYLINDER RESEARCH ENGINE

By

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FINAL PROJECT REPORT

Submitted to the Electrical & Electronics Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

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CERTIFICATION OF APPROVAL

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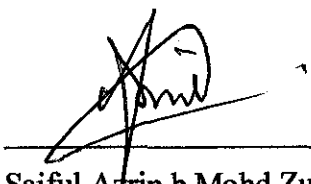
Approved:



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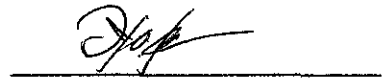
December 2009

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.



Mohd Helmie b Mohd Kalimi

ABSTRACT

A single-cylinder engine research is conducted to study operational aspect of a single-cylinder engine. The development of a LabVIEW-based data analysis program is meant to reduce cost and increase flexibility of a data acquisition system. The objective of the study is to study parameters used in determining performance of an engine, specifically the combustion process, and to develop a post-processing program for combustion analysis. The combustion analyses that are included in this program are Indicated Mean Effective Pressure (IMEP), Mass Fraction Burned (MFB) and Heat Release Rate (HRR). The result of this program will be compared to a combustion analysis program called DEWETRON CA for verification. In the end, the single-cylinder engine research can use the LabVIEW program for the purpose of test measurement display, logging and analysis. This program also can be revised and upgrade so that it will be implemented inside the online data acquisition and combustion analysis.

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LIST OF ABBREVIATIONS

AFR	Air Fuel Ratio
BDC	Bottom Dead Centre
IMEP	Indicated Mean Effective Pressure
HRR	Heat Release Rate
MFB	Mass Fraction Burned
PC	Personal Computer
RPM	Revolution per Minute
SI	Spark Ignition
TDC	Top Dead Centre

CHAPTER 1
INTRODUCTION

1.1 Background of Study

This project is conducted to develop a post-processing combustion analysis program for single-cylinder research engine. It will use logged data from 'online data acquisition and control program' and analyze engine performance. I will be using LabVIEW 7.1 to develop this program. The program needs to be fast enough so that it can also be implemented in 'online data acquisition and control program'. Universiti Teknologi PETRONAS (UTP) has a high speed 'online data acquisition and control program' that is capable of 10 kHz sampling rate. In one second, it is capable of capturing 10,000 measurement consists of time, crank angle, pressure, and volume. So the post-processing combustion analysis program needs to be able to fully complete and analyze all the 10,000 data in order for the program to be implemented in 'online data acquisition and control program'.

1.2 Problem Statement

UTP is currently researching on a direct-injection fuel, single-cylinder engine performance. They have already developed the online data acquisition that is able to capture the measurement directly from the running engine. It has the optional log button if the user wants to log the measurement for further analysis. They also have combustion analysis as part of the program. However, the online combustion analysis is not completed. To implement the online analysis, enough understanding of the parameters required for the analysis must be gained. Thus calculations for the combustion analysis parameters need to be studied.

Furthermore, the research teams already have a data acquisition (DAQ) system called DEWETRON CA, which is also capable of combustion analysis. However, since the DEWETRON CA is a self contained system, it is not flexible – display, logging and analysis cannot be catered to the user's preferences.

1.3 Objectives

1. To develop a post-processing combustion analysis program that capable to be transferred to an online program.
2. To design a user friendly and professional graphical user interface (GUI) of the program.

1.4 Scope of Study

The study on the development of the program is to be completed within approximately one year's timeframe (two semesters). Phase one consists of research on the single-cylinder engine, learn LabVIEW programming and develop post-processing combustion analysis. Phase two is continuation of develop post-processing combustion analysis and designs a user-friendly interface.

The most important step is to familiarize with the LabVIEW program itself. For the post-processing combustion analysis program, it involves the array and mathematical functions. The challenge is the test time taken to complete the analysis. It is crucial to have a very fast program as it will be implemented inside 'online data acquisition and control program'.

CHAPTER 2
LITERATURE REVIEW

2.1 Single-Cylinder Engine

Single-cylinder engine is a basic configuration of an internal combustion engine. In the research lab, it uses a single-cylinder four-stroke engine, which is commonly used in motorcycles and cars. It is simpler to use a single cylinder engine for research because it is simple and economical [1].

Each cylinder requires four strokes to complete once cycle. This cycle is called the Otto Cycle. It compromises [2]:

Intake Stroke: From 0^{o} to 180^{o}, piston drops, exhaust valve closes and intake valve opens. It will draw a fresh mixture of air and fuel into the cylinder. In order to increase the mass inducted, the inlet valve opens shortly before the stroke starts and closes after it ends.

Compression Stroke: From 180^{o} to 360^{o}, piston rises, exhaust valve closes and intake valve closes. In this stroke the mixture is compressed to a small fraction of its initial volume. Towards the end of the compression stroke, combustion is initiated by electric discharge across the spark plug.

Power Stroke: From 360^{o} to 540^{o}, piston drops, exhaust valve close and intake valve closes. This is when ignition occurs. The rapid rise of gas temperature and pressure will push down and force the crank to rotate.

Exhaust Stroke: From 540^{o} to 720^{o}, piston rises, exhaust valve opens and intake valve closes. In this stroke, the remaining burning gasses exit the cylinder due to higher cylinder pressure compared to exhaust pressure. After this stroke, the cycle will start again.

Below are pictures of the four different strokes that perform the Otto Cycle on the single-cylinder engine.

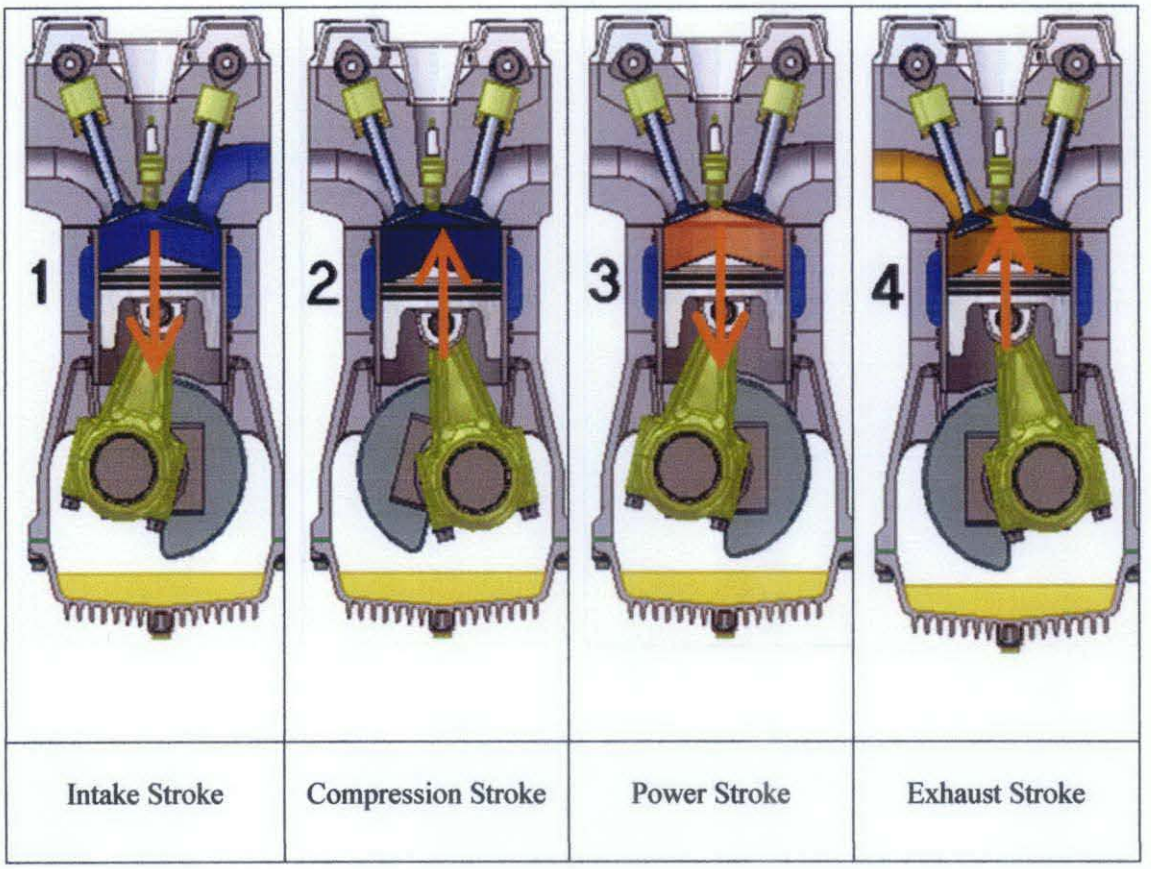


Figure 1: Otto Cycle of Single Cylinder Engine [3]

2.2 Combustion Analysis

The analysis can be done in two ways, either analysis during the acquisition process real time online, or analysis using the logged data: post-processing offline.

2.2.1 *Important Parameters*

The parameters that acquired from the engine data acquisition are cylinder pressure, cylinder volume and crank angle. There are three (3) graphs that are very important in combustion analysis:

2.2.1.1 Pressure vs. Crank-angle graph

a. The maximum pressure is at 0^{o} and 360^{o} where it is the top dead centre (TDC). This is due to ignition of spark plug and the rise of piston.
b. The minimum pressure is at 180^{o} and 540^{o} where it is the bottom dead centre (BDC). At 180°, the intake valve is open while at 540° the exhaust valve is open gives the equilibrium state to the cylinder.
c. The following is a typical graph of pressure vs. crank-angle.

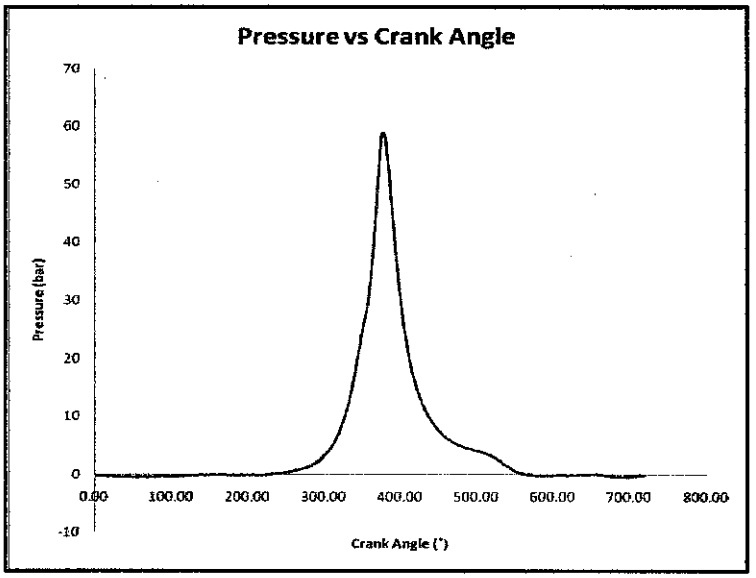


Figure 2: Pressure vs. Crank-angle Graph

2.2.1.2 *Volume vs Crank Angle Graph*

a. The minimum volume is at 360^{o} where it is the top dead centre (TDC), due to the piston rise.

b. The maximum volume is at 180^{o} and 540^{o} where it is the bottom dead centre (BDC), due to piston drop.

c. The following is a typical graph of volume vs. crank-angle

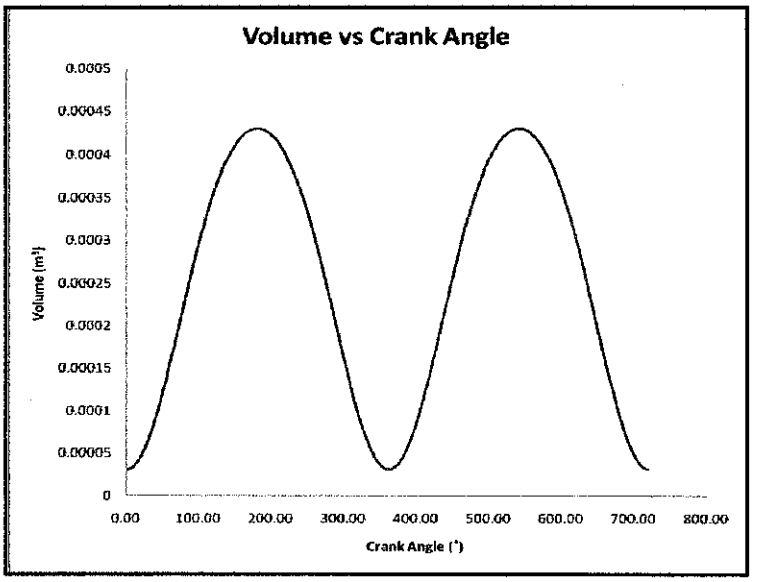


Figure 3: Volume vs. Crank-angle Graph

2.2.1.3 Pressure-volume (PV) Diagram

d. PV diagram maps pressure against the displaced volume.

e. PV diagram gives clear explanation regarding Otto cycle and power output of the engine.

f. The work done by the engine also can be obtained by integrating the area enclosed by the graph.

g. The following is a typical graph of PV diagram.

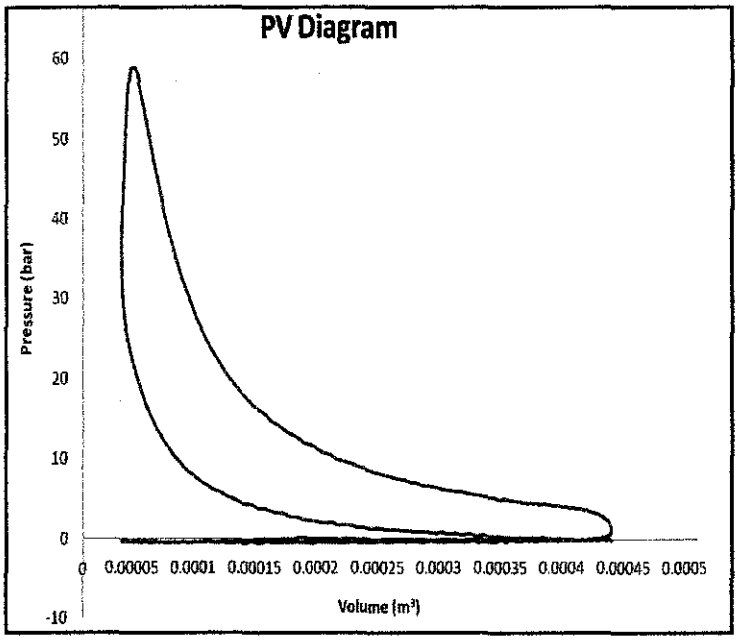
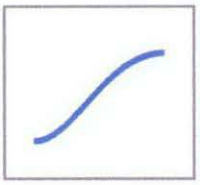
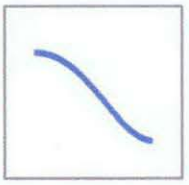
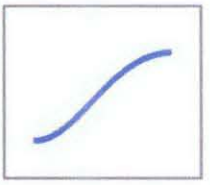
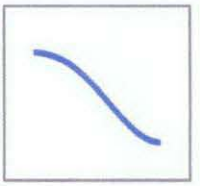
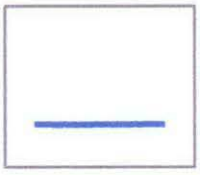
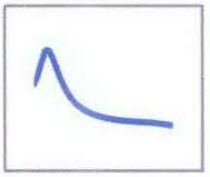
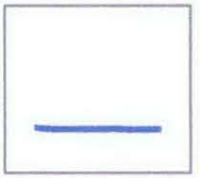
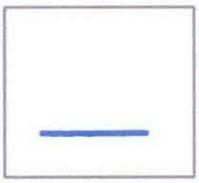
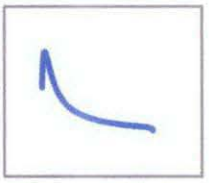
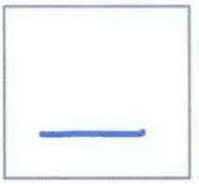


Figure 4: PV diagram

Below are cycle by cycle graphs of the important parameter for the combustion analysis.

Table 1: Cycle by Cycle Graph

	Intake Stroke	**Compression Stroke**	**Power Stroke**	**Exhaust Stroke**
Piston Movement	Downward	Upward	Downward	Upward
Corresponding Angle	0°-180°	180°-360°	360°-540°	540°-720°
Crank Angle Movement				
Volume vs. Crank Angle				
Pressure vs. Crank Angle				
PV Diagram				

2.2.2 *Combustion Analysis*

There are many performance analyses that can be done to determine the engine performance. In this project, three performance parameters will be implemented in the program:

2.2.2.1 Indicated Mean Effective Pressure, IMEP (bar)

a. IMEP is the area enclosed by the PV diagram that indicates the work done on piston by the gas or fuel.
b. It is a measure of work output per unit swept volume. It depends on size and number of cylinder and also engine speed.
c. IMEP is define as:

$$IMEP = \frac{W}{V_s} \tag{1}$$

where

W is the indicate work in Newton Meters

V_s is the swept volume per cycle in cubic meters

d. According to Brunt et al. state that error in calculating IMEP are mainly caused by thermal shock, crank angle phasing errors and transducer sensitivity. Coarse crank angle resolution, incorrect con rod length, signals noise and integration period error will produce relatively small errors. [5] Thus, the IMEP equation that can resilient to large crank angle resolution is define as:

$$IMEP = \frac{\Delta\theta}{V_s}\sum_{i=n_1}^{n_2} p(i)\cdot\frac{dV(i)}{d\theta} \tag{2}$$

where

p(i) is cylinder pressure at crank angle I in Pascals

V(i) is cylinder volume at crank angle I in cubic meters

V_s is cylinder swept volume in cubic meters

n_1 is BDC intake crank angle

n_2 is BDC at exhaust crank angle

2.2.2.2 Heat Release Rate (Joules/degree)

a. Computes how much heat would need to have been added to the cylinder contents in order to produce observed pressure variations [8]

b. Using the first law of thermodynamic, the heat release equation is:

$$\frac{dQ_{net}}{d\theta} = \frac{1}{\gamma - 1}\left(\frac{\gamma \cdot p \cdot dV}{d\theta} + \frac{V \cdot dp}{d\theta}\right) \quad (3)$$

where

γ is the ratio of specific heats

Q_{net} is the net heat release rate in Joules per degree

P is the in-cylinder pressure in Pascal

V is the in-cylinder volume in cubic meters

c. The γ (gamma) value can be obtain from the slope of log P vs. log V graph during the combustion intake (from 180° to 360°)

d. The following is a typical graph of Heat Release

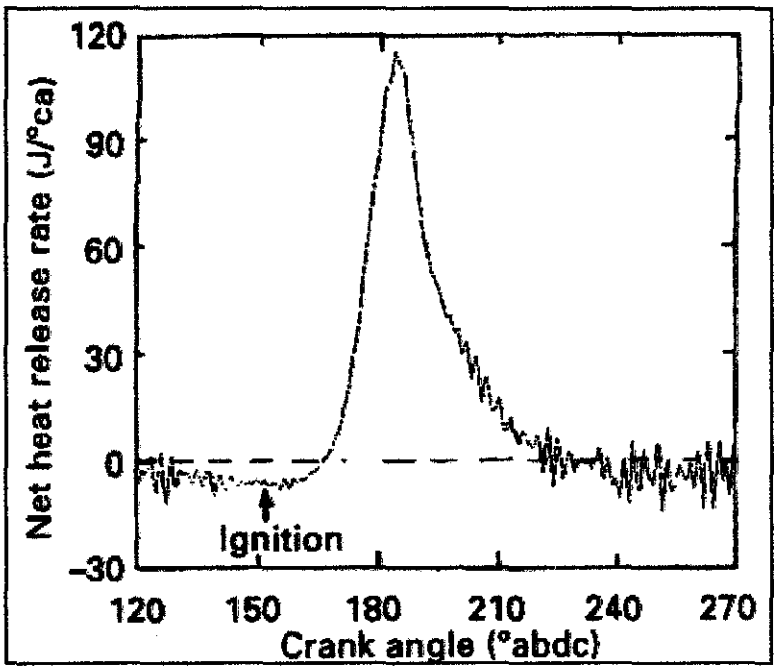


Figure 5 : Heat Release Graph

2.2.2.3 Mass Fraction Burned, MFB (%)

a. MFB is obtained by pressure sensing and ion sensing through a conventional spark plug

b. MFB concern on the change of pressure during combustion period.

c. During combustion, the pressure rise Δp during crank interval $\Delta\theta$, is due to pressure rise due to combustion, Δp_c and pressure change due to volume change, Δp_v.

$$\Delta P = \Delta P_c + \Delta P_v \tag{4}$$

d. As the crank angle change from θ_i to θ_{i+1}, the volume change from V_i to V_{i+1} and the pressure change from p_i to p_{i+1}. It is assume that the pressure change due to volume change can be compute from polytrophic process of constant. After rearranging the equation above. The equation will be as shown.

$$\Delta P_c = P_{i+1} - P_i\left(\frac{V_i}{V_{i+1}}\right)^k \tag{5}$$

e. Because the combustion does not occur at constant volume, the pressure rise rate due to combustion is not directly proportional to the mass of fuel burned. Therefore the pressure rise must be reference to a datum volume which is at TDC, V_{TDC}.

$$\Delta P_c^* = \Delta P_c\left(\frac{V_i}{V_{tdc}}\right) \tag{6}$$

f. By identifying the end of combustion and the number of crank angle interval between start and finish combustion, N, the mass fraction burned can be calculated.

$$MFB = \frac{\sum_0^i \Delta P_c^*}{\sum_0^N \Delta P_c^*} \tag{7}$$

g. The overall equation would be

$$MFB = \frac{\sum_{0}^{i}\left(p_{i+1} - p_i\left(\frac{v_i}{v_{i+1}}\right)^k\right)\bullet\left(\frac{v_i}{v_{TDC}}\right)}{\sum_{0}^{N}\left(p_{i+1} - p_i\left(\frac{v_i}{v_{i+1}}\right)^k\right)\bullet\left(\frac{v_i}{v_{TDC}}\right)} \quad (8)$$

where

N is the total number of data

i is current number of data

V_{TDC} is top dead centre volume, 360°

k is polytrophic process of constant

h. The following is a typical graph of MFB

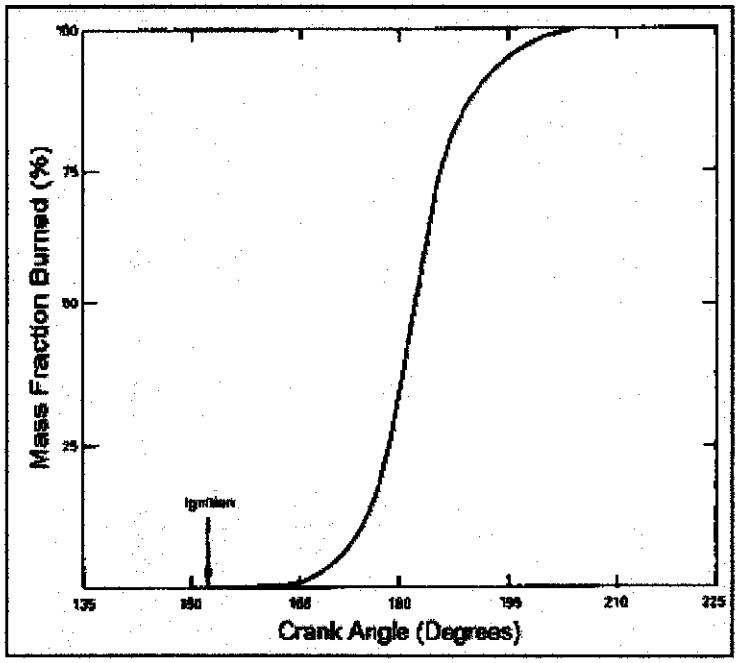


Figure 6: Mass Fraction Burned vs. Crank Angle Graph

Other than the IMEP, Heat Release and MFB, there also other performance analysis that is consider, but not implemented into the present post-processing program:

1. Power (kW)
2. Torque (Nm)
3. Air/Fuel Ratio (AFR)

2.3 LabVIEW Program

LabVIEW stands for Laboratory Visual Instrumentation Engineering Workbench. It is a software from National Instruments (NI). LabVIEW uses a graphical programming language. It is different from other programming software that uses text language such as C and Java. LabVIEW is commonly use for data acquisition, instrumentation control and industrial automation [4]. LabVIEW also can be programmed as any other programming languages. For example, if Visual Basic can create its own instant messenger program, LabVIEW can also do the same.

LabVIEW graphical programming environment has several features that allow the developer to design its own test software. Furthermore, the LabVIEW program does not need to be compiled seperately into executable in order to run the program not like other program that need to be compiled after any change is made. LabVIEW also have the library function in conventional languages that readily implemented by "point and click" to wire a block diagram to another to perform various action rather that text-based programs. [7]

LabVIEW program is called VI (virtual instrument). It consists of Front Panel and Block Diagram. Front Panel is meant for the user to use the software, while the Block Diagram is meant for the developer to modify the software. Same like other programming language, LabVIEW also can call a function. In this case, it is called subVI.

The uniqueness of this LabVIEW is it uses different color of wire for different types of data. Orange color is for real number data, pink color is for string data, green color is for boolean data and blue is for integer data. The thickness of wire indicates the array size of the data.

Below is the example of Front Panel and Block Diagram for a program called "Linear Algebra Calculator".

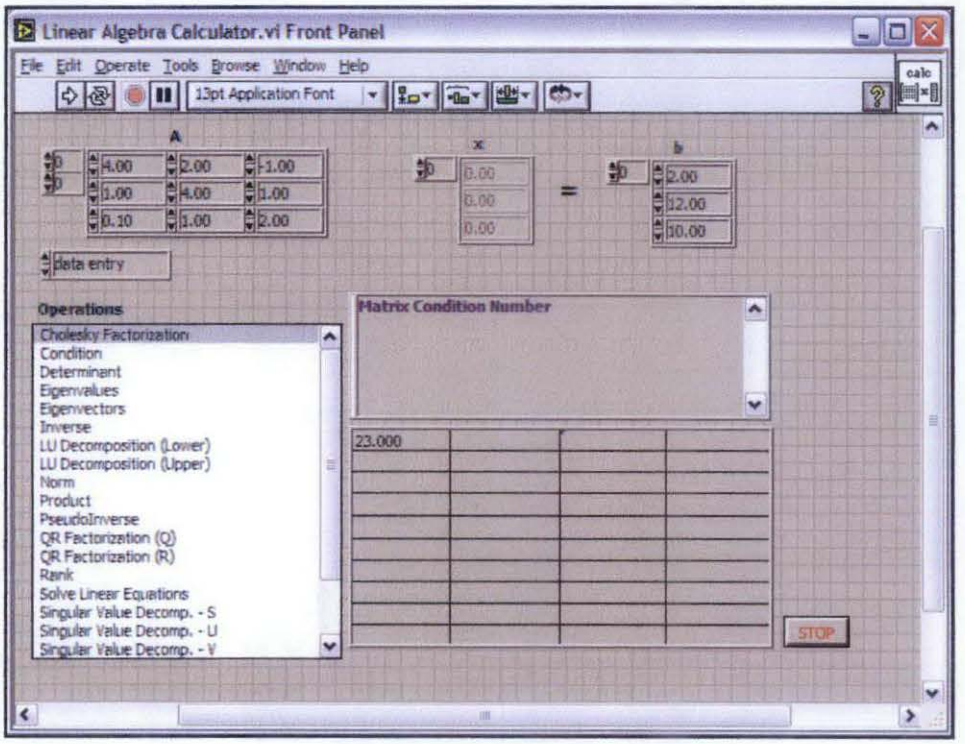


Figure 7: Front Panel

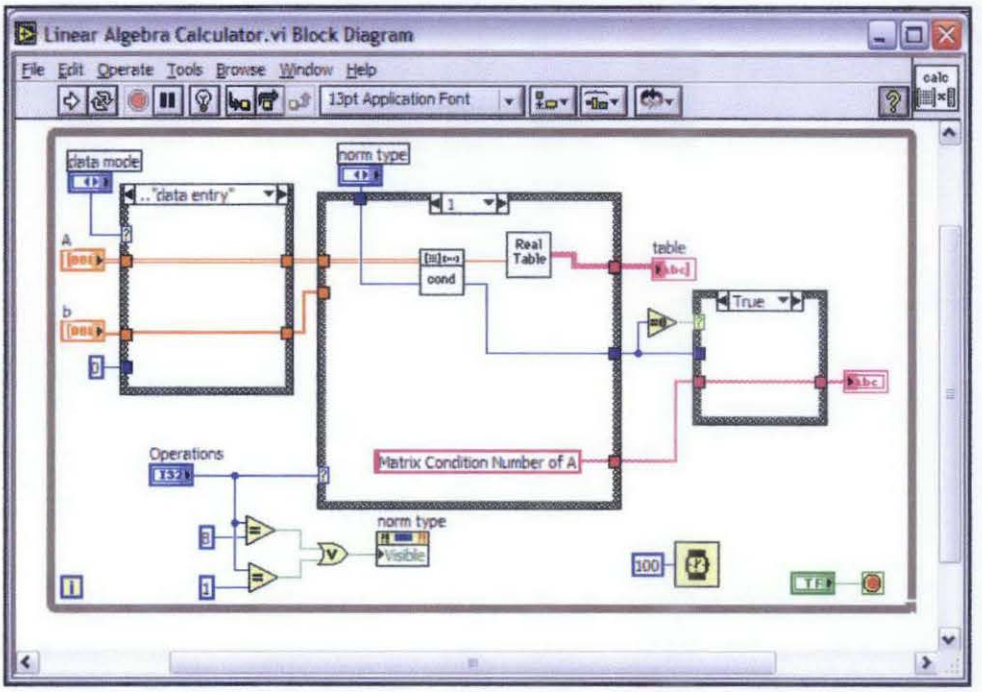


Figure 8: Block Diagram

CHAPTER 3
METHODOLOGY

3.1 Flow of Project

Below is the flow of project that I will follow:

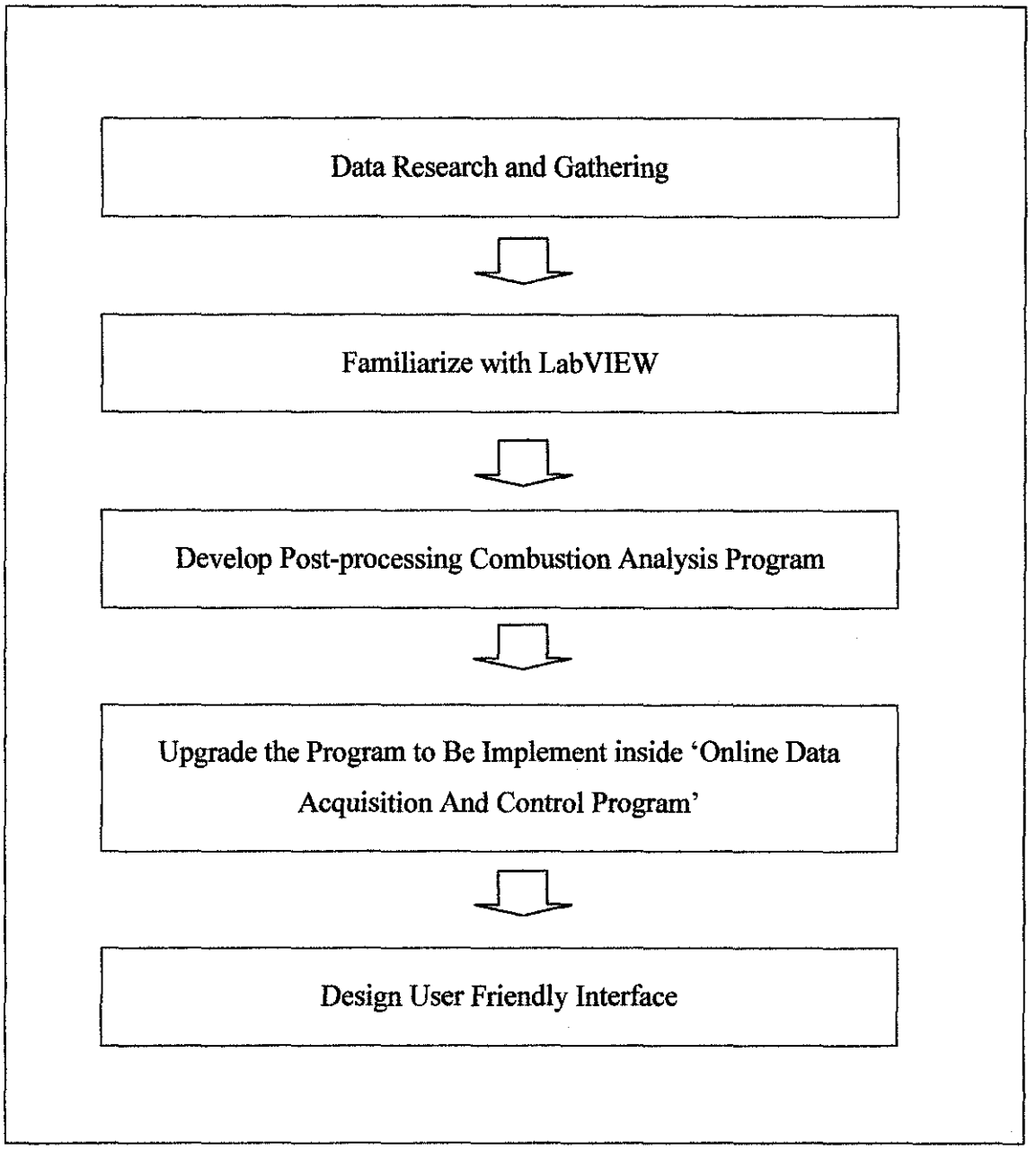


Figure 9: Flow Identification

3.2 Procedures

These are procedures to be followed in order to carry out the project. These procedures are to ensure that the project can be accomplished within the given timeframe.

3.2.1 *Data Research and Gathering*

Since this project is still new to me, I will first do some data gathering regarding the single-cylinder engine and also the test equipment that involve with the test.

3.2.2 *Familiarize with LabVIEW*

I've already been exposed with LabVIEW before during my Internship. I need to learn more regarding this software in order to develop a fast program.

3.2.3 *Develop Post-processing Combustion Analysis Program*

It is simple for me to start with the post-processing performance analysis program since it focuses on the program flow architecture only.

3.2.4 *Upgrade the Program to Be Implement inside 'Online Data Acquisition and Control Program'*

The program that I develop needs to be fast enough to be implemented inside the online data acquisition and control program.

3.2.5 *Designing User Friendly Interface*

The final step will be refining the GUI to be more users-friendly and more professional-looking. Some control buttons need to be placed to assist the user.

3.3 Tools and Equipment

In my final year project, there are no equipments or instruments are used. I only use LabVIEW 7.1 and Microsoft Excel 2007 to develop the post-processing combustion program.

LabVIEW 7.1 is necessary in my development. **Microsoft Excel 2007** is used for verification. After completing the sub-VI of the program, I verify the result using Microsoft Excel to check either the combustion analysis equation that is used in the program is correct or not.

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1 Early Development of Post-processing Combustion Analysis Program

The post-processing program that I will develop is quite different with the previous program. Below is the flow of my post-processing program. I separate my program into different blocks and develop them one by one. It eases my work since I can skip some block that I'm stuck with. I will explain in detail about the block throughout this chapter.

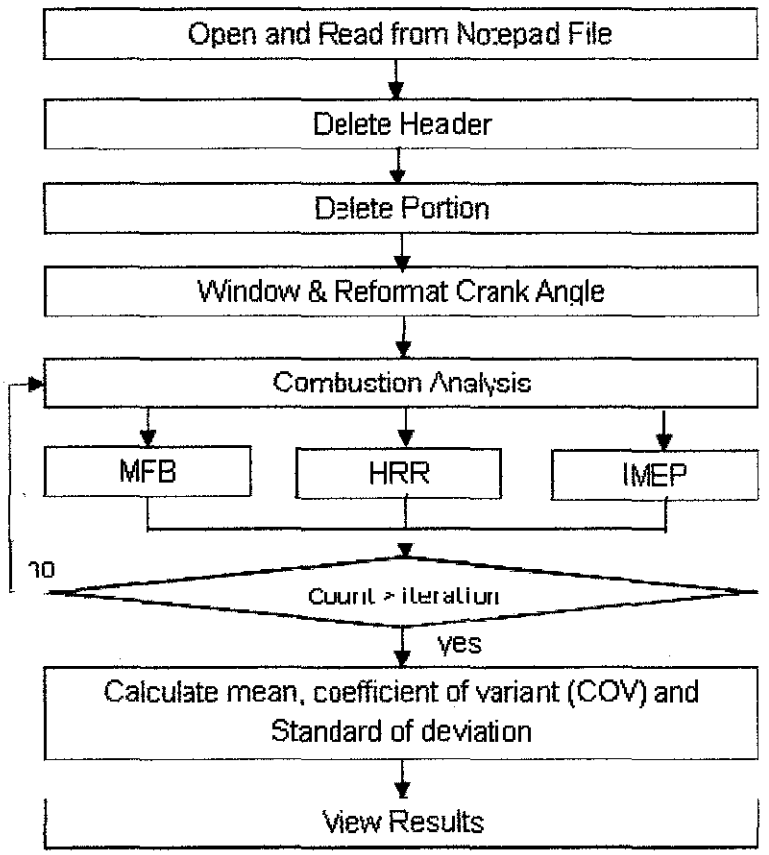


Figure 10: Flow Diagram of the Post-processing Program

4.1.1 *Initialization and Crank Angle Processing*

In this part I will only focus on the initialization of data processing. Before going into the engine performance calculation, I need to remove unnecessary things like header and incomplete early cycle.

4.1.1.1 Read from Text File Block

This block will read the text file and show the data in an array. It consists of very simple function block. It reads the spreadsheet from text file and displays the array. The input of this block diagram is the text file. We need to open the path of the text file and it will display the array of the data. The output of this block diagram is a set of array called 'raw data'.

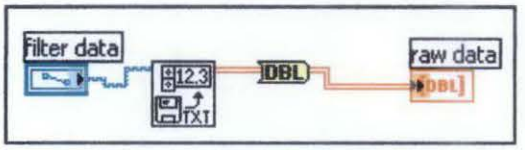


Figure 11: Read File Block

4.1.1.2 Delete Header Block

The input of this block is 'raw data' array which consists of many set of measurement. Each set of measurement contains a header and measurement. In this program, the loop iteration will access each set of measurement and delete the header for that particular set of measurement. As the iteration continues it will build the array of measurements-only until all the sets of array in 'raw data' are fully accessed. The output of this block is called 'clean data'.

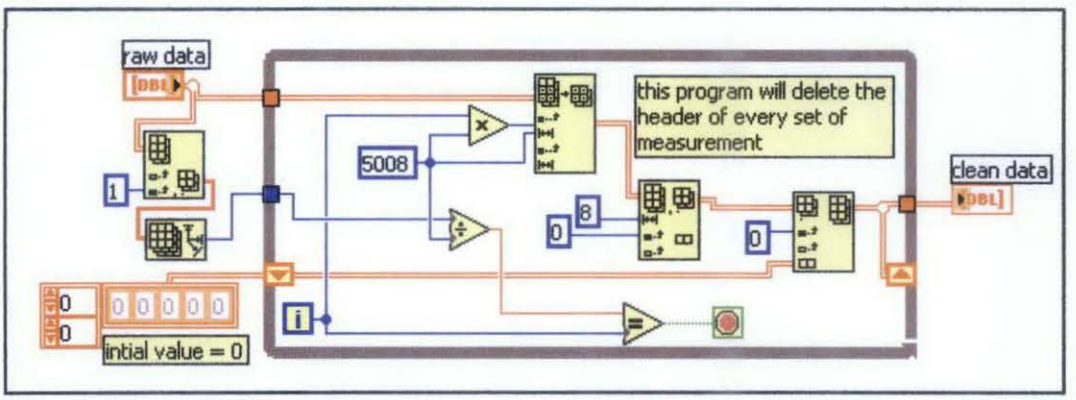


Figure 12: Delete Header Block

The raw data consists of many sets of measurements. Each set of measurements contain 5000 rows of measurement and 8 row of headers. From row 1 up to row 8 are the header, while the measurement is from row 9 up to row 5008. Below is the example of one set of data.

Table 2: Sample of Sets of Measurement Data

1					
2	Measurement	Crank Angle	Volume	Cylinder Pressure	IMEP 1
3	Units	(Deg)	(m3)	(bar)	(bar 1)
4	Date	38966.00	9/6/2006	9/6/2006	9/6/2006
5	t0 (Time)	0.47	21:34.7	21:34.7	21:34.7
6	delta t (sec)	0.00	0.0001	0.0001	1
7					
8	Time	Y[0]	Y[1]	Y[2]	Y[3]
9	21:34.7	147.50	0.000408339	-0.054931641	125685.8989
10	21:34.7	149.00	0.000410297	-0.189208984	
...	...	...	...	...	
5008	21:34.7	150.50	0.000412161	-0.177001953	

4.1.1.3 Delete Portion Block

Complete cycles consist of intake stroke, compression stroke, power stroke, and exhaust stroke. The 'clean data' contains many cycles. Since I don't know if the early measurement is a complete cycle or not, I decided to build a block to remove the early data that is incomplete cycle. The block below will access every row of data and check the condition, if the condition is met, the loop will terminate and the block will remove the incomplete cycle. It uses the loop iteration as the length of row that is needed to be deleted. The output of this block is an array of complete cycle called 'filter data'.

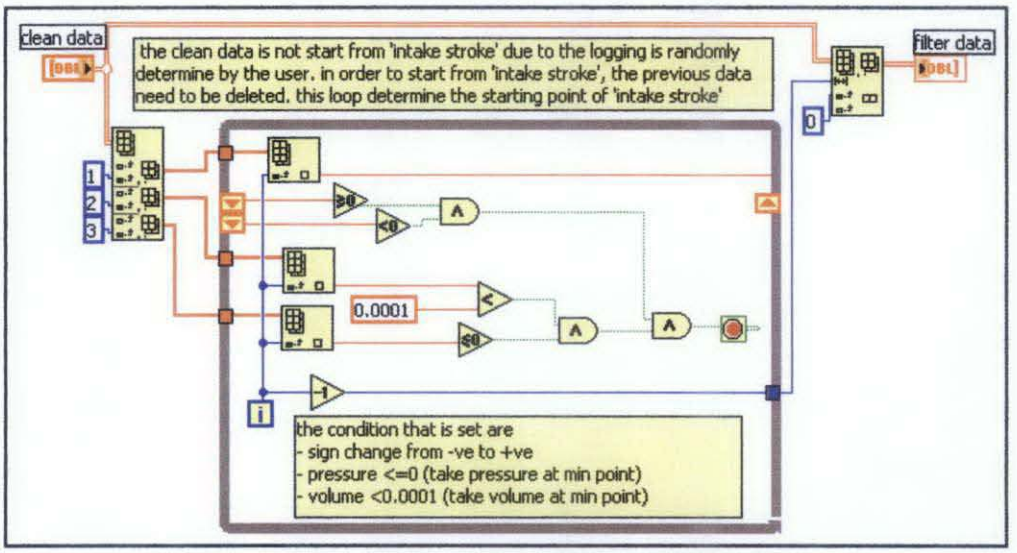


Figure 13: Delete Portion Block

Below is some of the case of incomplete cycles. The early data is incomplete cycle, and it needs to be removed. This incomplete cycle is due to data logging not at fixed initial value. In the online data acquisition and control program, the data logging is optional. The program will log data right after the user clicks the log button regardless of which cycle the measurements are in.

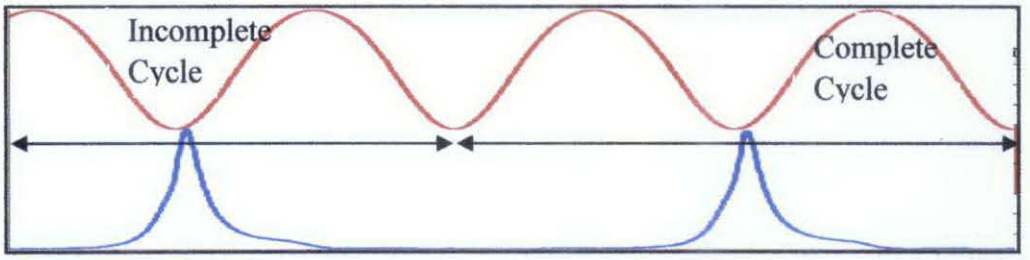


Figure 14: Incomplete Data of Early Data

In order to determine the incomplete cycle, a study regarding Otto cycle was conducted. It is found that every stroke has its own condition in term of volume, pressure and crank angle. Below is the table that determines the condition of the stroke transition. Out of the four transitions, the Exhaust to Intake Stroke is use to determine the incomplete cycle. This program will consider the first intake stroke as starting cycle and remove the data before it.

Table 3: Condition of Strokes Transition

Condition	Exhaust to Intake Stroke	Intake to Compression Stroke	Compression to Power Stroke	Power to Exhaust Stroke
Volume	>0.0001	<0.0001	>0.0001	<0.0001
Pressure	<0	>0	<0	<0
Sign Change	From positive to negative	From negative to positive	From positive to negative	From negative to positive

4.1.1.4 Chunk Stroke Block

The input of this block is 'filter data'. It will chunk data every time it detects a sign change. By doing so, it actually chunks the stroke since the sign change represents the stroke transition from one stroke to another. The output of the block is 'stroke data'. The stroke data contains the length of every stroke.

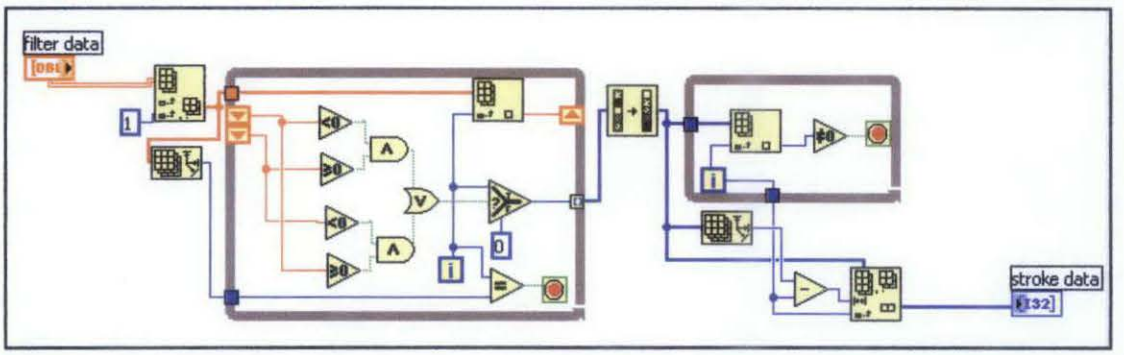


Figure 15: Chunk Stroke Block

4.1.1.5 Window Cycle and Reformat Crank Angle

The inputs of this block are 'filter data' and 'stroke data'. Using the length of each stroke in 'stroke data', the program will divide the filter data according to its corresponding stroke. Then it will reformat the crank angle in each corresponding stroke into a linear measurement. This will help in further analysis. The output of this block is 3x3 matrixes called 'Otto cycle'.

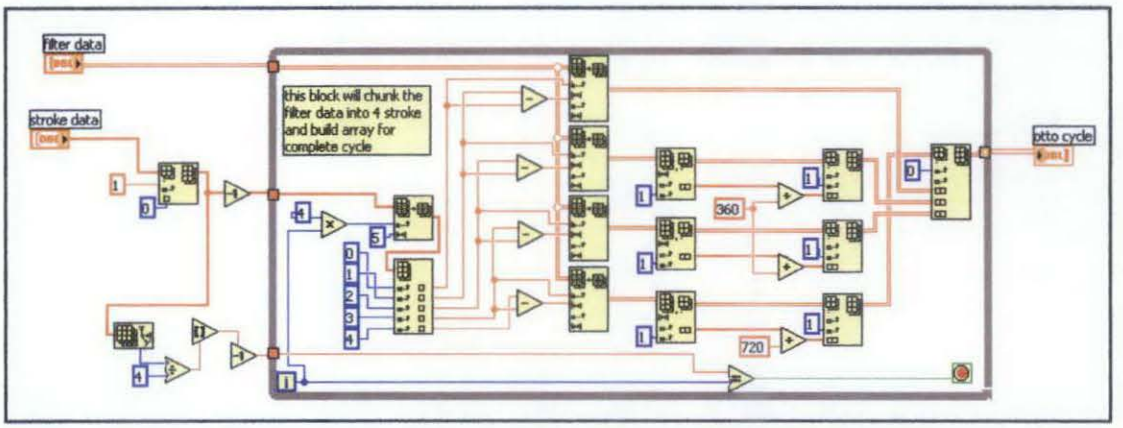


Figure 16: Window Cycle and Reformat Crank Angle Block

Below is the table that is used to reformat the crank angle. AVL Optical Encoder only captures data from 0 to 180 only. It is easier to do analysis if the crank angle is linear from 0 to 720 since most of the analyses are crank-angle based.

Table 4: Alteration of Crank Angle

Stroke	Measurement	Desired	Alteration
Intake stroke	0 – 180	0 – 180	No
Compression stroke	-180 – 0	180 – 360	Measured + 360
Power stroke	0 – 180	360 – 540	Measured + 360
Exhaust stroke	-180 – 0	540 – 720	Measured + 720

4.1.1.6 Window Certain Crank Angle

There are some blocks that need this block to help on the calculation. In calculating heat release, only the compression stroke data is needed (from 180° to 360°) to find the gamma, γ value. The block will window the data from starting angle up to final angle, and the user will determine the starting and final angle. While loop in this block will determine initial data and for loop will determine length of the data. Based on these parameters, the data can be windowed. The input is 'Otto cycle data' while the output is called 'windowed data'.

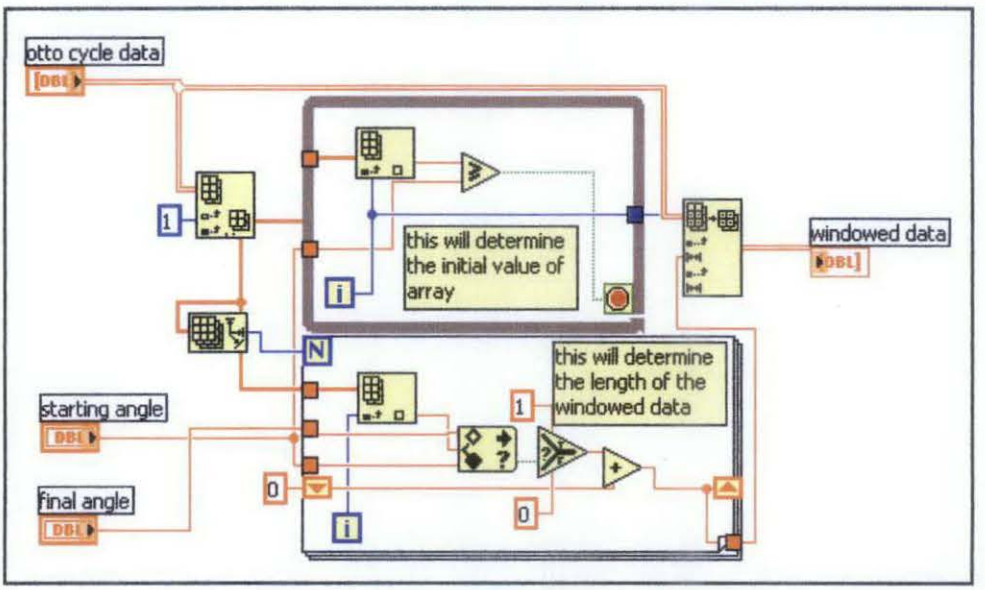


Figure 17: Window Certain Angle Block

4.1.2 ***Combustion Analysis***

At this particular part I will explain further detail regarding the combustion analyses, which are Heat Release Rate (HRR), Mass Fraction Burned (MFB) and Indicated Mean Effective Pressure (IMEP). Basically, for combustion analysis, the block diagram is quite simple. I only need to represent the combustion analysis mathematical model into the block diagram.

4.1.2.1 *MFB Calculation Block*

I used the mathematical model below to develop the block diagram. k in this model is a polytrophic constant 1.35.

$$MFB = \frac{\sum_{0}^{i}\left(p_{i+1} - p_i\left(\frac{v_i}{v_{i+1}}\right)^k\right) \bullet \left(\frac{v_i}{v_{TDC}}\right)}{\sum_{0}^{N}\left(p_{i+1} - p_i\left(\frac{v_i}{v_{i+1}}\right)^k\right) \bullet \left(\frac{v_i}{v_{TDC}}\right)} \tag{8}$$

Below is the block diagram of Mass Fraction Burned.

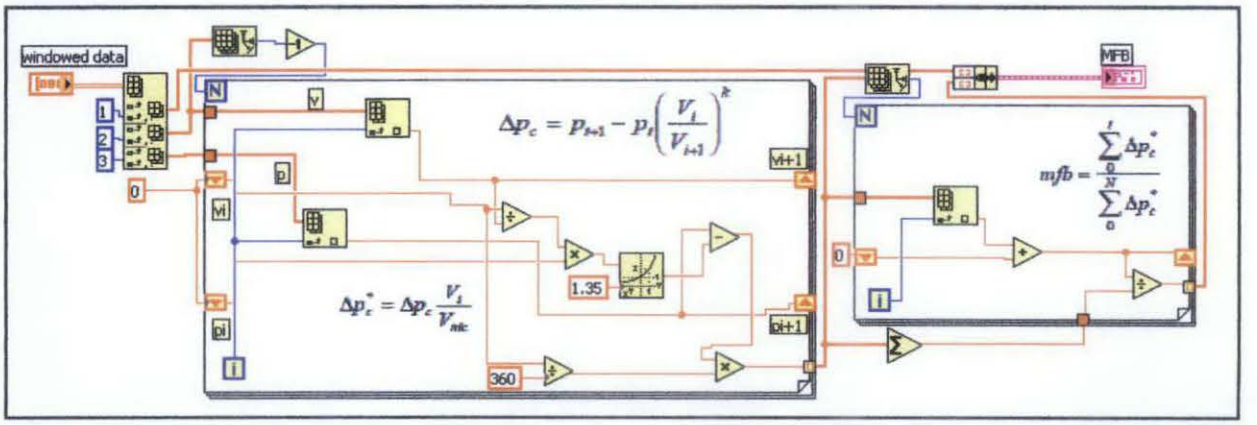


Figure 18: Mass Fraction Burned Calculation Block

Below is the output of the block diagram. Based on the output below, the shape is quite similar with the curve in my literature review.

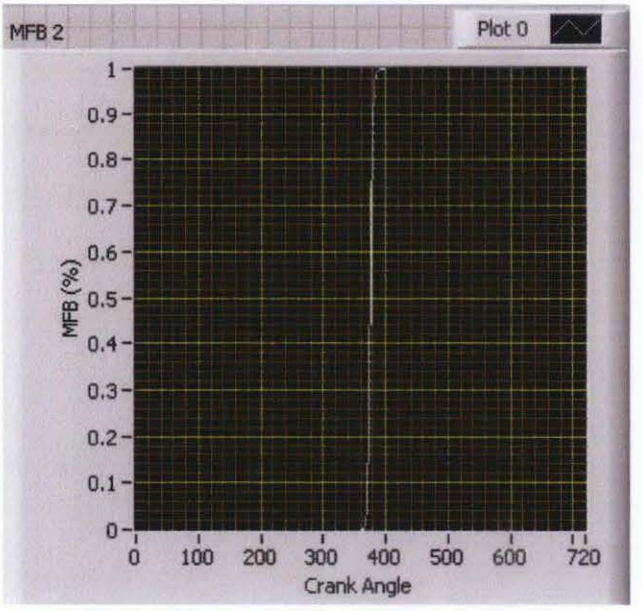


Figure 19: Mass Fraction Burned Output

4.1.2.2 Heat Release Rate (HRR) Calculation Block

Below is the mathematical model I used to develop this block diagram. the gamma value is vary depend on cycle.

$$\frac{dQ_{net}}{d\theta} = \frac{1}{\gamma - 1}\left(\frac{\gamma \cdot p \cdot dV}{d\theta} + \frac{V \cdot dp}{d\theta}\right) \tag{3}$$

Below is the block diagram to calculate gamma for each cycle. It takes the slope of log P vs. log V at the combustion stroke. Below is the block that is simplified. Instead of taking the slope, I design it so that it takes two points on the combustion stroke data and calculate the gamma. The input of this block is 'otto cycle data' while the output called 'gamma'.

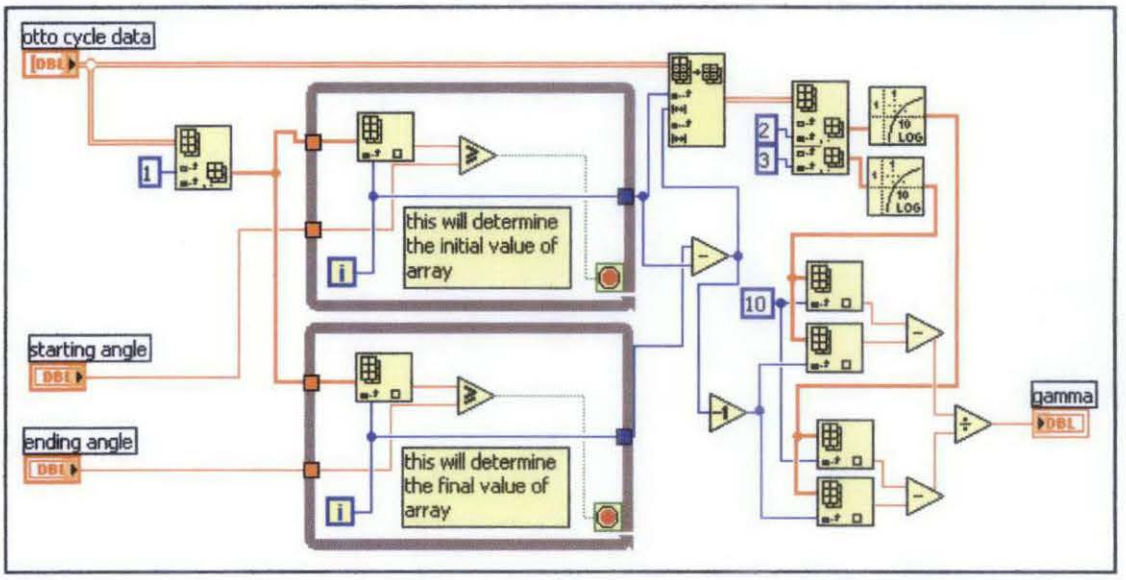


Figure 20: Gamma Calculation Block Diagram

I use the same model but with the gamma as variable.

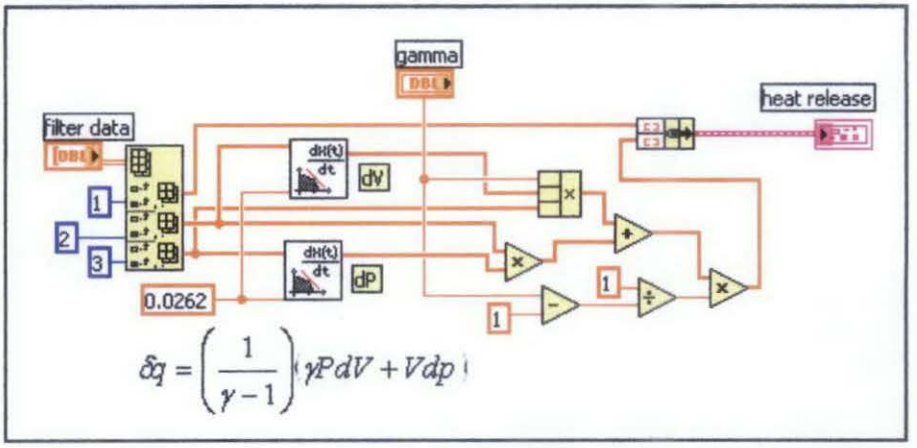


Figure 21: Heat Release Rate Calculation Block

Below is the output of the block diagram. Based on the output below, the shape is quite similar with the curve in my literature review.

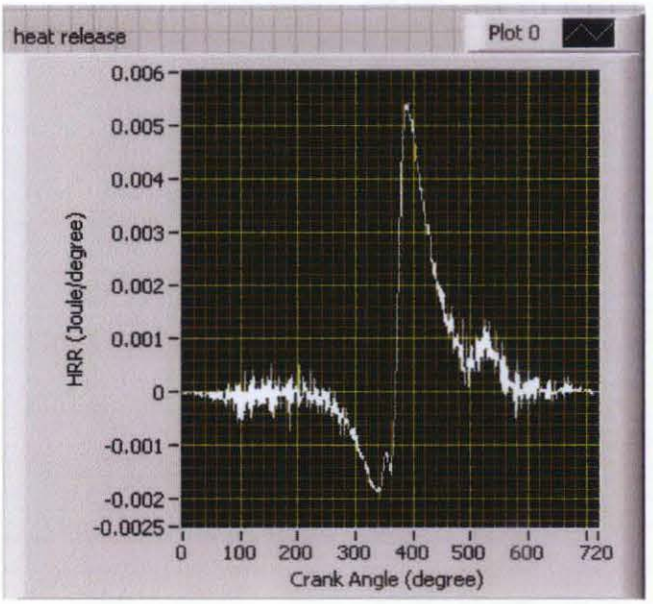


Figure 22: Heat Release Rate Output

4.1.3 *Draft Program*

After completed developing individual sub-VIs, below is the draft program that will be used for the post-processing combustion analysis. The program will do cycle by cycle analysis. But this program was not complete yet since I'm not develop the IMEP calculation block yet.

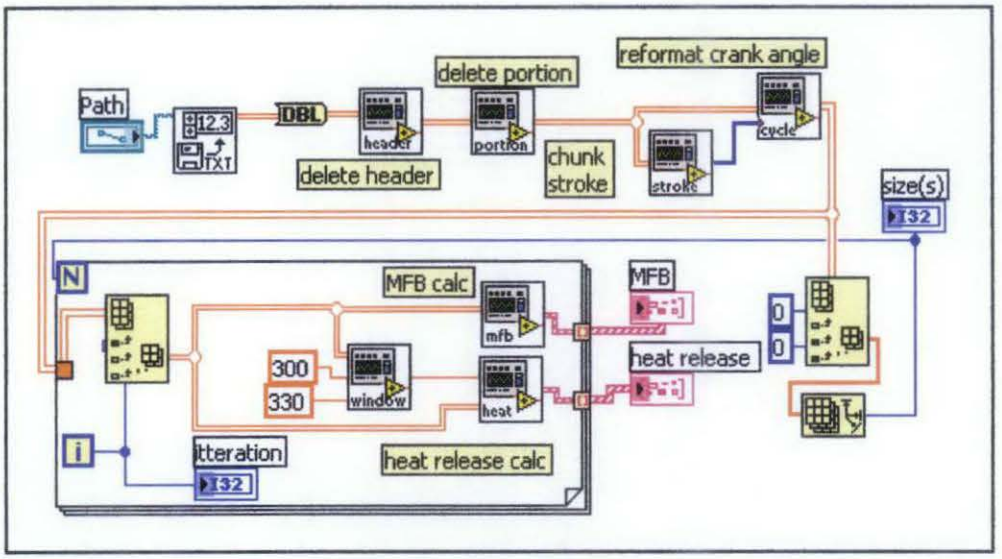


Figure 23: Draft Program for Post-processing Combustion Analysis Block Diagram

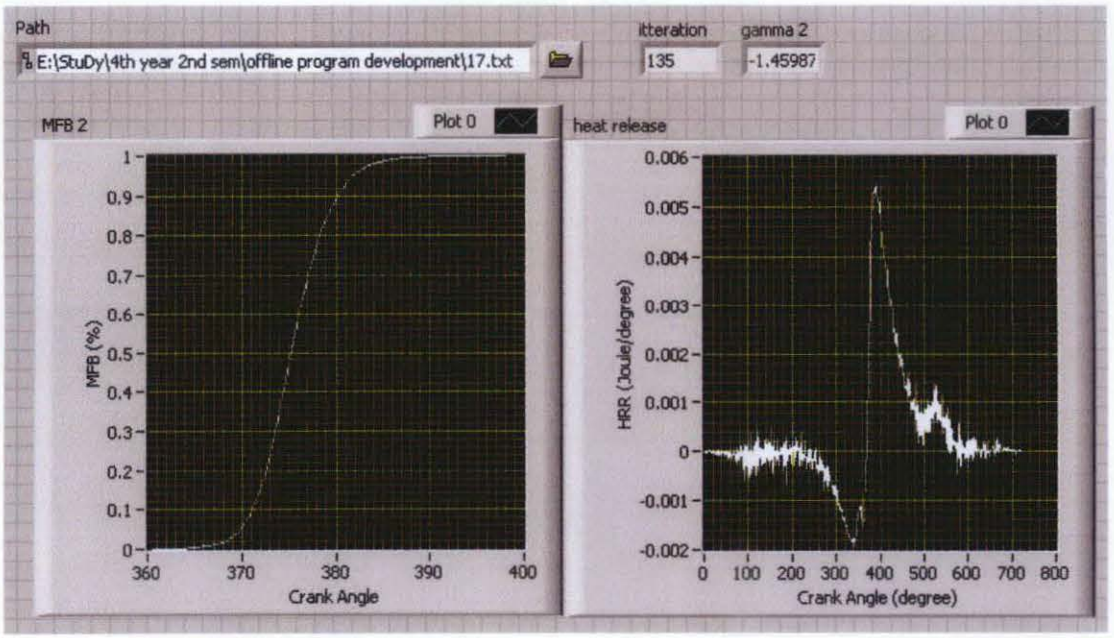


Figure 24: Draft Program for Post-processing Combustion Analysis Front Panel

4.2 Correction of Analysis

After consulting with the research engineer, Mr. Naveen, I found out that the draft program was not accurate. Below are the reasons of in accuracy of my combustion analysis program:

1. Not compensate offset pressure. There will be an offset for the pressure every time the engine is turn on.
2. Not change the unit of pressure from bar to kPa.

So a new block diagram needs to be developed. Mr. Naveen gave me a excel macro file for my guidance to develop the accurate combustion analysis.

4.2.1 *Correction in Mass Fraction Burned and Heat Release Rate Calculation Block*

Since both combustion analysis is interrelated to each other, both can be combine in a single block diagram. Below are the equations that compensate for offset pressure and pressure unit to calculate Heat Release Rate. This model use constant gamma value which is 1.33.

$$P = \left(P_{measured} - P_{offset}\right) \cdot 101.325 \tag{9}$$

$$\frac{dP_c}{dt}_i = P_i - P_{i-1} \cdot \left(\frac{V_{n-1}}{V_n}\right)^{\gamma} \tag{10}$$

$$\frac{dQ}{dt}_i = \frac{1}{\gamma - 1} \cdot \frac{V_i - V_{i-1}}{2} \cdot \frac{dP_c/dt_i}{CA_i - CA_{i-1}} \tag{11}$$

Mass Fraction Burned is the continuation of Heat Release Rate. Thus, the equation involve will use the Heat Release Rate parameter. Below are the equations that compensate the offset pressure for Mass Fraction Burned calculation.

$$\frac{dP_c}{dt}accumulate_i = \frac{dP_c}{dt}accumulate_{i-1} + \frac{dP_c}{dt}_i \tag{12}$$

$$P_{max\,rise} = \max(\frac{dP_c}{dt}accumulate_i) \tag{13}$$

$$MFB = \frac{\frac{dP_c}{dt}accumulate_i}{P_{max\,rise}} \tag{14}$$

Below is the block diagram for Heat Release Rate and Mass Fraction Burned.

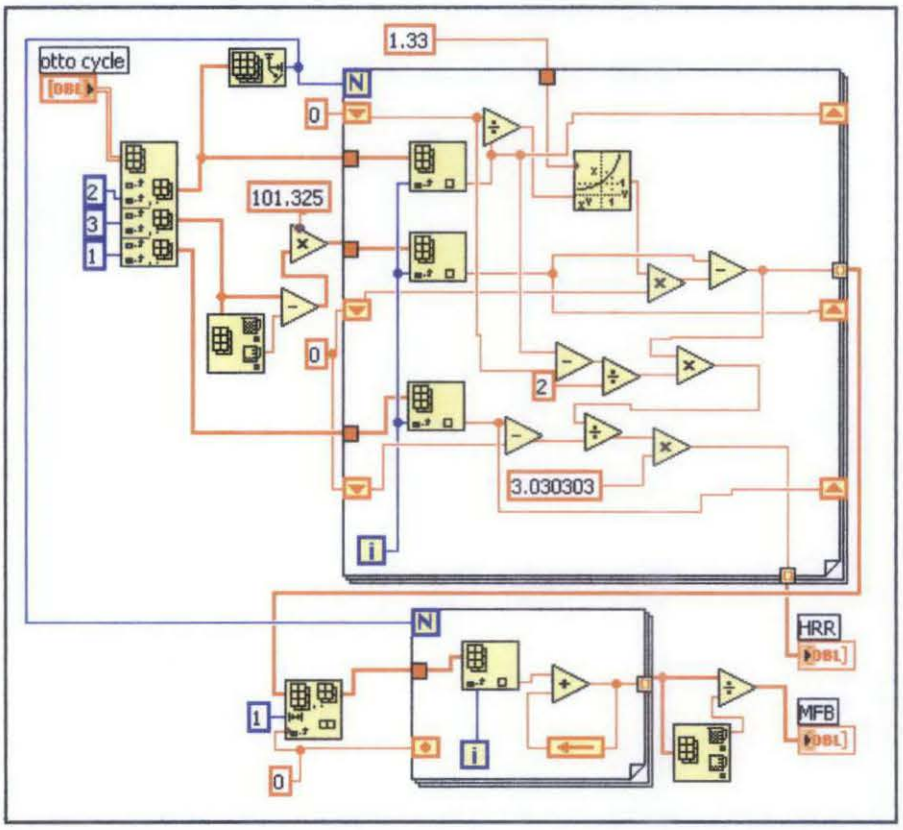


Figure 25: HRR and MFB Corrected Calculation Block

Below is output for Mass Fraction Burned.

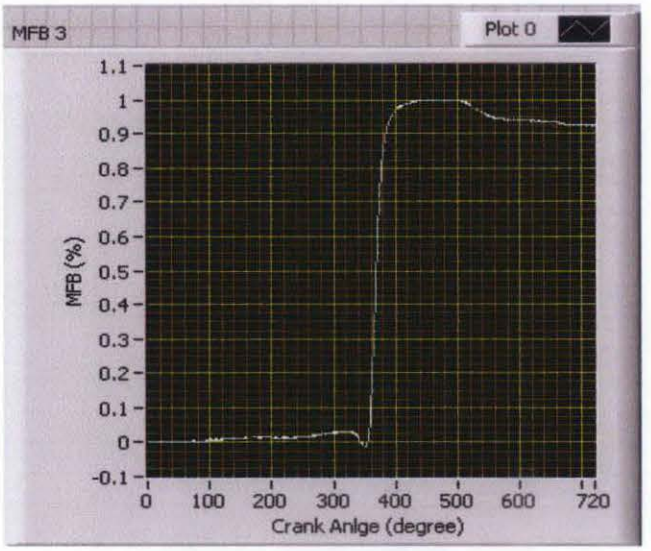


Figure 26: Mass Fraction Burned Corrected Output

Below is output for Heat Release Rate.

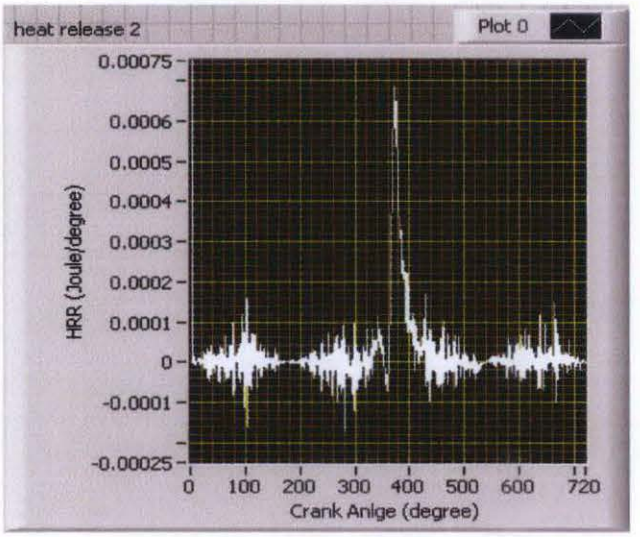


Figure 27: Heat Release Rate Corrected Output

4.2.2 *IMEP Equation*

Below is the mathematical model used to calculate IMEP.

$$P = P_{measured} - P_{offset} \tag{15}$$

$$IMEPinst_i = \frac{(V_i - V_{i-1})\left(\frac{P_i + P_{i-1}}{2}\right)}{V_{\min}} \tag{16}$$

$$IMEP = \sum_{i=0}^{N} IMEPinst_i \tag{17}$$

Below is the block diagram corresponding to the mathematical model.

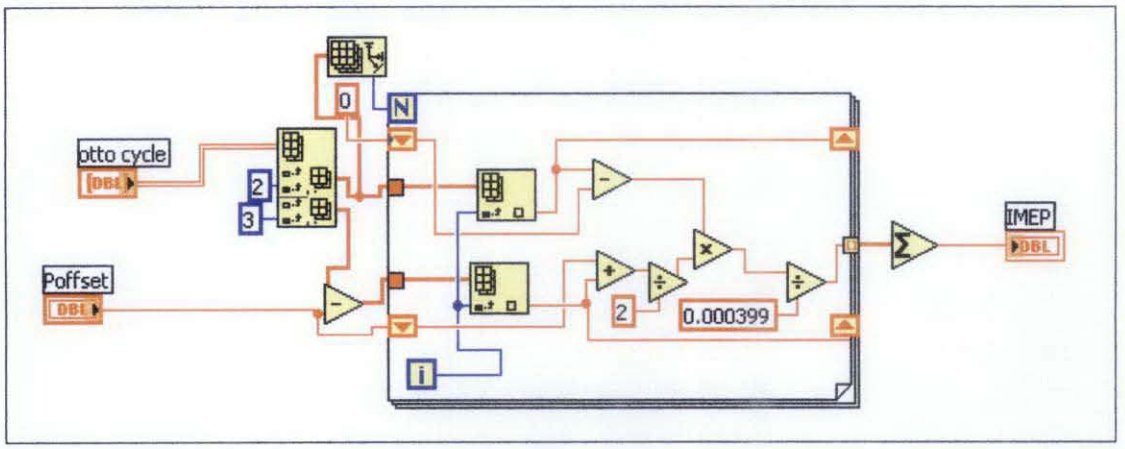


Figure 28: IMEP Block Diagram

Below is result of the program

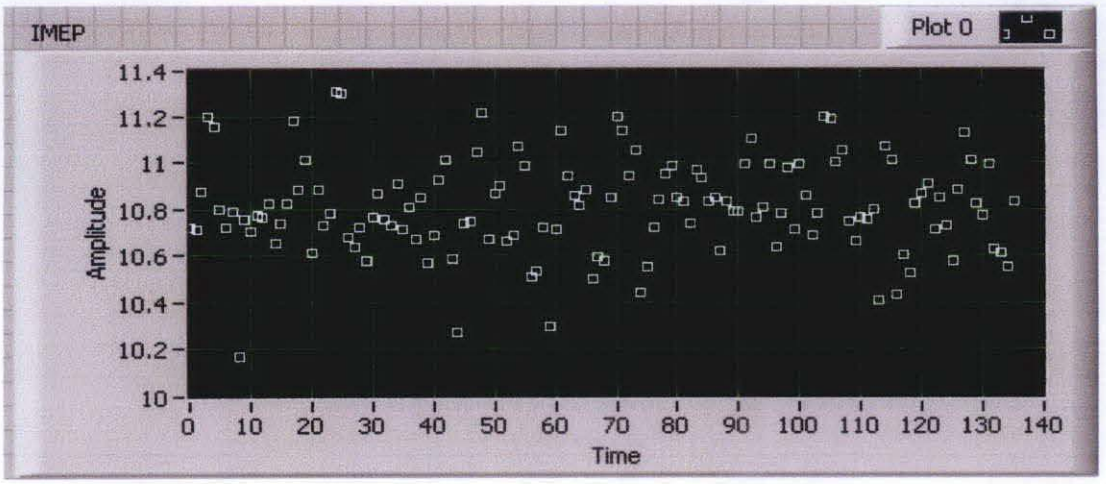


Figure 29: IMEP Output

4.2.3 *Final Program*

There is minor modification made from the draft program. Below is the final program for the post processing combustion analysis.

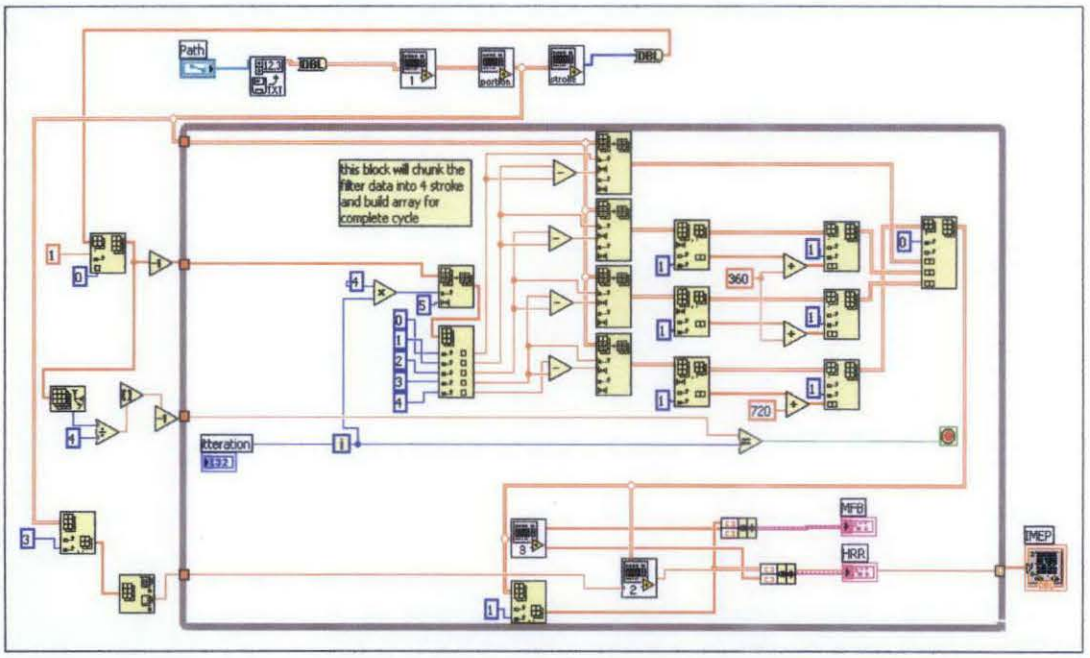


Figure 30: Final Program for Post-processing Combustion Analysis Block Diagram

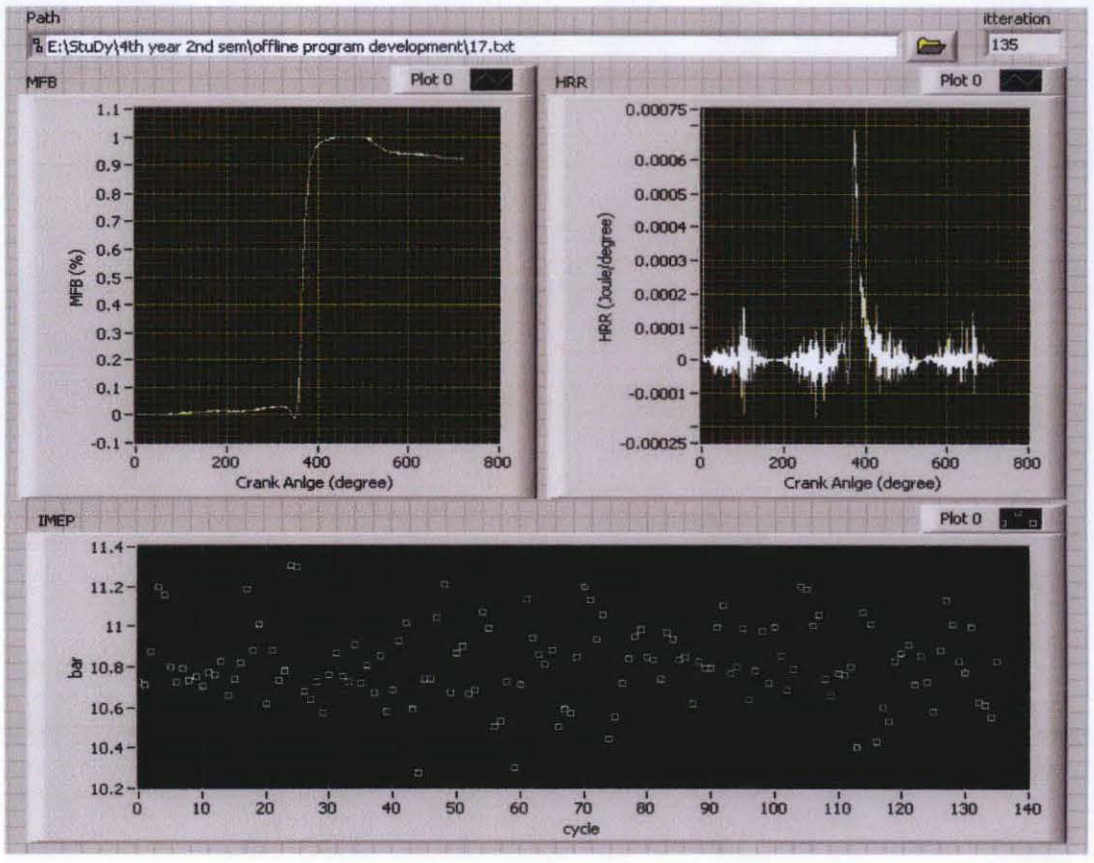


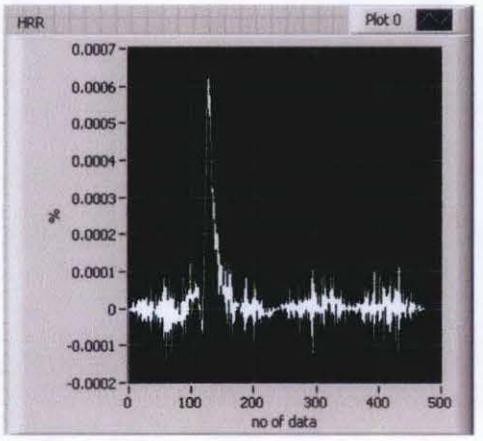
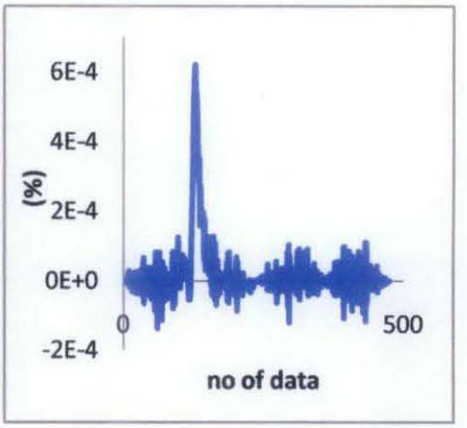
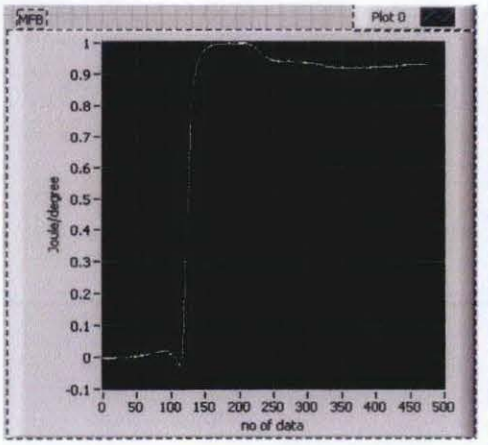
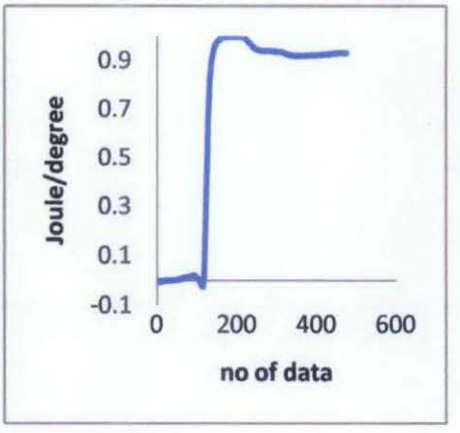
Figure 31: Final Program for Post-processing Combustion Analysis Front Panel

4.3 Verification of Program

At first, I want to compare the program output with the DEWETRON CA. But problem arises when the engine is not running due to some maintenance. Since I cannot verify it with the actual program, I compare the LabVIEW output with the Excel Macro output given by Mr. Naveen. By doing so, I'm ensuring that the program was accurate and reliable.

To compare side by side, only one complete cycle is used – much easier to compare. Below are the table of comparison between LabVIEW output and Excel Macro output.

Table 5: Comparison between LabVIEW and Macro Excel Output

	LabVIEW Output	**Macro Excel Output**
IMEP		IMEP 10.54277
HRR		
MFB		

4.4 Enhancement of Online Data Acquisition and Control Program

In order to implement inside the online data acquisition and control program, the post-processing combustion analysis must be altered a little bit. Some blocks need to be removed, some blocks need to be altered and all the blocks need to be placed in nested loop. It will be very messy and quite hard to understand the process flow. The block diagram used is nested loop where each block runs simultaneously with one another. It is very different with the post processing program which runs block by block.

Below is the draft program for online implementation. Inside the program, only combustion and power stroke are to be analyze. Intake and exhaust stroke can be neglected due to almost zero pressure. It cannot be verified yet since the engine is not running. However, this program needs to be further debug for correction. It can be further continue by other student.

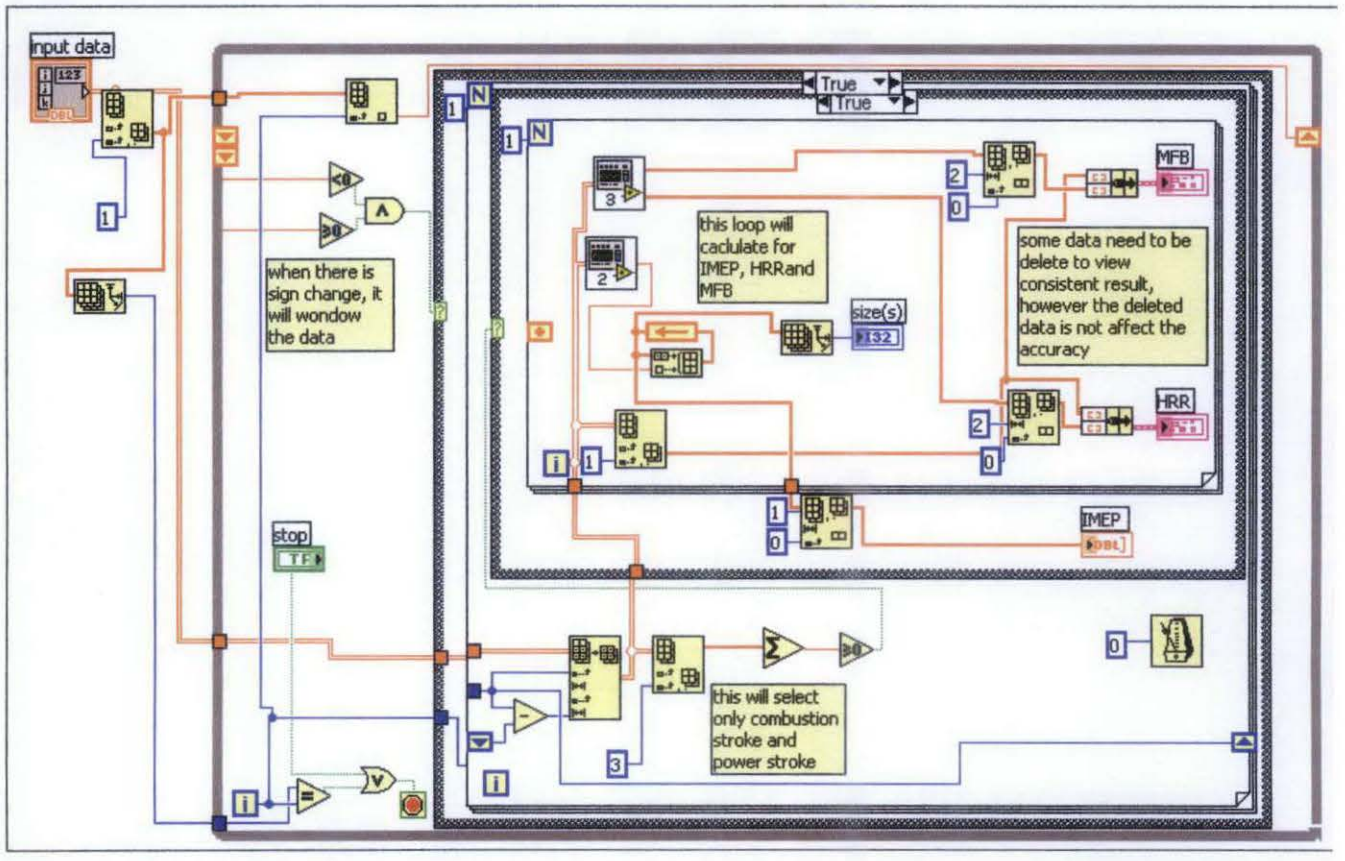


Figure 32: Draft Program for Online Implementation

4.4.1 *Program Test Time*

In order to test the time taken to complete the post-processing combustion analysis, a program called 'Timing Template (data dep).vi' from NI Example is used. This program will compute difference of time elapse. Below is the block diagram of the program.

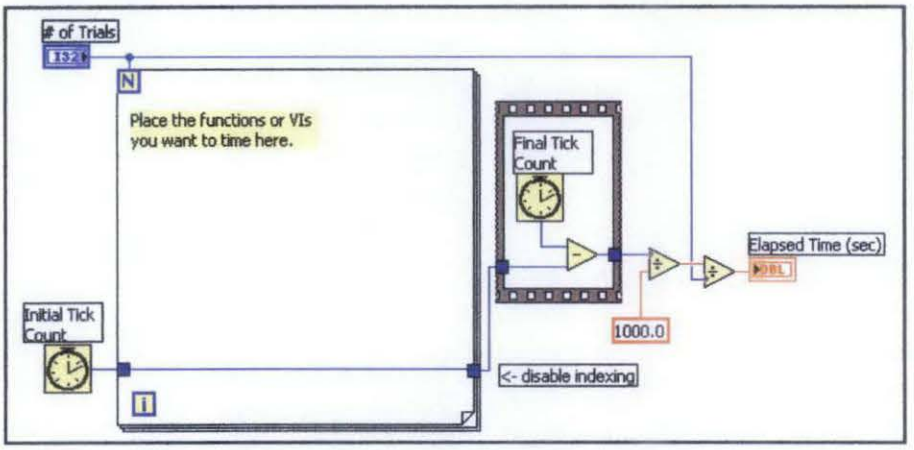


Figure 33: Timing Template (data dep).vi Block Diagram

In 'online data acquisition and control program', 10000 data we acquired from test engine for every one second. The draft program for online implementation will be injected with 10000 data instead of the original data which is 65000 data for test time purpose. Below are the results of the test.

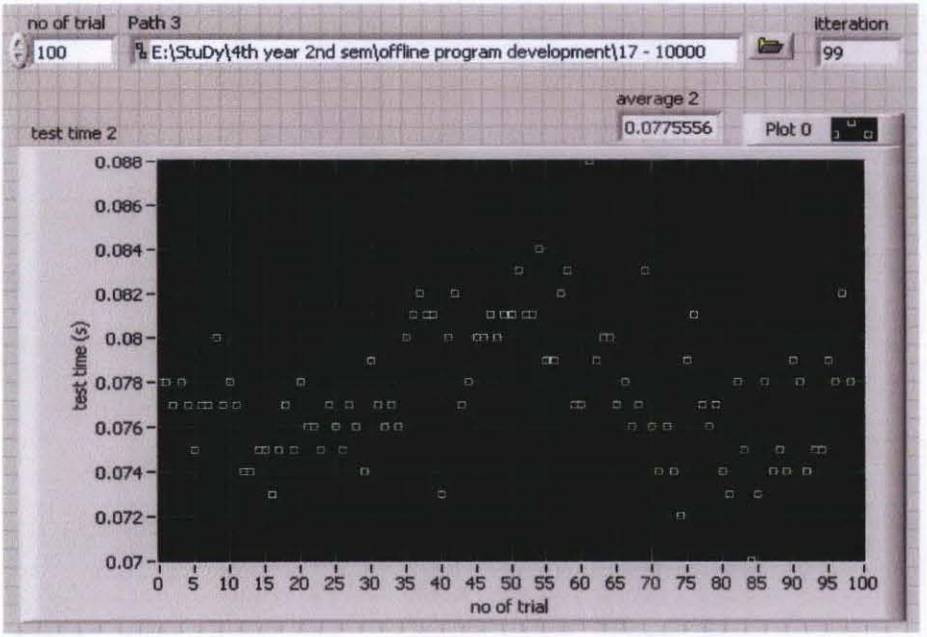


Figure 34: Time Taken to Analyze 10000 Data

Based on the result, it found out that this program can be implemented inside 'online data acquisition and control program'. After 100 trial are done, it takes averagely 0.0775556 second to complete analyze 10000 data. This is more than enough time taken to be implemented inside online program since it takes less than one second to complete analyzes 10000 data.

Further research and development need to be done to implement the program. The computer memory usage needs to be considered. High memory usage will slow down the computer and it might affect the consistency and reliability of the data acquisition. Some delay need to be place inside the program to reduce high memory usage. The delay should be just enough for the program to run but not slow down the computer performance. Many trial and error need to be conducted before it is succeed.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Overall this project was focusing on development of LabVEW based post-processing data analysis program. This program includes IMEP, MFB and HRR as the main combustion analysis parameters. Before performing combustion analysis, it will delete the unnecessary data and window the data into cycle first.

This project is still not complete yet. The future works that need to be taken care of are:

1. Validation of analysis result, by comparing the results with the results from DEWETRON CA. This is very crucial to ensure that this program is reliable enough for the combustion analysis.
2. Simulate online program – since the engine is currently not available, an input simulator is needed to determine either this program can run in an online environment or not. The simulator needs to be able to inject 10000 data for every one second without redundancy.
3. Design user friendly interface – this is necessary as it will ease the researcher's work. There are many thing need to be done to design the friendly user interface. Below are some of the criteria need to be look on:
    a. Fix number of cycle – it is necessary for comparison purpose. To compare different condition of engine, a fix number of cycle is needed for accuracy pupose.
    b. Graph view – some engineer prefer -180° to 180 ° instead of 0 ° - 720 °. They put more concern on combustion and power stroke.
    c. View average output – instead of viewing all graph for every cycle, the engineers want to see average graph for the whole cycle.

d. Save output – the average graph need to be save to be view back by the engineers.

4. Calculate average, coefficient of variant (COV) and standard deviation – to ensure that data is consistent and reliable. This is applicable for IMEP analysis.

It can be concluded that LabVIEW-based program can be used for monitoring the performance of a single-cylinder engine. It also gives flexibility to the user to revise and update program preferences.

5.2 Recommendation

After I complete this project, there is a recommendation to enhance this post-processing combustion analysis program. This program doesn't include time into the analysis. It is best if time is included as well. The researcher can check what actually happen at certain particular time if there is any shift in the analysis result.

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