DESIGN AND IMPLEMENTATION OF A MICROCONTROLLER-BASED IGNITION SYSTEM

by

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Abstract: *This manuscript describes design and implementation of an ignition system which is controlled by a PIC16F877 microcontroller. This microcontroller based ignition system demonstrates the application of computer based power electronics to automotive technology. The manuscript provides details regarding both hardware and software aspects of the ignition system design.*

I. Introduction

Power electronics is a disciplinary area of electrical engineering which deals with the processing and control of the flow of electrical energy. Power electronics is a technology which holds key to efficient electrical energy conversion [1]. Efficient and flexible power electronics circuits are used in a wide range of industrial applications, including dc and ac motor control, automotive, home audio systems, and battery-powered portable electronics [2]. Due to the availability of better semiconductor devices and fast processors, electronic systems designers are now producing energy-efficient, more reliable, and quite sophisticated power electronic systems [3].

An important application of power electronics involves the use of computer-based electronics in electric vehicle technology. Rizkalla, et. al. [4] described development of an undergraduate electrical engineering course focusing on the use of power electronics circuits, computer-based data acquisition systems, and microcontrollers to design electric vehicle subsystems. As described in [4], the focus on automotive systems helps motivate students because they see the course material as real, relevant, and career oriented.

This manuscript focuses on the use of computer-based power electronics to control an automotive ignition system. This microcontroller based ignition system uses a PIC16F877 microcontroller. The capacity, size, and the operating speed of PICs make them well suited for the direct control tasks [5]. This is why, the application described in this manuscript, uses a PIC microcontroller.

II. Basic Design

The block diagram for the microcontroller-based ignition system is shown in Figure 1.

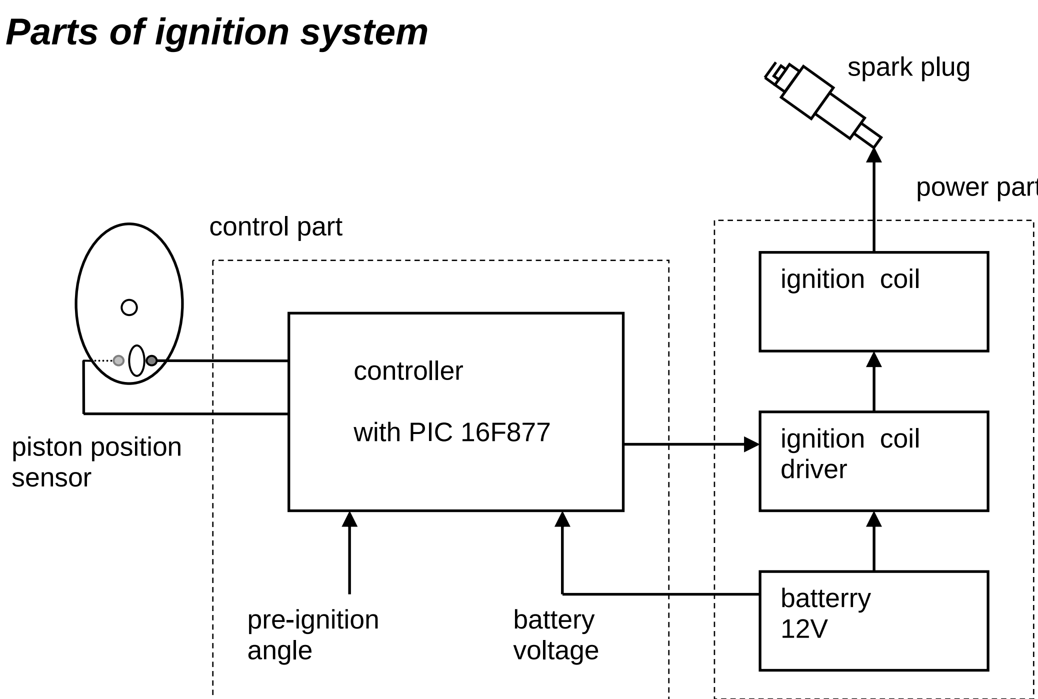


Figure 1. Ignition system block diagram

The above mentioned ignition system is designed for a four-cylinder motor. The various parts of this microcontroller-based ignition system are described as follows:

<u>Piston position sensor</u>: As ignition time depends on the piston position, this position has to be measured by an angle position sensor placed on the crankshaft.

<u>Controller</u>: This part receives signals from the position piston sensor and generates pulses for the ignition coil driver.

Ignition coil driver: This part of the ignition system provides interface between the low voltage controller and the high voltage ignition coil.

Ignition coil: Produces high voltage for the spark plug.

Spark plug: This part of the ignition system produces spark from firing gas in the cylinder.

III. Description of System Hardware

Control Part:

A block diagram of the control part of the ignition system is shown in Figure 2.

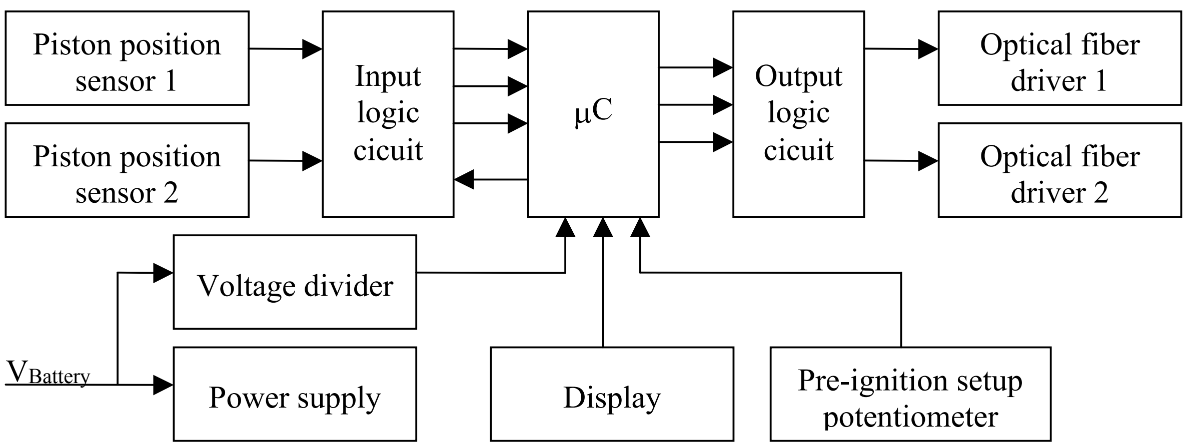


Figure 2. Control part block diagram

The control part receives signals from the piston position sensors and generates pulses for ignition coil driver according to the battery voltage, the motor speed, and the demanded pre-ignition angle. The piston position is established by an optical sensor which consists of a LED, a phototransistor, and a plate with an orifice between them. As shown in Figure 3, the plate is fixed on the crankshaft so that the slot on the plate is at the piston position.

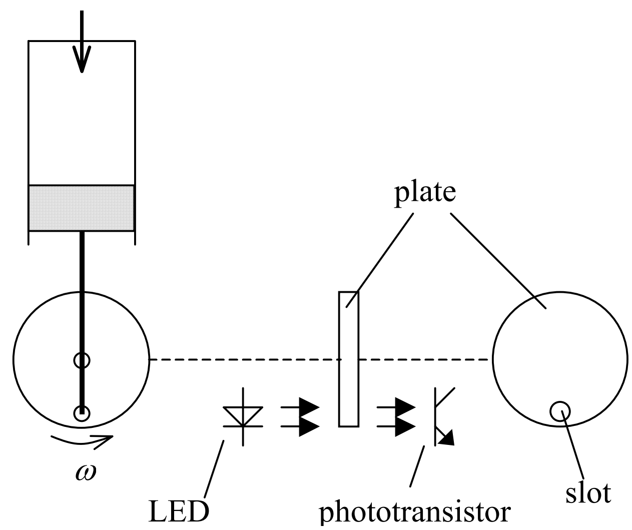


Figure 3. Piston position sensor

The LED continuously lights but the emitted light does not get across the plate except when it is at the piston position. The photo transistor is switched off by default but the emitted light getting across the slot switches it on. The presence/absence of light is converted into voltage levels using an electrical circuit shown in Figure 4.

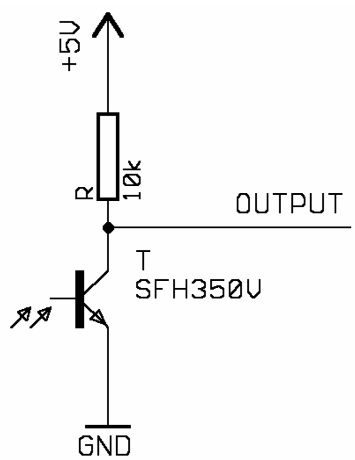


Figure 4. Conversion of light into voltage levels

As shown in Figure 4, when the transistor detects light, it switches on, so the output voltage becomes 0V. When it does not detect any light, the output voltage will be +5V.

The main component in the ignition system control block is a PIC16F877 microcontroller. This microcontroller is capable of detecting the falling and rising edges of a pulse (capture mode) and generating the rising and falling edges at a pre-defined time (compare mode). Using the PIC16F877 microcontroller, it is possible to measure the time when piston reaches the position sensor. The use of microcontroller also makes it possible to calculate the required switch-on and switch-off time for the ignition coil and to generate an impulse at the calculated time.

The input logic circuit used to interface the microcontroller to the piston position sensors is shown in Figure 5 below.

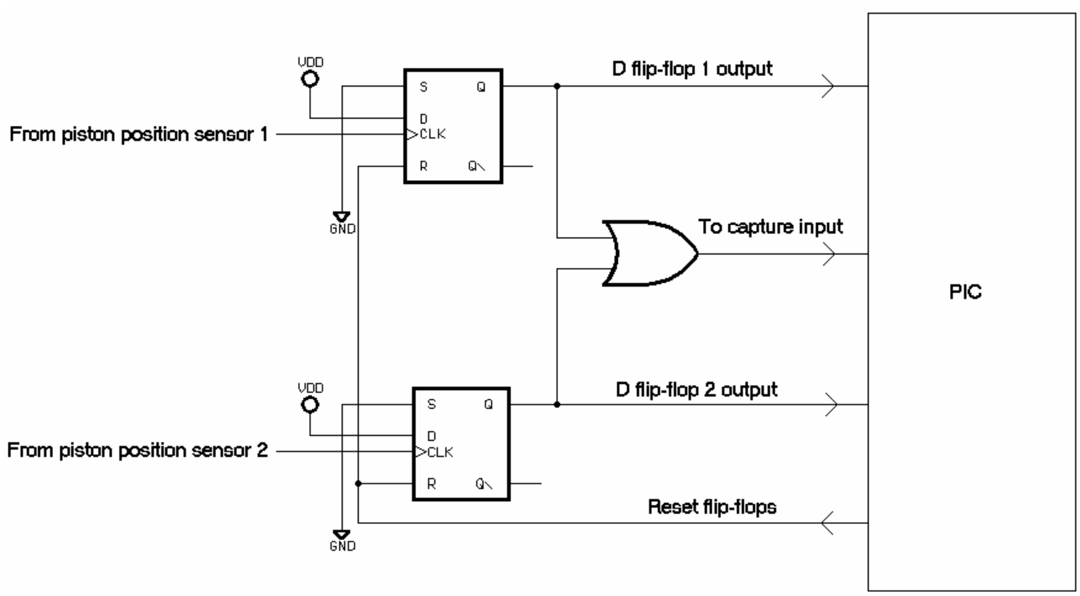


Figure 5. Input logic circuit

The input logic circuit contains a D flip-flop for each piston sensor. When an impulse arrives from a piston sensor, the corresponding D flip-flop will be set. The output signal of the flip-flop goes through the OR gate whose output is connected to the capture input of the PIC microcontroller. After the microcontroller determines which flip flop is set, it stores this value, resets the flip flop, and starts calculating the output impulse time. When the calculation is finished, the microcontroller establishes the time when the impulse is to be generated and it also sets the required enable output to let the impulse arrive at the required optical fiber driver. The output logic circuit is shown in Figure 6 below.

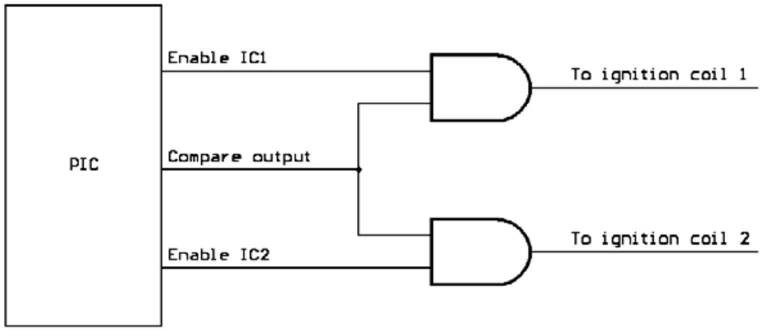


Figure 6. Output logic circuit

The ignition coil must be switched off when piston reaches the position determined by the current pre-ignition angle α_{spark} which is given relative to the top dead point of the piston. The time when spark has to be made is t_{spark} which is given as follows:

$$t_{spark} = t_{sensor} + \left(\frac{\alpha_{sensor} - \alpha_{spark}}{360}\right)T$$

where:

t_{sensor} = time taken by piston to reach the piston position sensor

α_{sensor} = position of the piston position sensor relative to the top dead point of the piston.

α_{spark} = pre-ignition angle given relative to the top dead point of the piston

$T = \frac{2\pi}{\omega}$ where ω is the angular velocity of the motor

Figures 7 and 8 given below show the partial circuit diagrams of the control part. While testing the circuits using a one-cylinder motor, it was realized that the piston position sensor inputs get a lot of noise when the spark is generated on the spark plug, so a capacitance value of 33 nF must be connected between pins 1 and 2 on the connectors CON 101 and CON 201

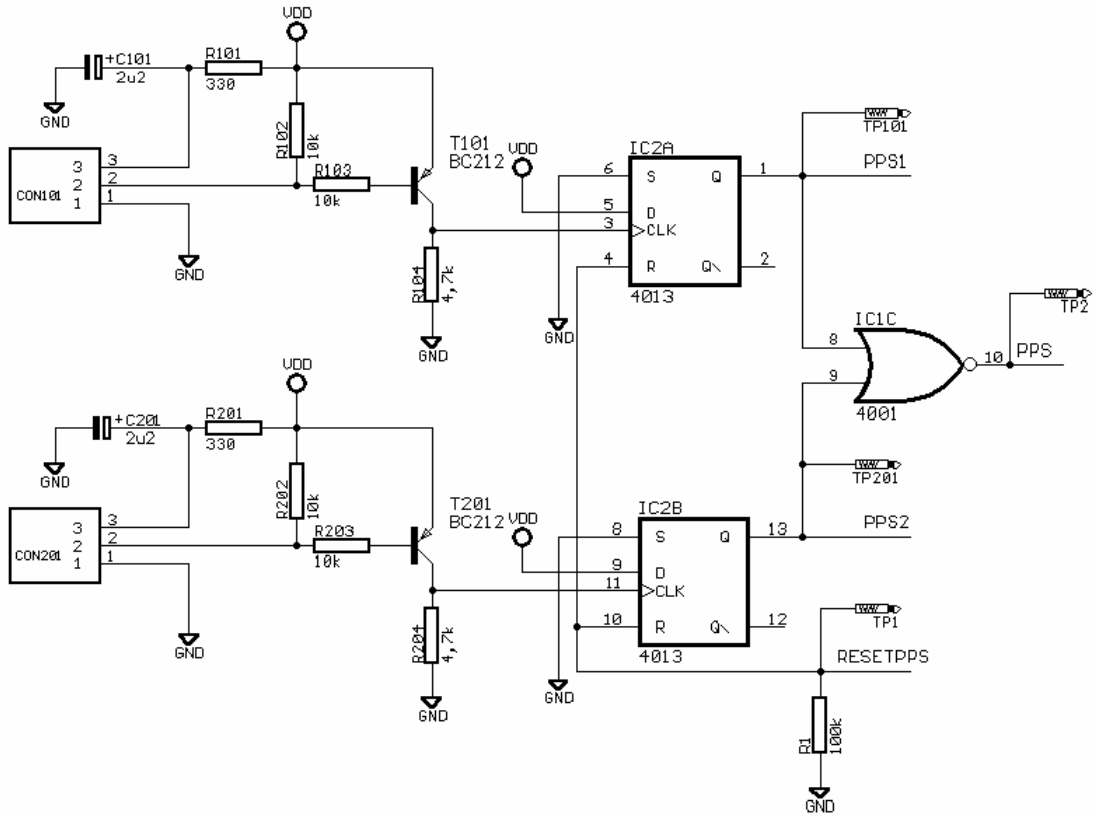


Figure 7. Partial circuit for the control part

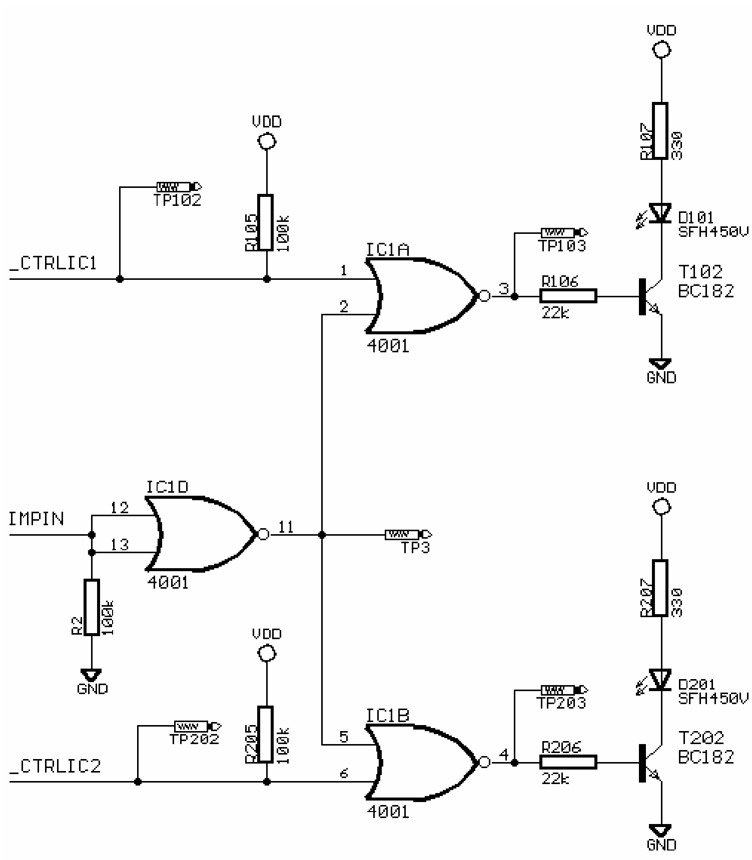


Figure 8. Partial circuit for the control part

IV. Description of the System Software

Operation of the program for one channel is illustrated through the flowchart shown in Figure 9 below.

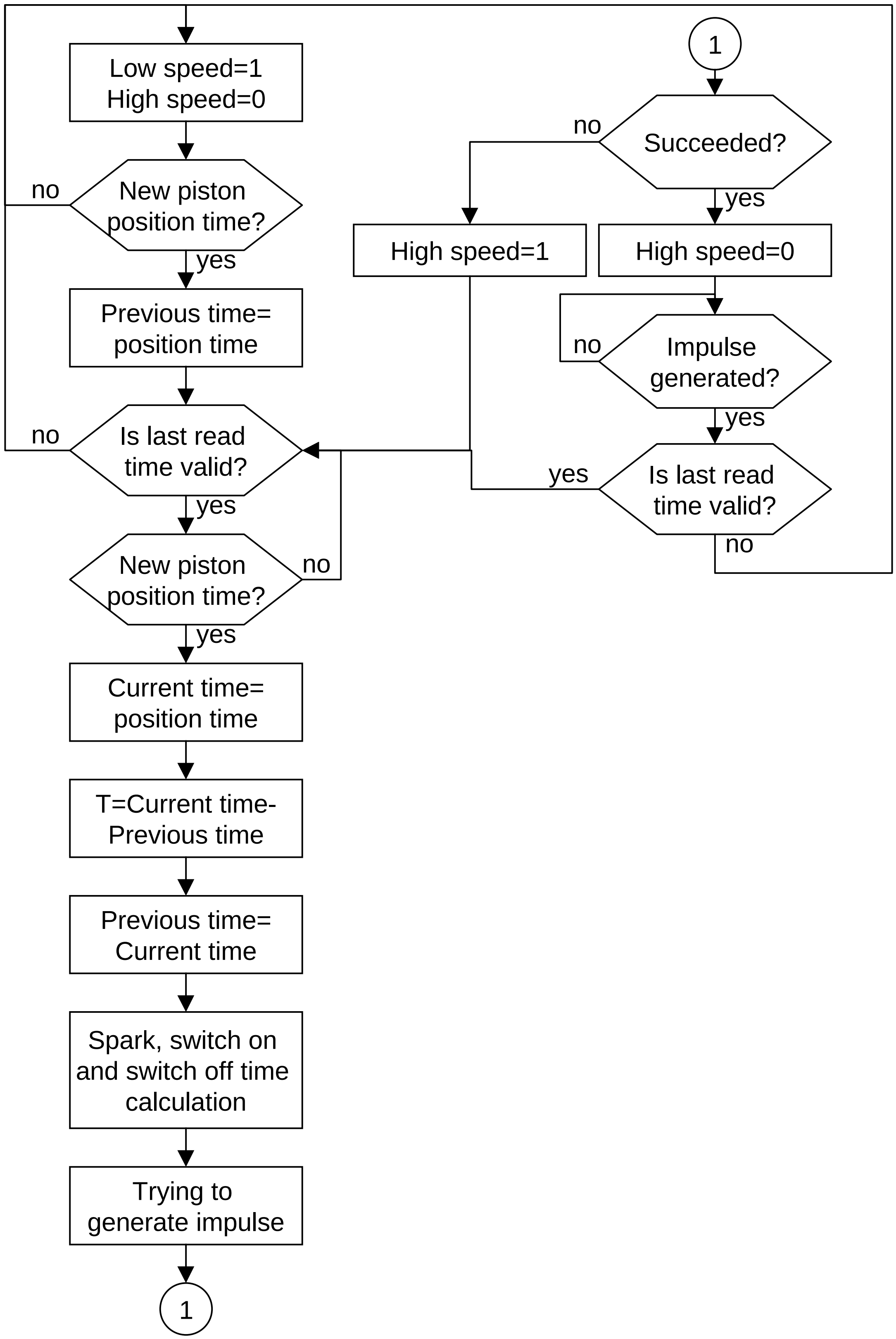


Figure 9. Flowchart for the program operation

The program for the system operation shown in the flowchart of Figure 9 is written in C language. This program is divided into several modules. The key module is termed Main. This module initializes inputs, outputs, and other modules in the program. The Main module also enables interrupts. In this module some constants are defined in order to configure the operation of the entire program. They are:

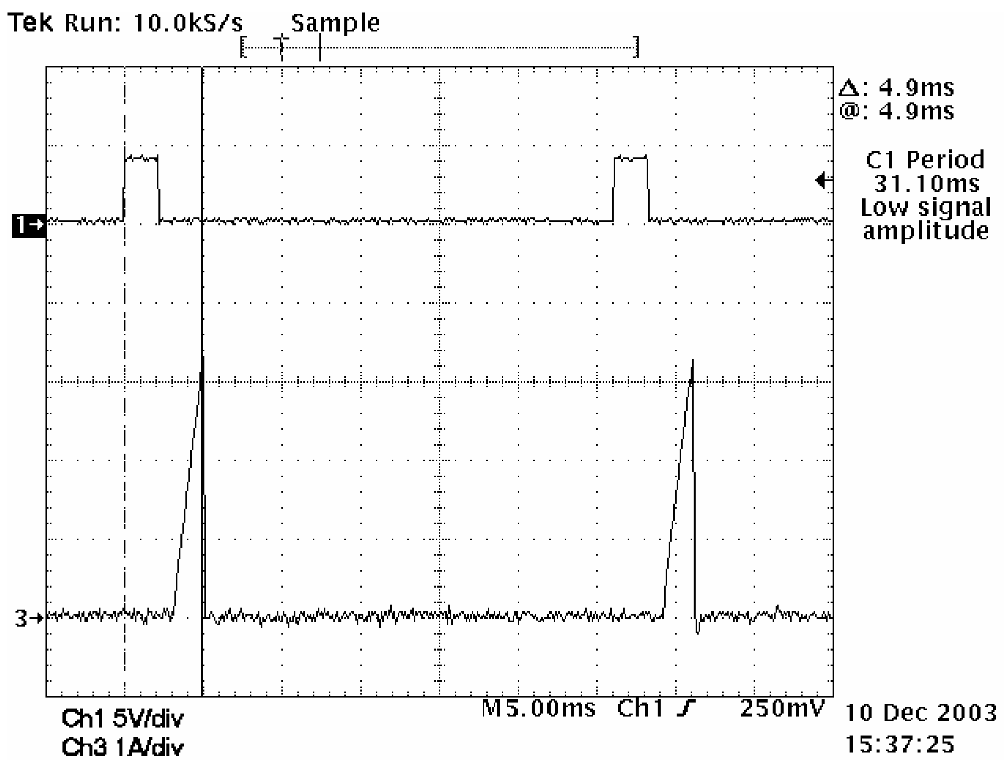
- position of piston position sensor
- delay times
- peak current set up constants
- minimum speed of the motor at which spark must be generated

V. Testing of the System

The above mentioned system was tested to determine:

(i) how peak current depends on the supply voltage
(ii) maximal motor speed at different values of the pre-ignition angle.

Tests and the results are described below:



Current dependency on supply voltage:

Measured waveforms at supply voltage values of 10V and 12V are shown in Figures 10 and 11 respectively. As expected, the switch-on period of the current varies with the supply voltage.

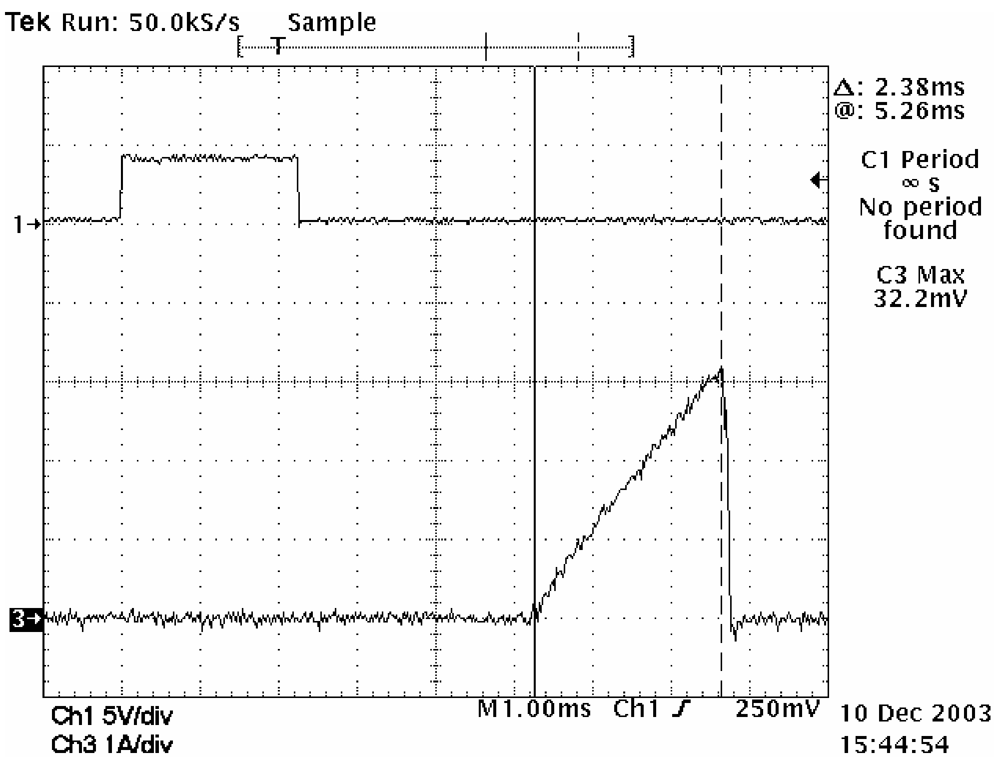


Figure 10. Measured waveform at 10V.

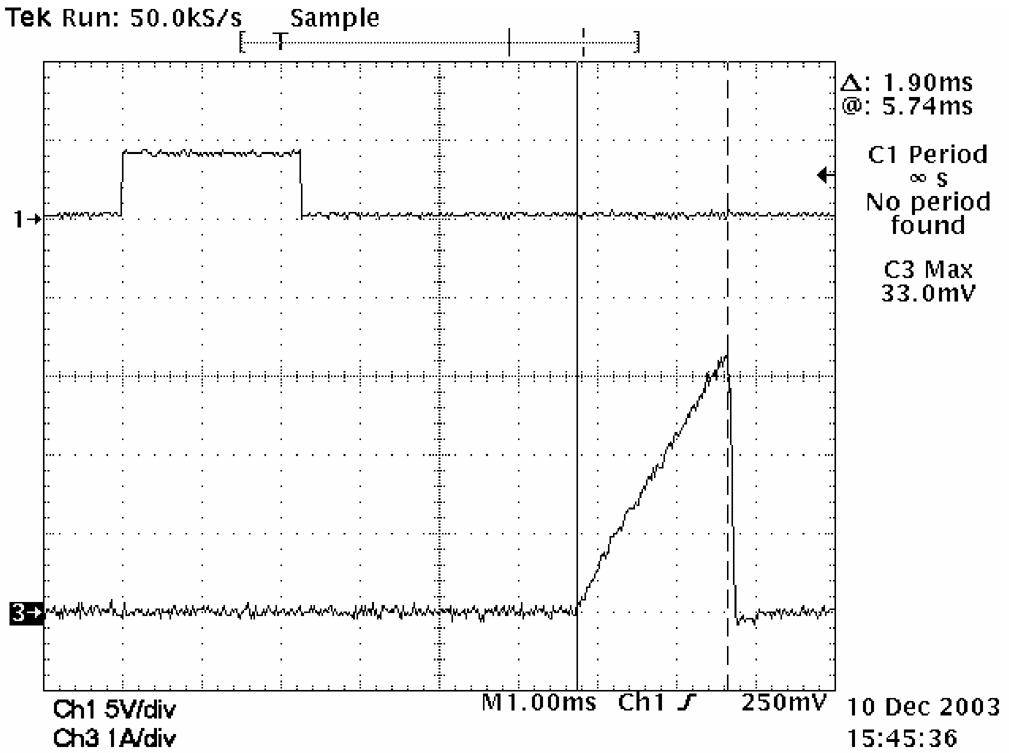


Figure 11. Measured waveform at 12V.

Peak current values were measured at several different values of supply voltage. Figure 12 shows the measured values of peak current versus the measured values of supply voltage.

Supply Voltage (volts)	Peak Current (amperes)
10.0	3.2
10.5	3.3
11.0	3.3
11.5	3.3
12.0	3.3
12.5	3.4
13.0	3.2
13.5	3.1
14.0	3.0
14.4	2.9

Figure 12. Peak current versus supply voltage

<u>Maximal motor speed</u>:

Maximal motor speed is determined by the supply voltage and by the pre-ignition angle. The smaller the supply voltage and the larger is the pre-ignition angle, the earlier the ignition coil must be switched on. The earlier the ignition coil switches on, the less time the PIC microcontroller has to calculate switch-on time. The graph of maximal motor speed versus supply voltage is shown in Figure 13 below:

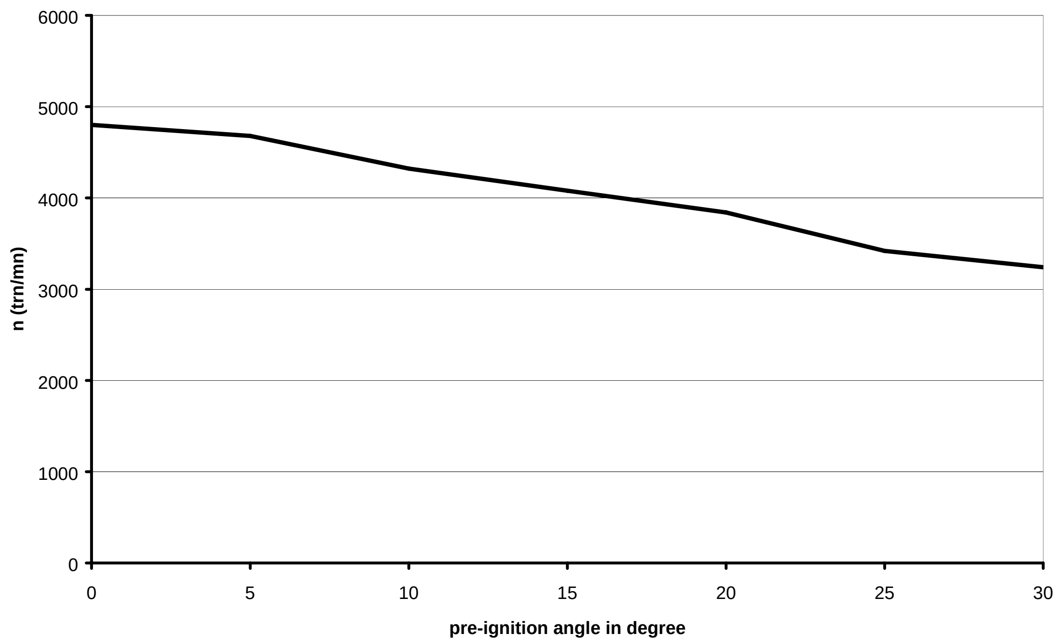


Figure 13. Maximal motor speed versus supply voltage

VI. Conclusion

Design and implementation of a PIC16F877 microcontroller-based ignition system is described in this manuscript. This system demonstrates the application of computer based power electronics to automotive technology. Details regarding the hardware and software aspects of microcontroller-based ignition system are described in the manuscript.

The measurements conducted on the system show that the maximal motor speed of the ignition system is not very high. This is because there are several computations in the program which take quite a long time when PIC16F877 microcontroller is used. It is recommended that a PIC18 family microcontroller should be used to develop this ignition system because it makes 8 bit x 8 bit multiplication by hardware faster resulting in a higher maximal motor speed.

References

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