DEVELOPMENT OF LIQUID SPRAY TRIGGERING AND CONTROL

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JUDUL: **DEVELOPMENT OF LIQUID SPRAY TRIGGERING AND CONTROL**

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MR. IDRIS BIN MAT SAHAT
Examiner Signature

DEVELOPMENT OF LIQUID SPRAY TRIGGERING AND CONTROL

RAJA SHARUL AZUAN BIN RAJA KAMARALZAMAN

A thesis submitted in fulfillment of the
requirements for the award of the degree of
Bachelor of Mechanical Engineering with Automotive Engineering

Faculty of Mechanical Engineering
University Malaysia Pahang

DECEMBER 2010

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Automotive Engineering.

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Date : 6 DECEMBER 2010

DEDICATION

Dedicated to my beloved

parents and friends

for their support and motivation that they gave

while working on this thesis

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In the name of Allah, the Most Benevolent, the Most Merciful. First of all, I would like to express the gratitude and appreciation to all those who gave me the possibility to complete this project. Special thanks is due to my supervisor Mr. Hj. Amirruddin B. Abdul Kadir whose help, to suggestions and encouragement helped me in all time from the concept design until finish fabrication process and in writing the report. Without his opinion and idea there could be difficult to me to complete and successful for this final year project. I also thanks to Dean Faculty of Mechanical Engineering, Prof. Dr. Rosli Bin Abu Bakar for his advice and instruction toward finish this project.

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ABSTRACT

This project presents the study about development of liquid spray triggering and control in a direct injection gasoline injector of a gasoline engine. The objectives of the study is to develop control system using a parameters of time and pressure in order to identify the spray characteristics including spray angle, spray tip penetration and spray width. The scopes of this research are choosing control system due to type of injection, setup test rig for experimental using high pressure chamber and develop control and triggering system in order to control the timing and delay of the injector. After test rig fabrication is done and all equipment has been setup, experiment is done by supplying pressure at 4 Bar from high pressure pump to fuel injector that attach to high pressure chamber. Ambient temperature was set to 300 K and ambient pressure is 0.1 Mpa. Simple triggering and control has been developing using MATLAB Simulink and the result was analyzed due to sample of calculation.

ABSTRAK

Projek ini menunjukkan kajian tentang membangunkan sistem kawalan semburan cecair dalam injektor petrol bagi enjin gasoline. Tujuan kajian ini adalah untuk membangunkan sistem kawalan dengan menggunakan parameter masa dan tekanan untuk mengenal pasti ciri-ciri semburan termasuk sudut semburan, penetrasi semburan dan lebar semburan. Ruang lingkup dalam penelitian ini adalah memilih sistem kawalan mengikut jenis injektor, menyediakan rangka ujian bagi melakukan eksperimen dengan menggunakan kebuk bertekanan tinggi dan membina sistem kawalan untuk mengawal masa dan kelewatan Injektor. Setelah fabrikasi rangka ujian dilakukan dan semua peralatan telah disediakan, eksperiman dilakukan dengan membekalkan tekanan sebanyak 4 bar dari pam bertekanan tinggi ke injektor yang terletak di kebuk tekanan tinggi. Suhu persekitaran ditetapkan untuk 300K dan tekanan diberi sebanyak 0,1Mpa. Sistem kawalan injektor dibina menggunakan aturcara MATLAB Simulink dan analisis keputusan dibandingkan dengan penyelidikan terdahulu dan contoh pengiraan.

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LIST OF ABBREVIATIONS

GDI	Gasoline Direct Injection
ECU	Electronic Control Unit
EFI	Electronic Fuel Injection
Fps	Frames Per Second

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Fuel injection control system directly affects the fuel efficiency and pollution level of automotive engines. Since 1970s, the environment pollution and energy consumption have become serious concerns associated with engine control technology. The self-tuning control technique is applied to improve the engine performance by controlling the engine speed and exhaust flow. Most fuel injection systems are for gasoline or diesel applications. With the advent of electronic fuel injection (EFI), the diesel and gasoline hardware has become similar. EFI's programmable firmware has permitted common hardware to be used with different fuels.

The fuel injection system, on the other hand, is actually quite simple. Fuel is forced under pressure, through a fuel supply line to the injectors. The control unit tells each injector when to open, and the fuel is then released into the cylinder. The fuel injector is made to atomize the fuel as it passes through, and the fuel that's under pressure helps the atomization. Each cylinder virtually receives the same amount of fuel, which means the fuel is burned more completely thus increasing fuel economy.

In addition to the fuel economy of the injectors, the computer control system also consists of several sensors that are strategically placed on the engine, that help the computer determine how much fuel to release into the cylinders.

1.2 PROBLEM STATEMENT

In most spray applications, spray characteristics, such as droplet size and distribution, are highly dependent on the specific spray nozzle used,control in the system which makes it difficult to alter them without a complete overhaul of the system. The implementation of spray control that could enable manipulation of spray behavior and parameters, as necessary, would enhance the versatility and efficiency of sprays.

1.3 PROJECT BACKGROUND

The aim of this project is to study about triggering and control system spray in a direct injection gasoline injector of a gasoline engine. Parameters like pressure and time will use to conduct the experiment.

1.4 OBJECTIVE

The objectives of the study are:

a) To study about fuel injection system.
b) To develop a triggering and control system based on time and pressure difference.

1.5 SCOPE OF WORK

There are three scopes in this study:

a) Study on fuel injection triggering and control system.
b) Setup test rig for experimental using 76mm high pressure chamber.
c) Develop simple triggering and control using MATLAB Simulink

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The purpose of this chapter is to provide a review of past research efforts related to fuel injection triggering and control system. A review of other relevant research studies is also provided. Substantial literature has been studied on injection timing and pressure. The review is organized chronologically to offer insight to how past research efforts have laid the groundwork for subsequent studies, including the present research effort. The review is detailed so that the present research effort can be properly tailored to add to the present body of literature as well as to justly the scope and direction of the present research effort. The research concludes about fuel injection system, control mechanism and spray behaviors.

2.2 FUEL INJECTION SYSTEM

A fuel injection system is designed and calibrated specifically for the types of fuel it will handle. Most fuel injection systems are for gasoline or diesel applications. With the advent of electronic fuel injection (EFI), the diesel and gasoline hardware has become similar. EFI's programmable firmware has permitted common hardware to be used with different fuels. Carburetors were the predominant method used to meter fuel on gasoline engines before the widespread use of fuel injection. A variety of injection systems have existed since the earliest usage of the internal combustion engine.

The primary difference between carburetors and fuel injection is that fuel injection atomizes the fuel by forcibly pumping it through a small nozzle under high pressure, while a carburetor relies on low pressure created by intake air rushing through it to add the fuel to the airstream.

Basic components in fuel injection system are fuel injector, high speed camera and electronic control unit (ECU) such as injector driver and digital delay generator for the signal line while other components such as fuel tank, fuel filter, high pressure pump and pressure regulator for the fuel line. In the laboratory experiment, high pressure chamber is used as a main character in order to identify spray patterns. Some of the experiment that using high speed camera can trigger with personal computer and ECU. The data gained will show in the personal computer automatically.

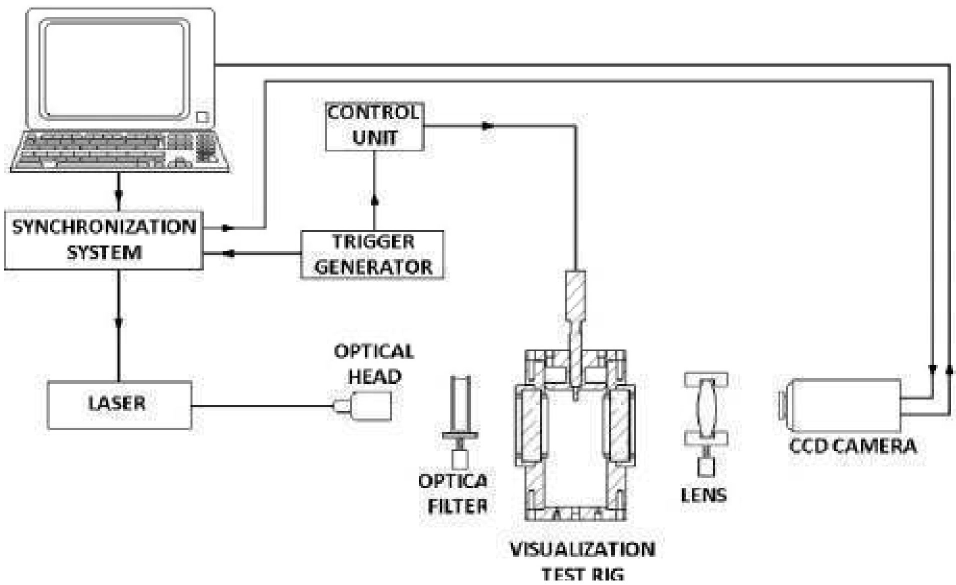

Figure 2.1: Fuel injection system

Source: J.M Desantes, 2009

2.2.1 Fuel Injector

Fuel injectors are nozzles that inject a spray of fuel into the intake air. They are normally controlled electronically, but mechanically controlled injectors, which are cam operated, also exist. A metered amount of fuel is trapped in the nozzle end of the injector, and a high pressure is applied to it, usually by a mechanical compression process of some kind. At the proper time, the nozzle is opened and fuel is sprayed into the surrounding air. The amount of fuel injected each cycle is controlled by injector pressure and time duration of injection.

An electronic fuel injector consists of the following basic components which is valve housing, magnetic plunger, solenoid coil, helical spring, fuel manifold and pintle (needle valve). When not activated, the coil spring holds the plunger against its seat, which blocks the inlet flow of fuel. When activated, the electric solenoid coil is excited, which moves the plunger and connected pintle (needle valve). This opens the needle valve and allows fluid from the manifold to be injected out the valve orifice. The valve can either be pushed opened by added pressure from the plunger or it can be opened by being connected to the plunger, which then releases the pressurized fuel. Each valve can have one or several orifice openings. In mechanically controlled injectors there is no solenoid coil and the plunger is moved by the action of a camshaft.

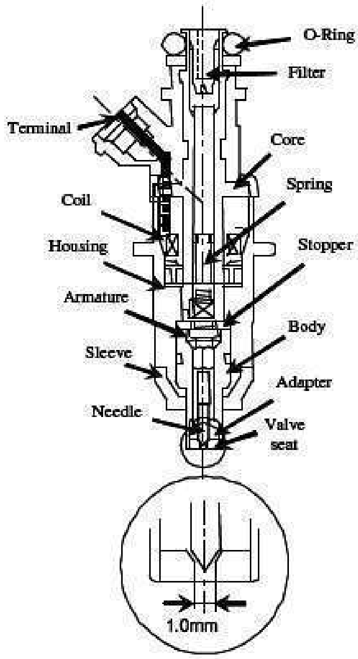

Figure 2.2 : Fuel Injector

Source: Lee, C.S 2009

2.2.2 High speed camera

In order to get different spray characteristic in term of different timing and pressure controlled by ECU, it is require a high speed camera. An example of high speed camera that mostly use is Photron, Fastcam-APX-RS. This camera provides full megapixel resolution images at frame rates up to 3,000 frames per second (fps), 512 x 512 pixels resolution at 10,000 fps and at reduced frame rates to an unrivaled frame rate of 250,000 fps.

Utilizing Photron's advanced CMOS sensor technology, the APX-RS provides the higher light sensitivity than any other comparable high-speed imaging system. Both color and monochrome models are available, both with excellent anti-blooming capabilities. A user selectable 'Region of Interest' function enables the active image area to be defined in steps of 128 pixels wide by 16 pixels high to allow the most efficient use of frame rate, image resolution and memory capacity for any event. Up to 20 commonly used configurations can be saved to memory for future operation. Available with Gigabit Ethernet, Fire wire and fiber optic communications, this compact camera can provide exposure durations as short as 2 microseconds and is easily operated in the field with or without a computer through use of the supplied remote keypad, enabling full camera setup, operation and image replay.

Figure 2.3: High speed camera

Source: Photron 2010

2.2.3 Injector driver

Injector driver modules work with the central computer system and the fuel injection system in a vehicle. Only vehicles with fuel-injection systems will use an injector driver module. Engines that need high pressure fuel injection rely on injector driver to control the fuel injection system. The main purpose of an injector driver is to control the amount and timing of fuel injection within the vehicle's system.

Fig 2.4 : Injector Driver

Source: www.thunderracing.com

2.2.4 Digital delay generator

Digital delay generator is a piece of electronic test equipment that provides precise delays for triggering, syncing, delaying and gating events. It is used in many types of experiments, controls and processes where electronic timing of a single event or multiple events to a common timing reference is needed. Similar to a pulse generator in function but with a digital delay generator the timing resolution is much finer and the delay and width jitter much less.

Figure 2.5: Digital delay generator

Source: www.highlandtechnology.com

2.3 SPRAY CHARACTERISTICS

The microscopic spray characteristic including axial spray tip penetration, spray width and spray angle are shown in figure 2.6. The spray tip penetration and spray width were defined as maximum distance from the nozzle tip of the side view spray image and maximum radial distance from the bottom view, respectively. Also the spray cone angle is defined as the interval which is formed by the nozzle tip and two straight lines wrapped with the maximum outer side of the spray. Amirruddin, A.K. (2009) says that the higher ethanol contains the spray spread faster, present longer penetration distance.

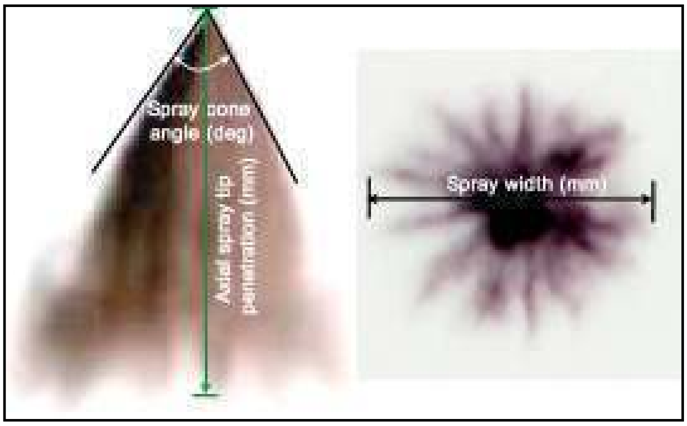

Figure 2.6: Definition of spray characteristic (sprays tip penetration, spray width and spray angle)

Source: Lee, C.S et al. 2009

An evaluation of the correlations between spray tip and function of time, indicated that the formula developed by Dent, best predict the equation :

$$S = 3.07\ (P/p)^{1/4}\ (tdn)^{1/2}\ (294/T)^{1/4} \tag{2.1}$$

Where P, pressure across the nozzle, *p*, density of fuel, t, time after start of the injection, d, diameter of nozzle and T, ambient temperature.

2.4 CIRCUIT 555 TIMER IC

The **555 Timer IC** is an integrated circuit (chip) implementing a variety of timer and multivibrator applications. The IC was designed by Hans R. Camenzind in 1970 and brought to market in 1971 by Signetics (later acquired by Philips). The original name was the SE555 (metal can)/**NE555** (plastic DIP) and the part was described as "The IC Time Machine". It has been claimed that the 555 gets its name from the three 5 kΩ resistors used in typical early implementations, but Hans Camenzind has stated that the number was arbitrary.

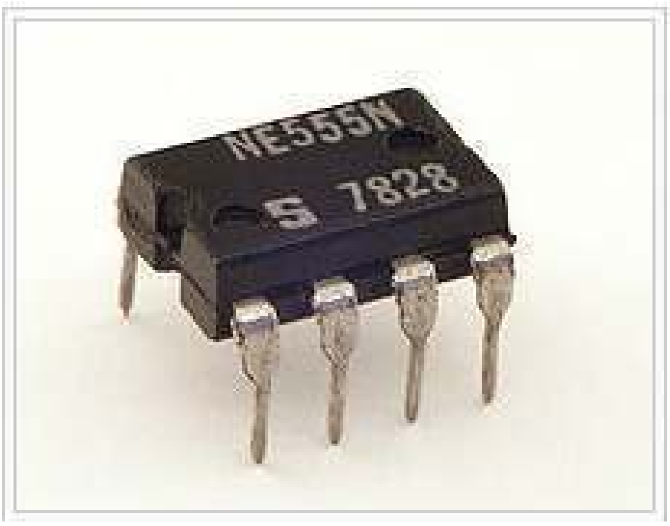

Figure 2.7: NE 555 IC

Source: Lubkin, Gloria B., Power Applications of High-Temperature Superconductors, Physics Today 49, March 1996.

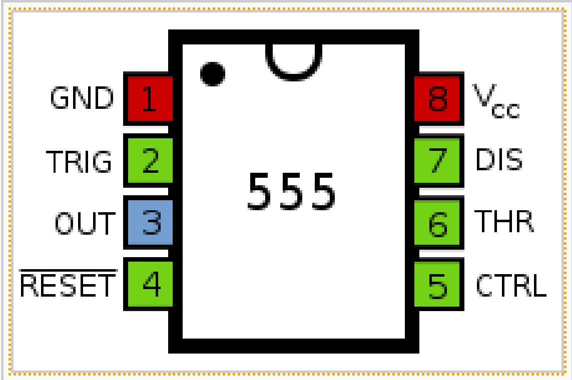

Figure 2.8: NE555 IC diagram

Source: Lubkin, Gloria B., Power Applications of High-Temperature Superconductors, Physics Today 49, March 1996.

Table 2.1: The connection of the pins

Name	**Purpose**
GND	Ground, low level (0 V)
TRIG	A short pulse high-to-low on the trigger starts the timer
OUT	During a timing interval, the output stays at $+V_{CC}$
RESET	A timing interval can be interrupted by applying a reset pulse to low (0 V)
CTRL	Control voltage allows access to the internal voltage divider (2/3 V_{CC})
THR	The threshold at which the interval ends (it ends if the voltage at THR is at least 2/3 V_{CC})
DIS	Connected to a capacitor whose discharge time will influence the timing interval
$V+$, V_C	The positive supply voltage which must be between 3 and 15 V

In astable mode, the '555 timer ' puts out a continuous stream of rectangular pulses having a specified frequency. Resistor R_1 is connected between V_{CC} and the discharge pin (pin 7) and another resistor (R_2) is connected between the discharge pin (pin 7), and the trigger (pin 2) and threshold (pin 6) pins that share a common node. Hence the capacitor is charged through R_1 and R_2, and discharged only through R_2, since pin 7 has low impedance to ground during output low intervals of the cycle, therefore discharging the capacitor.

In the astable mode, the frequency of the pulse stream depends on the values of R_1, R_2 and C: (van Roon Chapter: "Astable operation.").

$$f = \frac{1}{\ln(2).C.(R_1+2R_2\ )} \tag{2.2}$$

the high time from each pulse is given by Eq. (2.2)

$$high = ln\ (2).\ (R_1 + R_2)\ .C \tag{2.3}$$

and the low time from each pulse is given by Eq.(2.3)

$$low = ln(2)\ .\ R_2\ .\ C \tag{2.4}$$

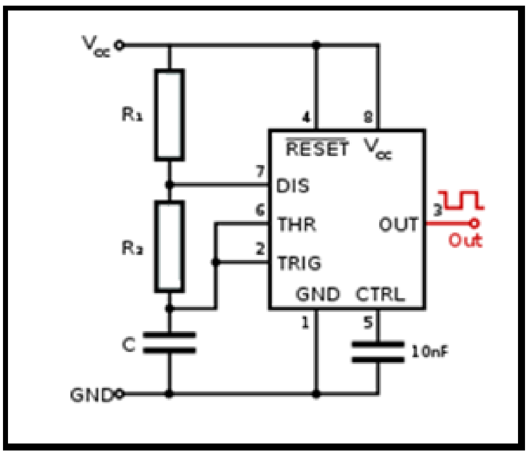

Figure 2.9: Astable Mode Circuit For NE555 IC

Source: Lubkin, Gloria B., Power Applications of High-Temperature Superconductors, Physics Today 49, March 1996.

2.5 MATLAB SIMULINK

Automotive engineers have found simulation to be a vital tool in the timely and cost-effective development of advanced control system. As a design tool, Simulink has become the standard for excellence through its flexible and accurate modeling and simulation capabilities. As a result of its open architecture, Simulink allows engineers to create custom block libraries so they can leverage each others work. By sharing a common set of tools and libraries, engineers can work together effectively within individual work groups and throughout the entire engineering department.

Simulink. Developed by MathWorks, is a commercial tools for modeling, simulating and analyzing multidomain dynamic systems. Its primary interface is a graphical block diagramming tool and a customizable set of block libraries. It offers tight integration with the rest of the MATLAB environment and can either drive MATLAB or be scripted from it. Simulink is widely used in control theory and digital signal processing for multidomain simulation and design.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

Overall this project according to the flow chart with the beginning of received the title from supervisor. Identify research background, problem statement, objective and scope are the second step for this research.

Literature reviews starts from finding books and journals related to the title as a references to study. From literature review it is enough to make a decision on how to conduct the project. It is first to determine the components to be used in the triggering and control solution for the fuel injection system.

When results are produced, develop triggering and control system according to the objectives of study and if it does not follow the objectives, the analysis is modified until the objective is achieve. Study will finish with documentation and presentation.

3.1.1 Flow chart

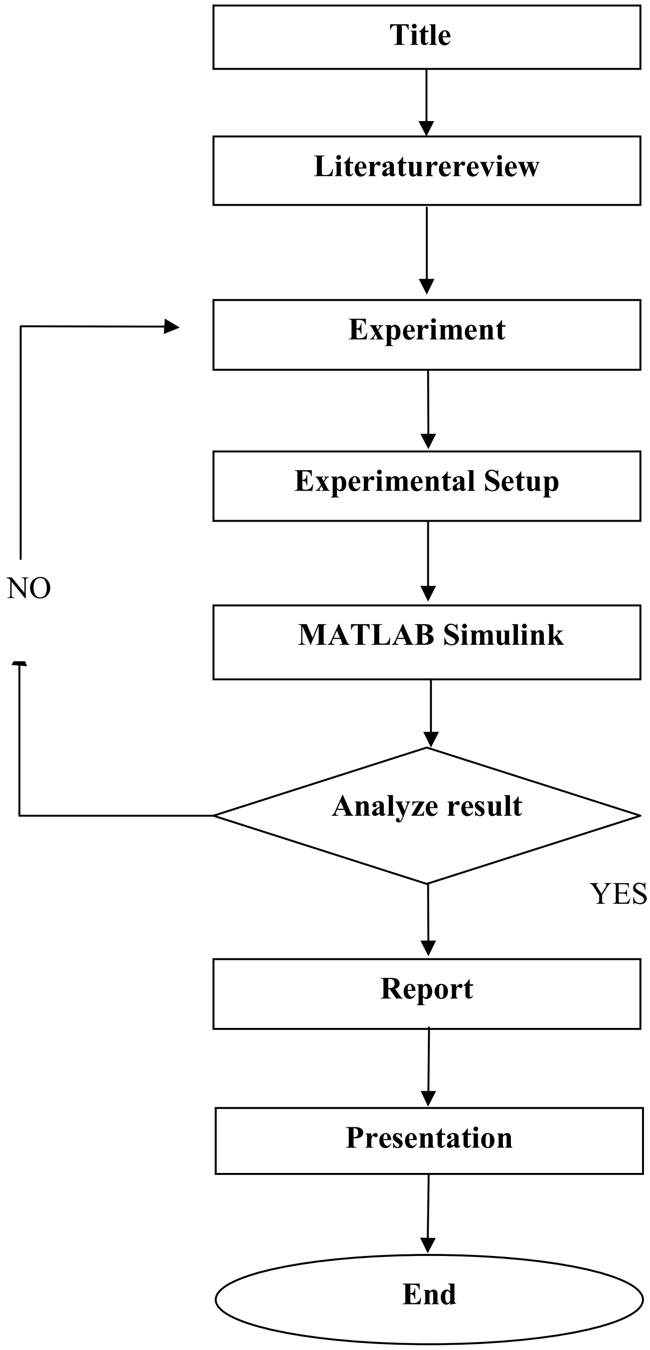

Figure 3.1: Flow chart

3.2 FUEL INJECTION SYSTEM ANALYSIS

In order to realize this fuel injection system which is based on GDI, we thought about 2 solutions.

3.2.1 Solution 1: Delphi Injection System

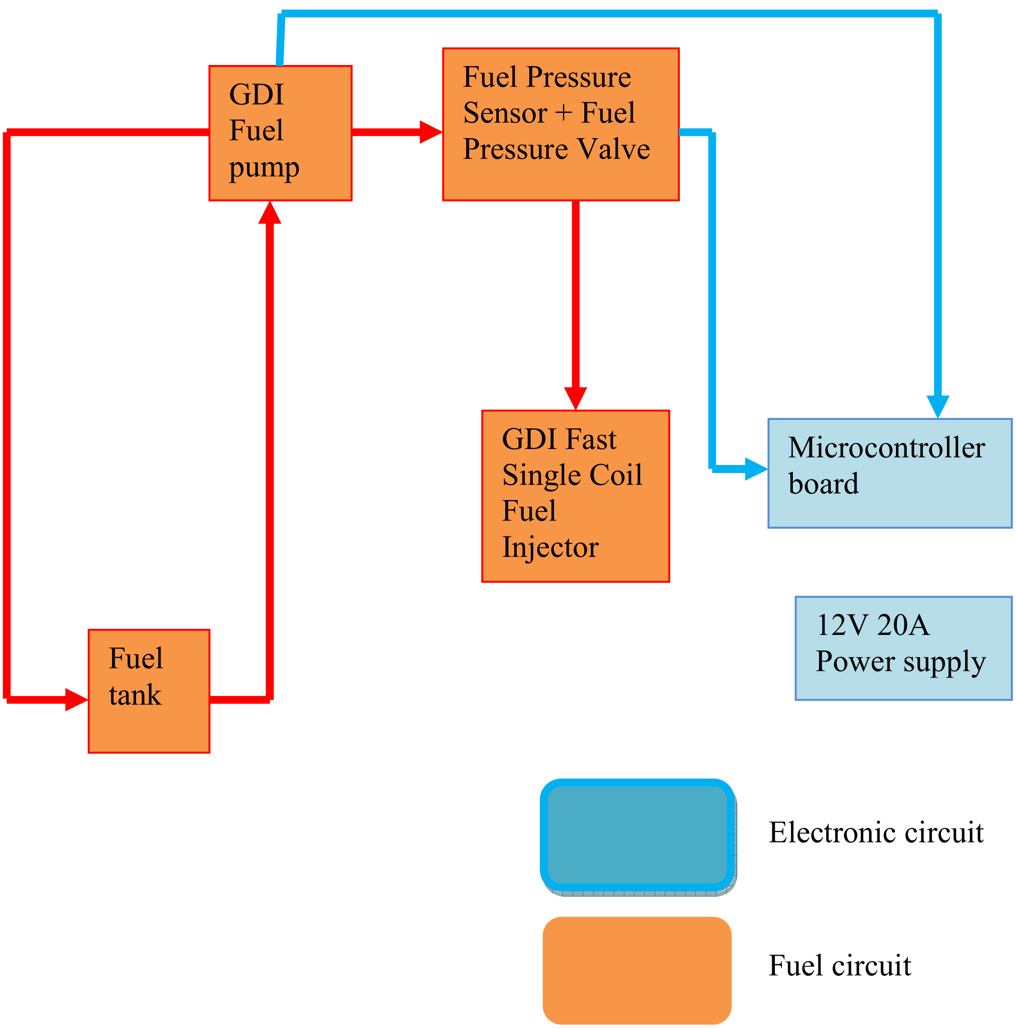

Figure 3.2: Delphi Injection System

3.2.1.1 Electronic circuit

In order to control GDI applications, we will use this system to control the injector.

a) A microcontroller
b) A power board
c) A pocket PC
d) A power supply

3.2.1.2 Fuel circuit

To realize the fuel circuit, we had to use the following parts:

a) A fuel tank
b) A GDI fuel pump
c) A fuel pressure sensor
d) A fuel pressure relief valve
e) A Fuel Injector
f) A Fuel Temperature

3.2.2 Solution 2: Bosch Injection System

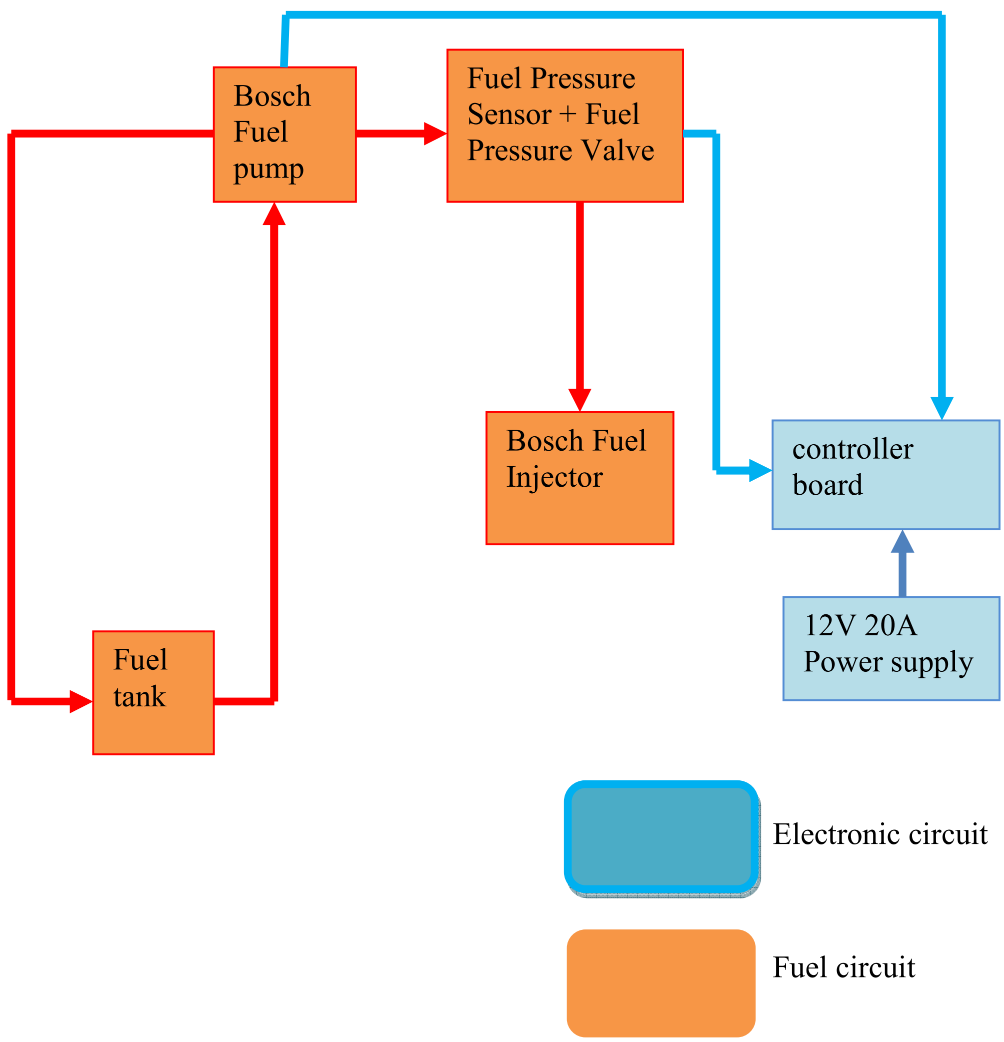

Fig 3.3: Bosch Injection System

3.2.2.1 Electronic circuit

a) A controller board
b) A power board
c) A pocket PC
d) A power supply

3.2.2.2 Fuel circuit

In order to be sure that we can get a GDI fuel pump and a GDI injector, we thought about finding these parts on an existing vehicle to find which car use GDI.

3.3 TEST RIG DEVELOPMENT

In order to setup the experiment, development of test rig has been done to locate all the equipment used. Design is proposed by using SOLIDWORK software and fabrication process have been done in laboratory. Hollow square mild steel with dimension of 50.8mm x 50.8mm and thickness of 16mm is used to fabricate the test rig. Joining process that been done is using MIG welding machine.

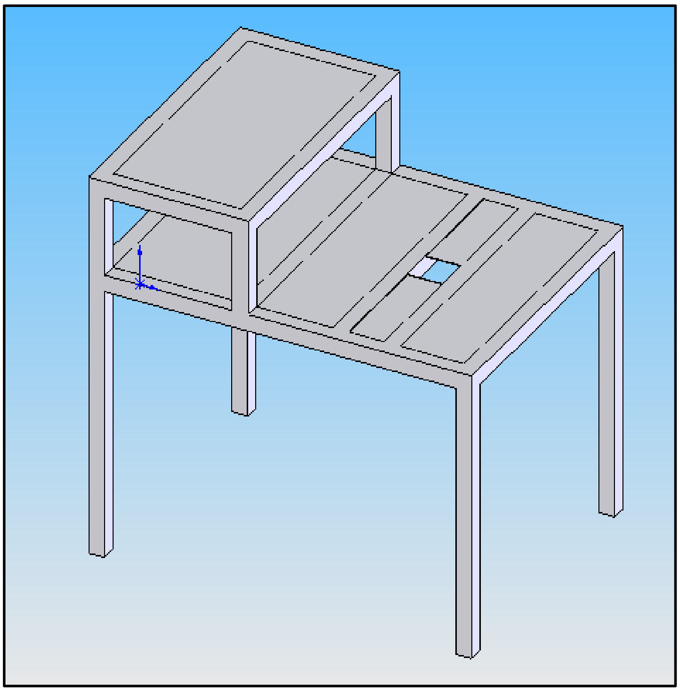

Figure 3.4: Test rig design

3.4 EXPERIMENTAL SETUP

Experimental setup for this study is decided to follow as literature review scheme of experimental setup from previous study. It consists of a high pressure chamber, a high pressure injector, a high pressure fuel supplying system, and digital camera to substitute high speed camera. The high pressure pump with approximately 4 bar supply high pressure fuel to injector from 12 liters fuel tank. Fuel pressure regulator ensures pressure in fuel rail is constant and returns any surplus fuel back to tank. The injection timing of the test injector was controlled by timer device.

Variables time and pressure control is taken to differentiate the spray patterns. To clarify the effect of ethanol fraction on the spray properties, experimental measurements have been carried out with pure ethanol, gasoline and several different ethanol–gasoline blends (E10,E25, E50 and E75), in which the number indicates the ethanol volume percentages. Spray evolution images were obtained using a digital camera (Sony Handycam).

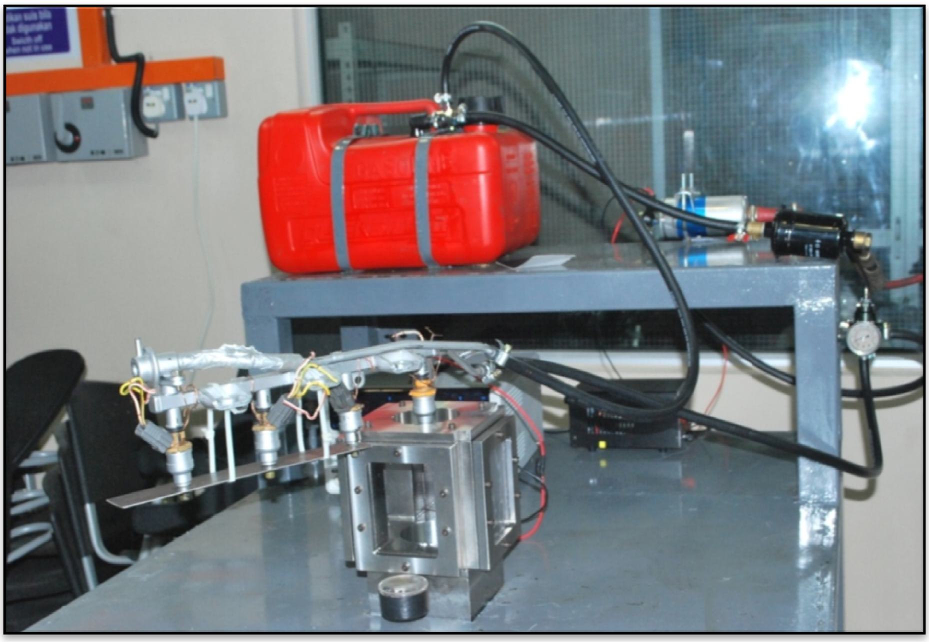

Figure 3.5 : Experiment test rig

3.5 TIMER CONTROL CIRCUIT

The circuit in figure 3.6 was design using simple electronic components such as resistor, diode, relay, capacitor, 4 pin push button and 8 pin integrated circuit that connected to 9 v power supply to control the injection timing and delay as shown in table 3.2.

The system takes the circuit as the core of its whole control system. The design idea adopts a modular design method to complete the testing tasks of the fuel injection time, the oil quantity display and the communication between circuit and injector system. The main goals of the system are to detect the parameters and control the injection. Considering technical improvement to the automatically control system, the basis of the application system is used. The system hardware connects with the external devices also as less as possible. The necessary periphery devices are the power supply A/D converter and the actuating mechanism like fuel tank, regulator, filter and high pressure pump.

When the main power supply turns on the switch on time, the fuel injection pump injects oil once, and the timer begins to count oil quantity using the output of the circuit. The relay is released to turn off the electromagnet, when the fuel injection time is equal to the preset value. Then the oil baffle is pulled out to prevent the fuel injection from overflow. The testing system is in the oil cut-off state. Now the oil capacity in the measuring chamber is the fuel injection gross of the given fuel injection time.

The fuel injection control system based on the design circuit is proposed for the injection automatic testing system. The experiments for the new testing system demonstrate that the measurement precision is improved and it is convenient to operate and repair.

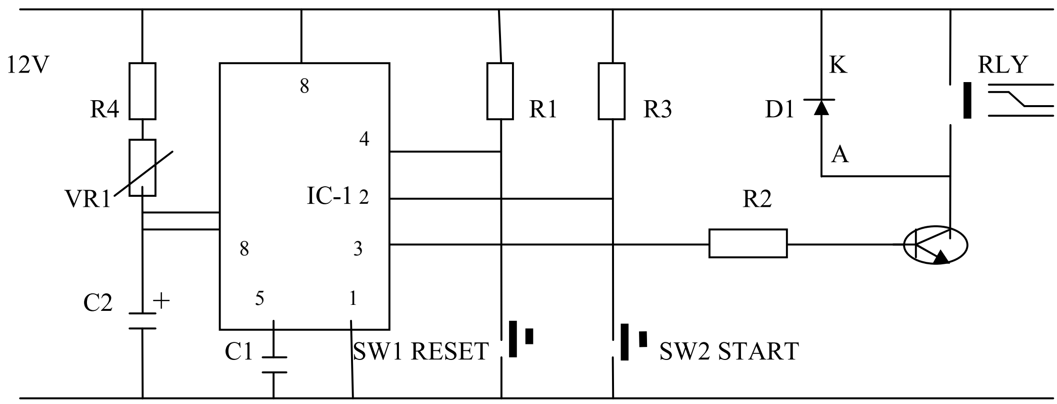

Figure 3.6: Timer control circuit

Table 3.1: Electronic part specification in the circuit

Component	Value	Unit
IC 555	8	pin
Resistor (R1)	22	k
Resistor (R2)	1	k
Resistor (R3)	22	k
Resistor (R4)	1	k
Capacitor C(1)	0.1	F
Capacitor (C2)	100	F
Relay	6	vdc
Preset Potentiometer Resistor (VR 1)	10	k

Table 3.2: Injector timing and delay

Specification		Time (ms)		
Spray time	10	20	30	40
Delay time	20	20	20	20

Table 3.2 shows that timing for injector spray and delay time. Sequence is repeated for the experiment to control the injector in order to get the spray characteristic. The time and delay purpose to easier in video image capturing. Each time given the different spray behaviors of the spray penetration, cone angle and droplet size.

Table 3.3: Data of time and pressure control

Pressure (Mpa)	Time (ms)			
0.2	10	20	30	40
0.3	10	20	30	40
0.4	10	20	30	40

Table 3.2 shows the control measurement of fuel injection in order to identify the spray behaviors such as tip penetration of spray due to time and pressure given. The injection time duration is controlled by timer control device while pressure change controlled by pressure regulator.

3.6 SIMULATION

The simulation of simple triggering and control for the injection were simulated using MATLAB Simulink. To gain the result of the controller, the step input with the value of 1000 were transferred to the block parameter. Math function is used to transfer the equation of spray tip as a block parameter. Ramp graph is added in order to get the same graph as shown in chapter 2.

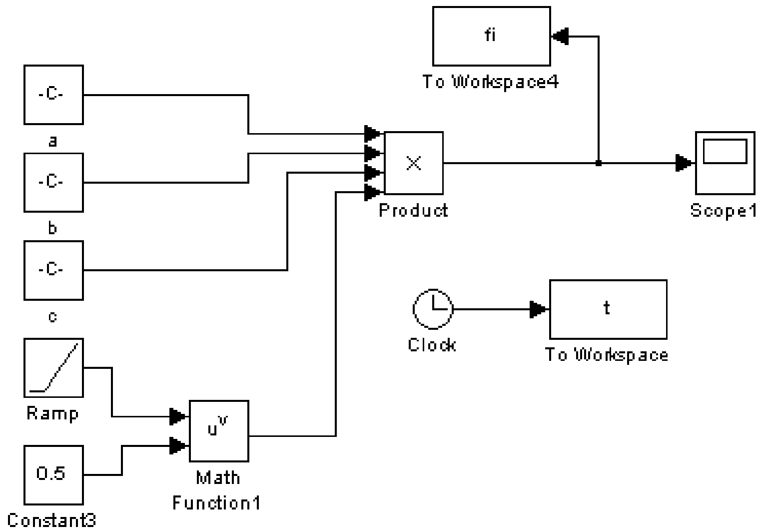

Figure 3.7: Diagram of control simulation

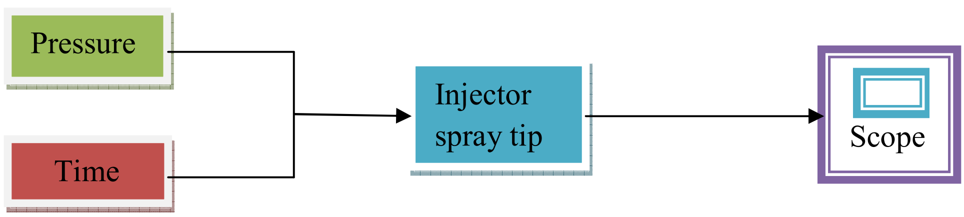

Figure 3.8 : Block parameters of control

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter concludes about the result gained from the experiment and some discussion made from analysis of the result. Simulation for triggering and control has been done and compare with the sample calculation.

To accomplish this task, fuel is usually drawn from the fuel tank by a supply pump, forced through a filter and pressure regulator to the injection pump. The injection pump sends fuel under pressure to the nozzle pipes which carry fuel to the injector nozzles. Excess fuel goes back to the fuel tank. The spray behaviors that occur in the experiment such as spray penetration, cone angle and droplet size distribution depends on the control system of time and pressure given.

In order to conduct the experiment, time range between 10 ms – 40 ms and pressure range between 2 bar – 4 bar are used. It was controlled by a timer control circuit. The image of the sprays gained then captured using the camera. Simple triggering and control using MATLAB Simulink have been developing to show the response of control system. Sample calculation of spray penetration is done by using the mathematic equation. It is useful to develop control systems which have the parameters of time and pressure.

4.2 SIMULATION RESULT

Based on the equation of injector spray tip in chapter 2, the simulations have been done for the triggering and control in MATLAB Simulink. Parameters of pressure and time are used to get the result. The simulation was excited by a step input with the height of 0.1 m at t= 0 sec. From the simulation, three graphs are produced. Figure 4.1, 4.2 and 4.3 show the response of injector spray tip in different pressure. X-axis shows the time while Y-axis shows the spray tip penetration.

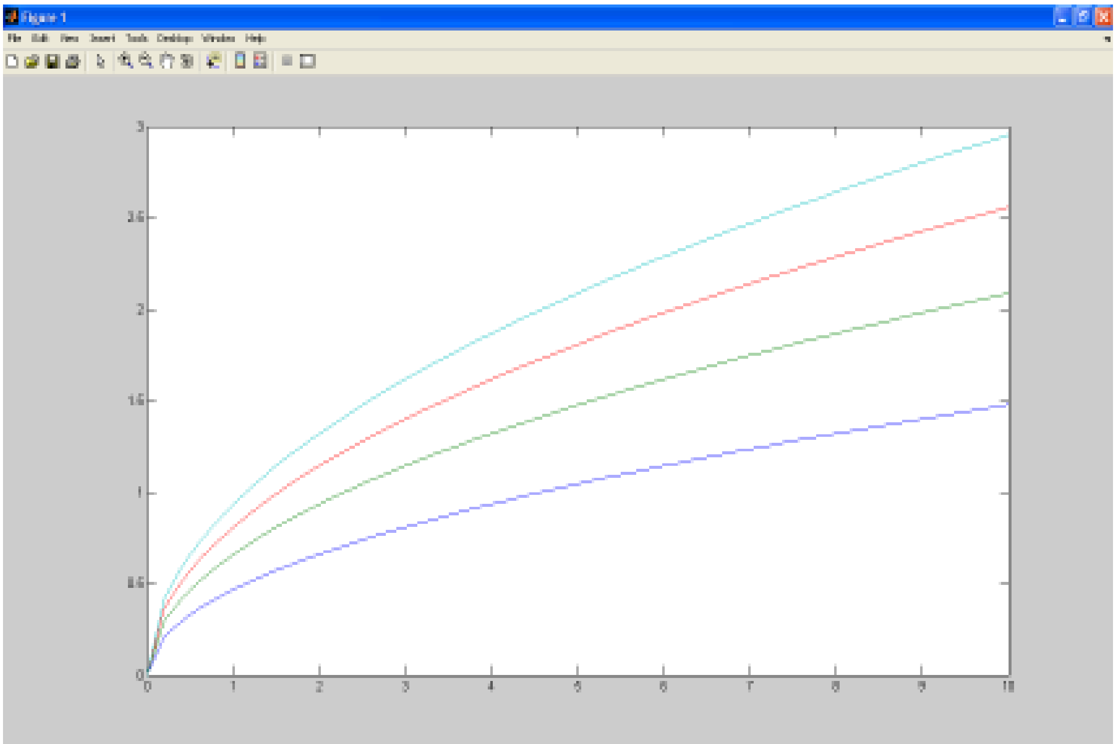

Figure 4.1: Spray tip for 0.4 Mpa

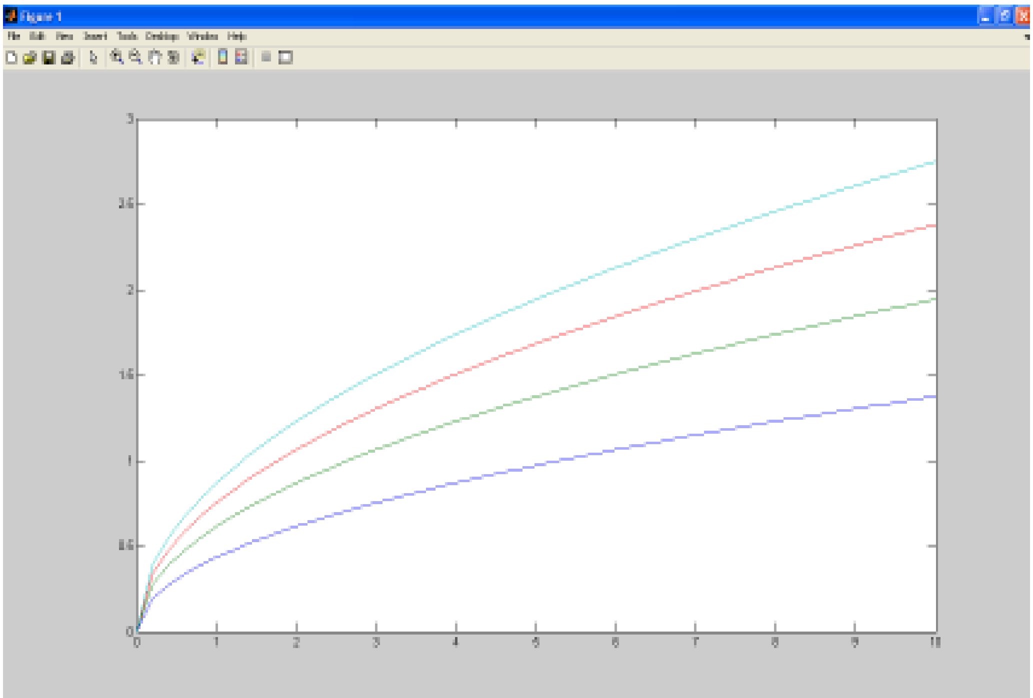

Figure 4.2: Spray tip for 0.3 Mpa

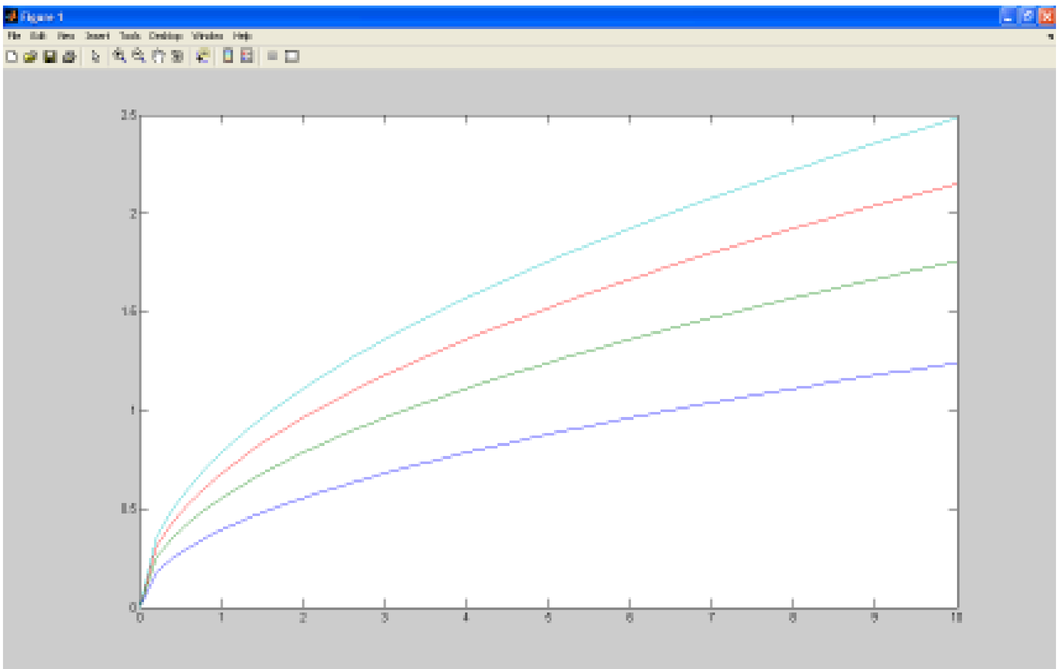

Figure 4.3 : Spray tip for 0.2 Mpa

From the graphs, the lines from different colors show the fuels used in the experiment such as Gasoline, Ethanol, E10 and E25 for each pressure given. The result from the graphs indicates almost the same. This is because the initial spray tip penetration increases linearly with time (the spray tip velocity is constant). For the fuel, the low density gives high penetration. Gasoline fuel shows the highest increment followed by Ethanol, E10 and E25.

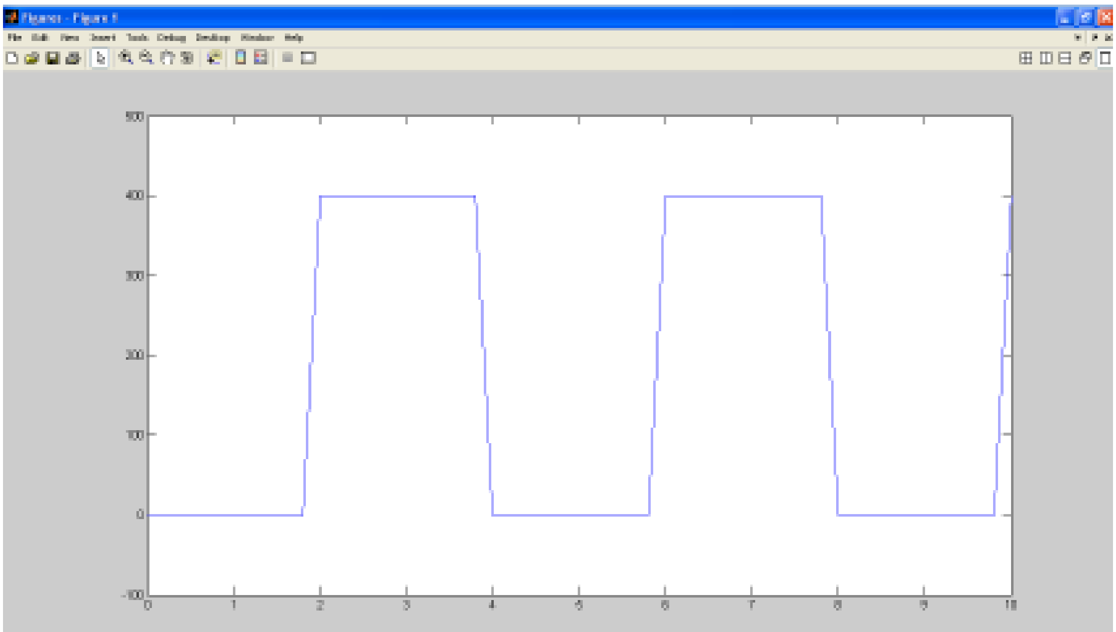

Figure 4.4 : Pulse generator graph

Figure 4.4 show the pulse generator graph produce by injection timing and delay in the control system. The sequence of times is repeated for the system.

4.3 CALCULATION

4.3.1 Calculation for 0.2 Mpa

Results data for 0.2 Mpa pressure and variables time of injection used in the experiment shown in below table using the spray tip penetration equation. Fuel used is Gasoline.

Table 4.1 : Spray penetration for 0.2 Mpa

Pressure	Injection time (ms)	Spray penetration (mm)
0.2	10	39.4568
0.2	20	55.8003
0.2	30	68.3411
0.2	40	78.9135

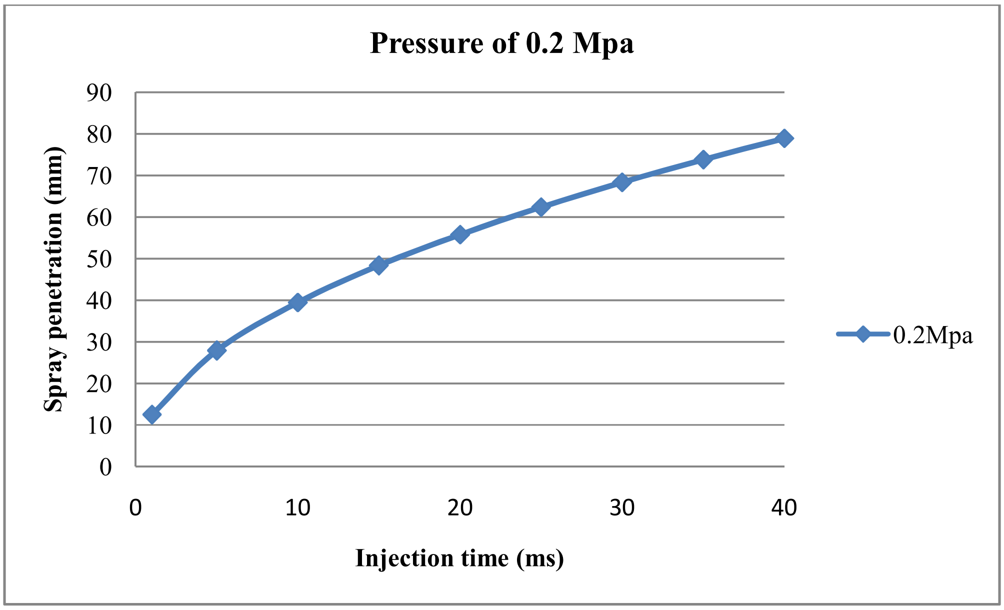

Figure 4.5 : Graph of spray penetration vs injection time for 0.2 Mpa

4.3.2 Calculation for 0.3 Mpa

Results data for 0.3 Mpa pressure and variables time of injection shown in below table using the spray tip penetration equation. Fuel used is Gasoline.

Table 4.2 : Spray penetration for 0.3 Mpa

Pressure	Injection time (ms)	Spray penetration (mm)
0.3	10	43.6661
0.3	20	61.7532
0.3	30	75.6319
0.3	40	87.3322

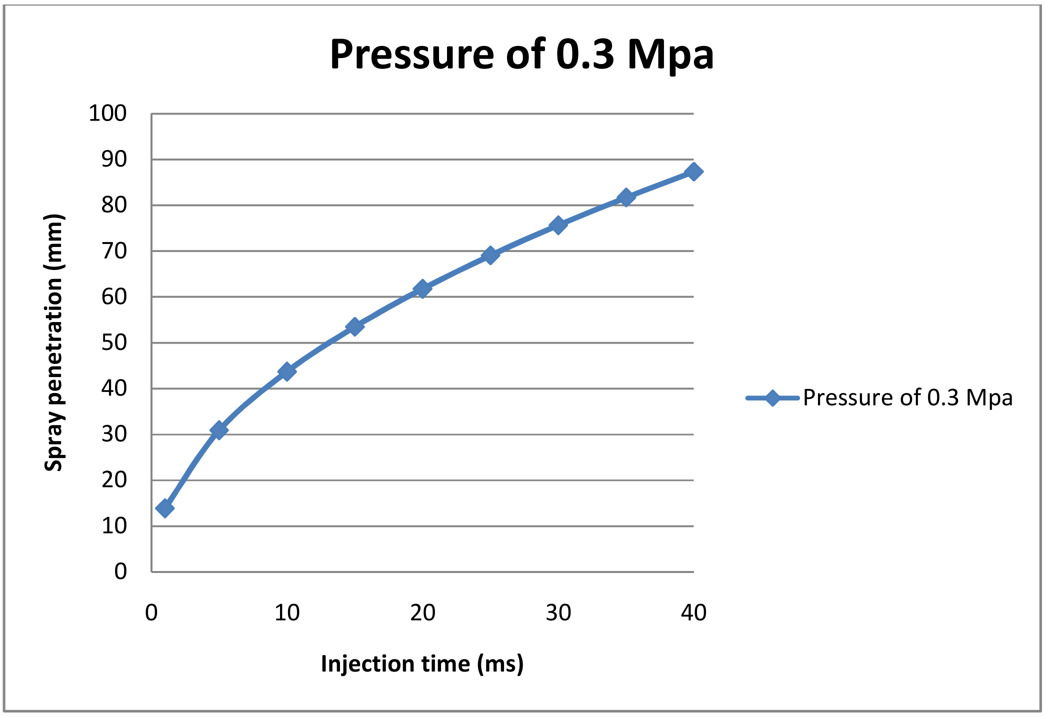

Figure 4.6 : Graph of spray penetration vs injection time for 0.3 Mpa

4.3.3 Calculation for 0.4 Mpa

Results data for 0.4 Mpa pressure and variables time of injection shown in below table using the spray tip penetration equation. Fuel used is Gasoline.

Table 4.3 : Spray penetration for 0.4 Mpa

Pressure	Injection time (ms)	Spray penetration (mm)
0.4	10	46.9223
0.4	20	66.3581
0.4	30	81.2717
0.4	40	93.8445

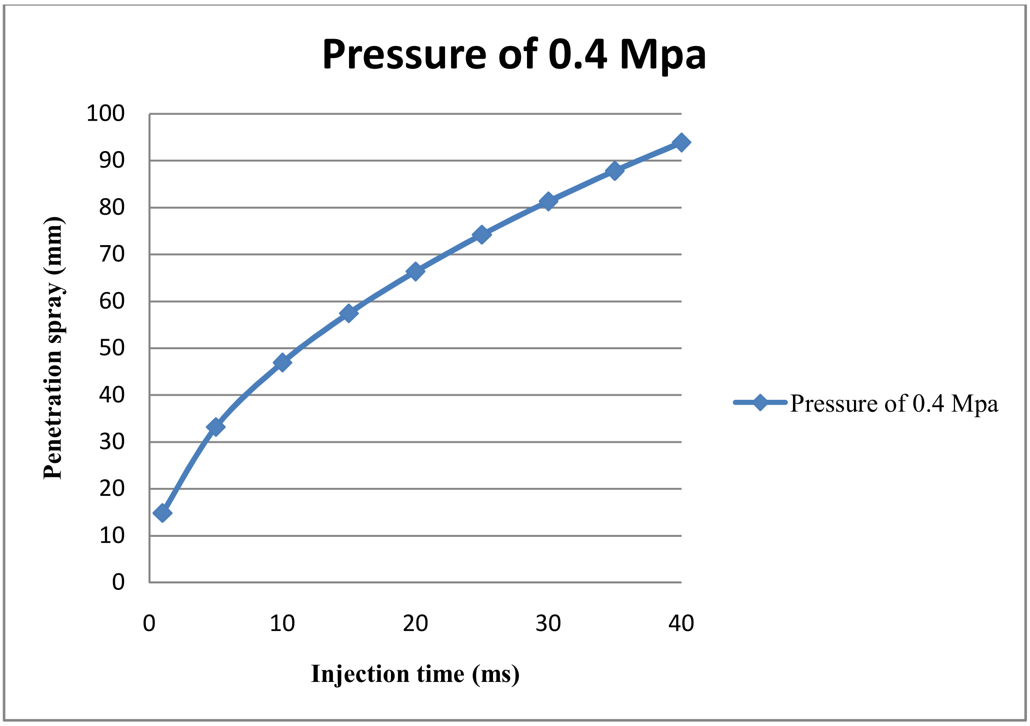

Figure 4.7 : Graph of spray penetration vs injection time for 0.4 Mpa

4.4 EXPERIMENT SPRAY RESULT

From the experiment, the image of spray pattern has been captured. Samples of 0.4 Mpa pressure shown in the figures of 4.8, 4.9, 4.10 and 4.11 due to different time control. The image shows that penetration of spray increase linearly with duration of injection time. Cone angle and spray width will expand when the time is increase.

Figure 4.8 : Spray pattern for 1ms at 0.4Mpa

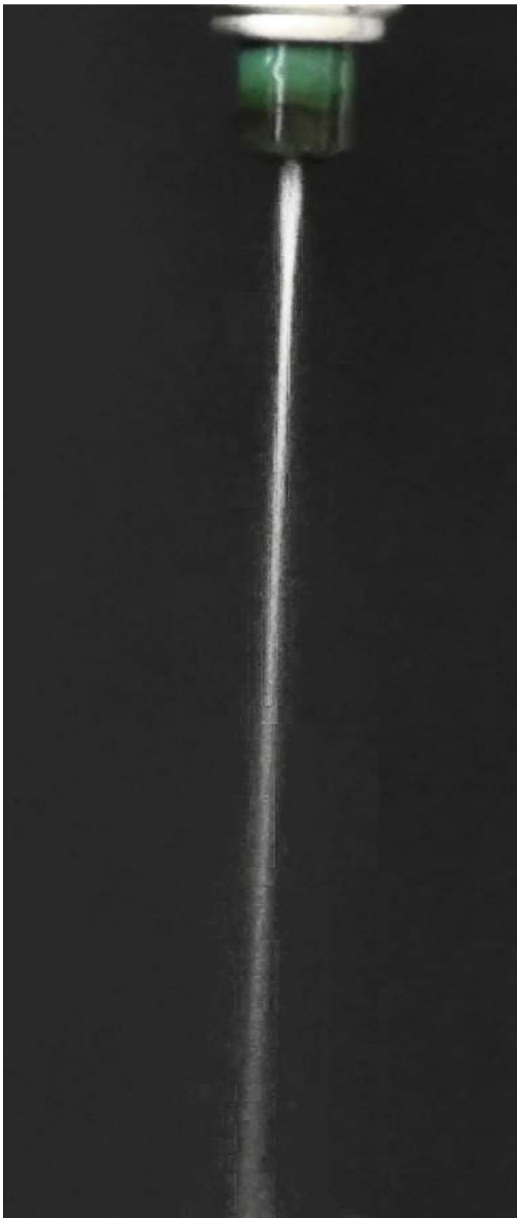

Figure 4.9 : Spray pattern for 2ms at 0.4Mpa

Figure 4.10 : Spray pattern for 3ms at 0.4Mpa

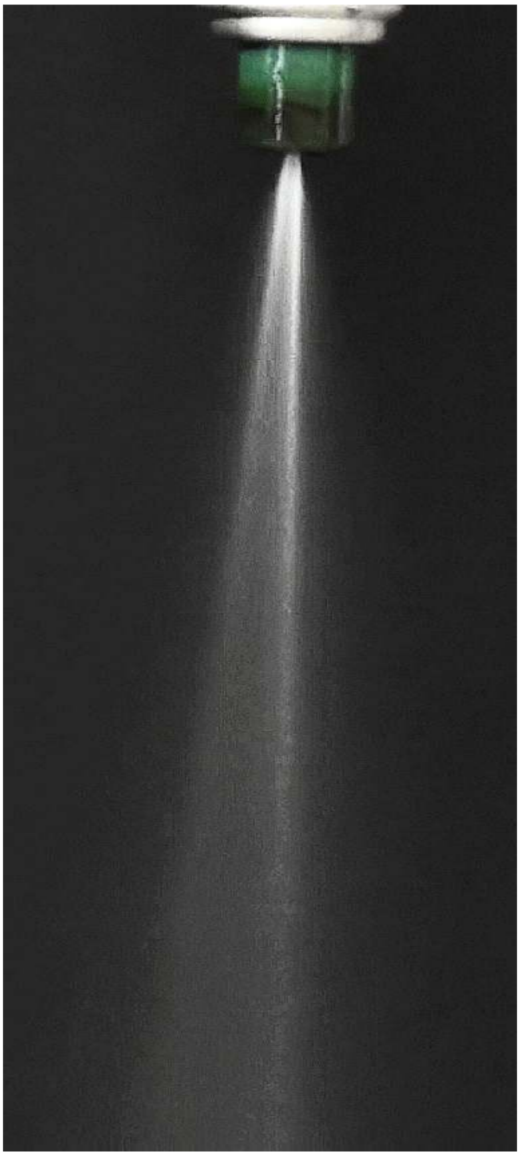

Figure 4.15 : Spray pattern for 4ms at 0.4Mpa

4.5 OVERALL DISCUSSIONS

From the analysis in simulation and sample calculation, the correlations between pressure and time in order to control the spray behaviors such as spray tip penetration have been proved. The result from the simulation graphs and calculation shows almost the same. It is indicate that spray control strongly effect the spray pattern.

In addition, from the experiment done, fuel used in injection system also play an important role because the density of each fuels effect of the velocity flow in the injector. So the spray pattern occurs will not be the same according to different fuel used.

CHAPTER 5

CONCLUSIONAND RECOMMENDATION

5.1 INTRODUCTION

This chapter consists of recommendation for improvement of the project and conclude overall project task. Future works and project limitations also given as a guide of previous research that has been done.

5.2 CONCLUSION

This paper outlines the simulation of spray triggering and control for fuel injection system. Simulation results shows that the control system using the parameter of pressure and time provide significant effects of spray behaviors

Overall of this project can conclude that the fuel injection triggering and control is important for the whole operation system. It is directly affects the spray patterns and behaviors. The advancement in electronics and measurement technologies has led to substantial improvement of fuel-injection control systems, both in hardware configuration and in control methodology. Improving the precision of the forecasting instantaneous injector timing is the key of improving the precision of controlling spurt.

5.3 RECOMMENDATION

Based on the result that has been analyzed, several recommendations can be issued to make the result more reliable and reduce the percentage error of the experiment. Some recommendation that can further improve the experiment for this research is to upgrade control system of injector timing with image grabber that can be synchronize to high speed camera. The studies of triggering still need to be improve and there are still scopes for further study.

5.4 FUTURE WORK

The future works of this research are:

a) Experimental setup for control system using high speed camera triggering with personal computer.
b) Capturing image of fuel spray pattern by using high speed camera.

5.4 PROJECT LIMITATION

Project limitations of this research are:

a) Financial constraint for choosing components to setup the experiment.
b) Lack of time to improve project experimental and analysis

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