DESIGN, CONSTRUCTION AND TESTING OF A COMPUTERIZED IGNITION CIRCUIT FOR AN INTERNAL COMBUSTION ENGINE

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

NEVZAT ÇAKMAK

IN PARTIAL FULLFILMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
MECHANICAL ENGINEERING

SEPTEMBER 2012

Approval of the thesis

DESIGN, CONSTRUCTION AND TESTING OF A COMPUTERIZED IGNITION CIRCUIT FOR AN INTERNAL COMBUSTION ENGINE

submitted by **NEVZAT ÇAKMAK** in partial fulfillment of the requirements for the degree of **Master of Science in Mechanical Engineering Department, Middle East Technical University** by,

Prof. Dr. Canan Özgen
Dean, Graduate School of **Natural and Applied Sciences** ________________

Prof. Dr. Süha Oral
Head of Department, **Mechanical Engineering** ________________

Prof. Dr. A. Demir Bayka
Supervisor, **Mechanical Engineering Dept., METU** ________________

Examining Committee Members:

Prof. Dr. Tuna Balkan
Mechanical Engineering Dept., METU ________________

Prof. Dr. A. Demir Bayka
Mechanical Engineering Dept., METU ________________

Prof. Dr. Engin Kılıç
Mechanical Engineering Dept., METU ________________

Assoc. Prof. Dr. Cemil Yamalı
Mechanical Engineering Dept., METU ________________

Dr. Anıl Karel
NUROL AŞ ________________

Date: 07.09.2012

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last Name: Nevzat Çakmak

Signature :

ABSTRACT

DESIGN, CONSTRUCTION AND TESTING OF A COMPUTERIZED IGNITION CIRCUIT FOR AN INTERNAL COMBUSTION ENGINE

Çakmak, Nevzat
Department of Mechanical Engineering
Supervisor: Prof. Dr. A. Demir Bayka

September 2012, 192 pages

In this study, an ignition unit was designed and constructed for a new design engine with eight cylinders and sixteen pistons. The ignition coils with two high voltage outputs were used to ignite sixteen spark plugs on the system. They were driven by PIC16F628A based igniter circuits triggered with digital signals. The igniter circuits receive ignition signals in a square wave form from a main control circuit; they open or close primary voltage of the induction coils to ignite spark plugs. This main control circuit is based on PIC16F877A; and there are two of them. The duty of main control circuit is to determine ignition advance according to engine speed and cooling water temperature, and send proper ignition signals to the igniter circuits. This main control circuit receives engine speed from the other main circuit (secondary control circuit) with serial communication and reads cooling water temperature and then it reads advance value from external eeprom memory according to engine speed and temperature. The main control circuit receives cylinder position signals from the secondary control circuit and adds advance value on them to form ignition timing signals which triggers igniter circuits. The secondary control circuit reads engine speed and determines cylinder positions with two magnetic pick-ups and LM2907 circuits on a gear wheel. This gear wheel was used to simulate disks on the crank shaft of the cars, and driven with an electric motor. The ignition unit was tested for different engine speeds, and its proper working was proved.

Keywords: Electronic ignition, microcontroller based ignition, internal combustion engine

ÖZ

İÇTEN YANMALI MOTORLAR İÇİN MİKROİŞLEMCİ TABANLI ATEŞLEME DEVRESİNİN TASARIMI, YAPIMI VE TEST EDİLMESİ

Çakmak, Nevzat
Yüksek Lisans, Makina Mühendisliği Bölümü
Tez Yöneticisi: Prof. Dr. A. Demir Bayka

Eylül 2012, 192 sayfa

Bu çalışmada, yeni bir tasarım olan, sekiz silindir ve on altı pistonlu bir içten yanmalı motor için elektronik atesleme ünitesi tasarlanmış ve test düzeneği haline getirilmiştir. Sistem üzerinde bulunan on altı adet bujiyi ateşlemek için çift çıkışlı indüksiyon bobinleri kullanılmıştır. Bu bobinler PIC16F628A tip mikrokontrolcü tabanlı bir ateşleme devresi vasıtasıyla sürülmüştür; bu ateşleme devresi dijital sinyallerle tetiklenebilmektedir. Ateşleme devreleri ateşleme sinyallerini kare dalga şeklinde bir ana kontrol devresinden alır, aldığı sinyale göre indüksiyon bobinlerinin primer voltajını açar ya da kapatır. Ana devre PIC16F877A tip mikrokontrolcü tabanlıdır ve sistemde bu devreden iki adet bulunmaktadır. Bu ana devrenin görevi devir ve sıcaklığa gore ateşleme avansını belirlemek ve uygun ateşleme sinyallerini ateşleyici devrelere göndermektir. Bu ana devre devir bilgisini diğer ana devreden seri iletişim ile alır, sıcaklığı üzerinde bulunan analog kanal vasıtasıyla ölçer ve bu iki bilgiye gore önceden belirlenmiş ve harici eeprom belleğe yazılmış avans bilgisini okur. Diğer ana devreden aldığı silindir posizyon sinyalleri üzerine okuduğu avans bilgisini ekleyerek ateşleme sinyallerini oluşturur ve ateşleyici devreleri tetikler. Diğer ana devre silindir pozisyonlarını ve motor devrini iki adet manyetik sensör ve frekans voltaj çeviriciler vasıtasıyla dişli bir disk üzerinden tespit eder. Bu disk, piyasadaki mevcut motorların krank mili üzerinde bulunan dişli diski simüle etmek için kullanılmıştır ve bir elektrik motoru vasıtasıyla sürülmüştür. Tasarlanan ateşleme ünitesi değişik devirlerde test edilmiş ve doğru ateşleme noktalarında ateşlemeyi gerçekleştirdiği görülmüştür.

Anahtar Kelimeler: Elektronik ateşleme, mikroişlemci tabanlı ateşleme, içten yanmalı motorlar

ACKNOWLEDGMENTS

I would like to thank my supervisor Prof. Dr. A. Demir Bayka for his guidance, advice and encouragements during the study. And I want to thank Utku Avgan for his answers and patience to my endless questions.

I would like to thank workshop personal of Mechanical Engineering Department, METU, technicians of Roketsan and Internal Combustion Engine Laboratory technician Levent Şahin.

Finally, I want to thank my friends and my family for their help, encouragements and patience during the study.

TABLE OF CONTENTS

LIST OF TABLES

TABLES

LIST OF FIGURES

FIGURES

NOMENCLATURE

R_S	: Source Impedance
R_{SS}	: Switch Impedance
R_{IC}	: Interconnect Resistance
C_{HOLD}	: Charge Holding Capacitor
T_{ACQ}	: Acquisition Time
T_{AMP}	: Amplifier Settling Time
T_C	: Holding Capacitor Charging Time
T_{COFF}	: Temperature Coefficient
T_{OSC}	: Oscillator Period
F_{OSC}	: Oscillator Frequency
V_{REF}^+	: Upper Limit of the ADC Reference Voltage
V_{REF}^-	: Lower Limit of the ADC Reference Voltage

CHAPTER 1

INTRODUCTION

Since the first day of mankind, people had been using tools to save their lives, these tools had always been advanced and this advance had affected the whole life, this simple rule will be always valid in human life, any advance in any area is going to affect the whole human life in social, economical and technological way. Advance process is the same in internal combustion engines, any advance in electronics, physics or material science have always affected internal combustion engines.

There has been a continuous progress in internal combustion engines because of the competitive nature of the automotive industry, and the progress is based on economical reasons; because as a commercial product, the internal combustion engine is an excellent trade object. For the last decades, some additional factors influencing progress in internal combustion engines have appeared; these factors are environmental regulations stated by governments. The aim of these regulations is to reduce effect of internal combustion engines on nature and to slow the decrease in fossil fuel reserves. After these regulations, automobile manufacturers have had to make various modifications in the operation of their engines. For example, to reduce NOx emissions car manufacturers started to use exhaust gas recirculation; this method works as follows. A certain amount of exhaust gas is sent into the cylinder with air gasoline mixture; this reduces peak temperatures which initiates NOx production during combustion. In the past, lead addition into gasoline was used against knock. However, concern over air pollution forced car manufacturers to abandon this method; and they started to use sensors and microcontroller based systems to avoid knock initiation. One of the issues which are regulated by rules is exhaust gas emissions. To reduce exhaust gas emissions to desired levels, manufacturers started using various sensors such as air/fuel ratio, ignition timing, valve timing, etc. to get efficient combustion. As a result, fully microcontroller based engine operating systems became popular; and most of the operations which were controlled mechanically, were controlled electronically by engine control units. One of the most important operations which are controlled electronically is ignition timing; because ignition timing affects combustion process directly; and poor ignition timing control results in ineffective engine operation and increase in exhaust gas emissions. Environmental considerations are not the only reason to use fully electronic ignition systems; use of such ignition systems also reduces maintenance costs and increases reliability and efficiency.

This study is based on a special kind of engine; it has 16 pistons, 8 cylinders and 2 axial cams which apply torque on a central shaft. The working principle of the engine is different than the engines which are assembled on the cars in the market. This ignition system is designed for this special kind of engine. Some ignition systems in the market may be modified to work with this engine, but there are some difficulties as follows. New generation ignition systems are fully electronic and microcontroller based, and also manufacturers make them so complicated because they do not want their rivals to copy them, so to design an ignition system may be easier way. An old fashioned ignition system which is designed for an engine with eight cylinders may be used, but to test a new design engine with an old fashioned mechanically triggered ignition system would not be satisfying. During designing a new ignition system for the engine, the working principles of old fashioned and new generation ignition systems were considered; advantages and disadvantages of them were examined. These ignition systems and their features are going to be given in the following parts.

1.1 Historical Background

The automotive industry had always been competitive, so it is too hard to follow the changes in this industry. The first reliable ignition system is magneto ignition system. Several inventors are credited with developing magneto ignition, but Siegfried Marcus held a patent in 1883 as magneto ignition electric ignition system [28]. In 1902, the double coil magneto ignition system was designed by Bosch. In this form of spark ignition system, a magneto supplies the ignition voltage for spark discharge independent of a battery or generator. The working principle of this system is that a time-varying magnetic flux is set up in the ignition armature as the rotating permanent magnets generate a current in a closed primary winding, this primary current is interrupted by breaker system to provide the magnetic flux to collapse rapidly to generate high voltage pulse in the winding which is connected to the spark plug electrode, this high voltage jumps to the ground electrode of the spark plug as a spark. Since the flux generated by the rotating pole wheel depends on engine speed, the magnitude of the ignition voltage varies with speed for this reason and combination of necessity, weight, cost, and reliability reasons this type of ignition system is not used in modern engines, it is used in small engines such as in mopeds or chainsaws.

To start an engine with a magneto ignition system hand cranking method was used and it was very hard. After the availability of large batteries to provide a constant source of electricity, magneto systems were abandoned and battery operated ignition systems were used. In this system, an ignition coil (transformer) was used to step the battery voltage up to necessary levels for ignition and a distributor to direct the high voltage pulse to the right spark plug at the right time. The first battery operated ignition system was developed by Charles Kettering [24] in Dayton Engineering Laboratories Co. and introduced in the 1910 Cadillac. By this method, starting the engine was brought into the push-button realm. This ignition system is the primitive version of conventional coil ignition system which is still used in engines.

1.2 Modern Ignition Systems

1.2.1 Mechanically Timed Coil Ignition Systems

The breaker operated inductive ignition system has been used in automotive engines for many years. The system includes a battery(1), main switch(2), breaker(6), condenser(5), induction coil(3), distributor(4), spark plugs(7) and necessary wiring, and it is based on Kettering`s ignition system principle. Figure 1.1 shows schematic view of mechanically timed coil ignition system. The working principle of the system is as follows. When the breaker point is closed; the current flows from battery through primary winding of the ignition coil, breaker point and to ground (chassis of vehicle). This flowing current generates a magnetic field with in the iron core of the induction coil. When the ignition is required, the distributor cam touches the breaker and opens the contact; this action interrupts the current flow in the primary winding and results to decay of magnetic flux. This decay of magnetic flux induces high voltage in the secondary winding because of common iron core and winding number.

The voltage induced in the secondary winding is routed by the distributor to correct spark.

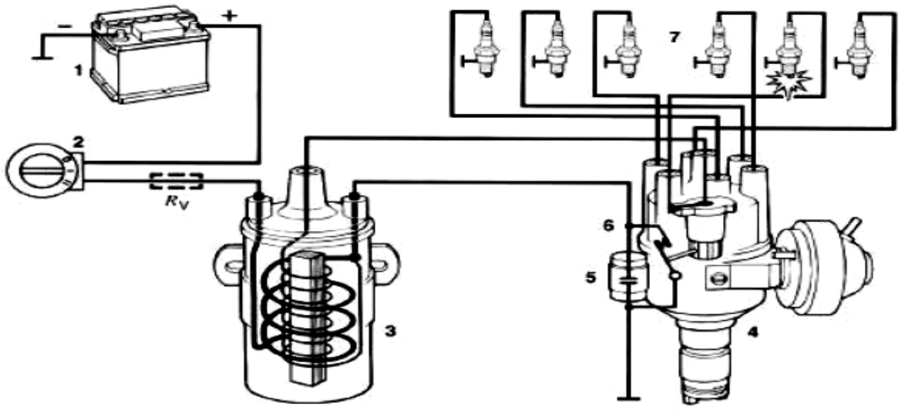


Figure 1.1: Schematic view of conventional mechanically timed ignition system to generate the spark

Mechanically timed coil ignition systems are used for many years, and they provide a useful introduction to ignition system design and operation. As it is stated before, any changes in electronics, material science and physics affects structure of engine and its control principle, such a change occurred in early 1950`s, transistor is produced in Bell Labs. The transistor is the key active component in all modern electronic applications. Many scientists consider it as one of the greatest inventions of the 20th century. The invention affected all aspects of life, ignition systems were affected, too. Mechanically timed coil ignition system was replaced with transistorized coil ignition systems with the usage of transistor in automotive applications.

1.2.2 Mechanically Timed Transistorized Ignition Systems

In previous version of ignition systems, the primary current is controlled with a mechanical contact; it has some disadvantages as follows. After a working period, because of metal-metal contact wearing occurs and affects engine performance. In low engine speeds, higher current flows through mechanical breakers and shortens the working life of mechanical contacts; also this higher current induces high voltage in the secondary winding and shortens the working life of spark plugs. In starting engine, mechanical contacts open and close slowly; it affects ignition in bad way. For the reasons stated above, transistor is used to eliminate metal-metal contact. In 1960`s, mechanically timed transistorized ignition system was started to be used. In mechanically timed transistorized ignition system, there is an additional transistor compared to conventional mechanically timed coil ignition system as seen in Figure 1.2 [25], and its working principle is the same with that ignition system.

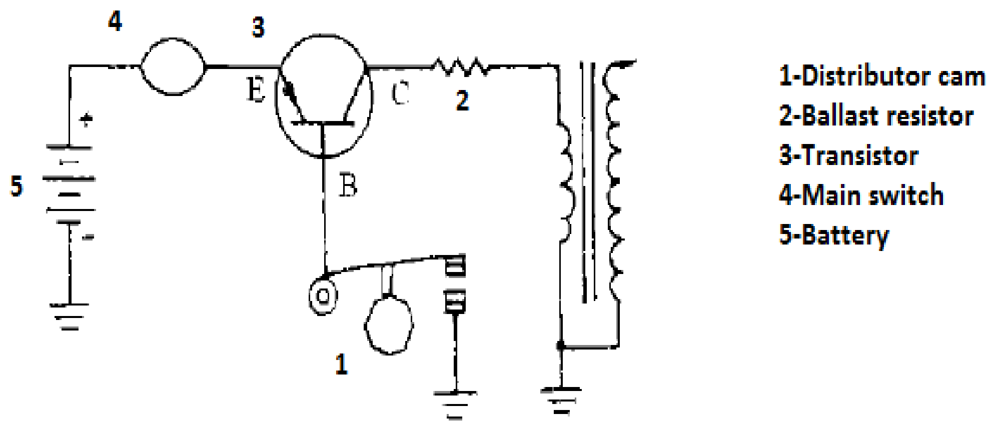


Figure 1.2: Schematic view of mechanically timed transistorized ignition system

In this ignition system, mechanical breaker controls the base current of the transistor so low current flows through mechanical contact; it means longer working life of mechanical contacts. The transistor also limits current flowing through the primary winding, so in low engine speeds high voltage does not induce in secondary winding; it provide longer spark plug life, better ignition timing, better ignition and better engine performance compared to conventional ignition systems. There are many transistor ignition types which were developed by big companies. Figure 1.3 shows a transistor ignition system which is developed by Courtesy of Ford Motor Co. [24]

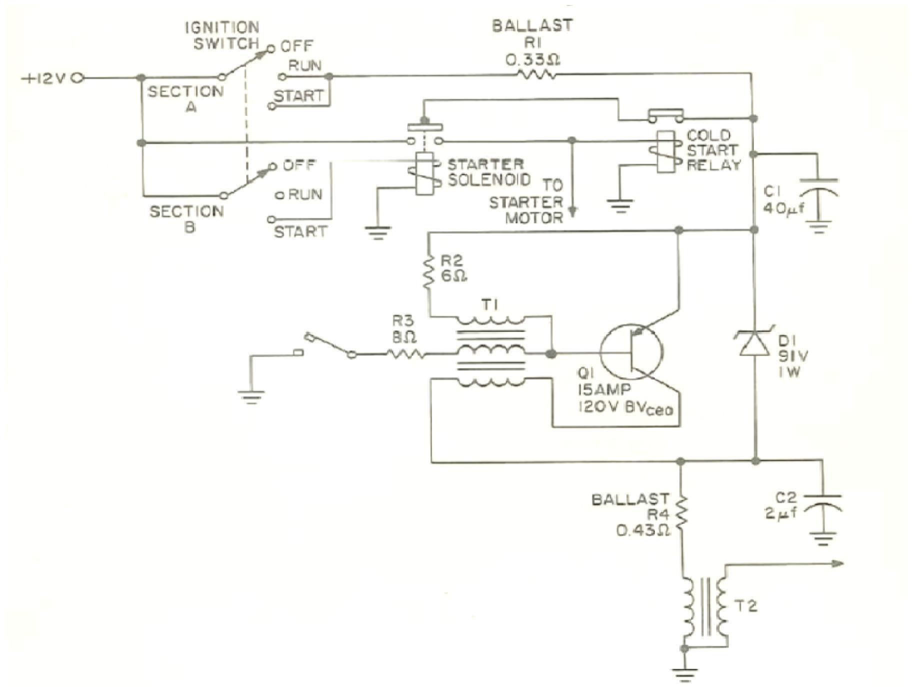


Figure 1.3: Using a pulse transformer to improve transistor-cutoff time (Courtesy of Ford Motor Co.)

1.2.3 Sensor Triggered Transistorized Ignition Systems

In automotive applications, the need for much reduced maintenance, extended spark plug life, improved ignition reliability, and increased ability to control resulted in usage of electronic circuits to control ignition process in 1980's. Figure 1.4 shows sensor triggered transistorized ignition system [25], in this system the distributor points and cam assembly of the conventional ignition system are replaced by a magnetic pulse generator or an optical sensor which detect the distributor shaft and sends signal pulses to electronic control module. This module switches off the flow of current to the primary winding of ignition coil and initiates the ignition. In older versions of this ignition system, mechanical advance system is in the distributor as in conventional ignition systems, but in newer versions advance is adjusted by control module. Also in former versions, signal pulses which are coming from magnetic or optical sensor directly trigger the transistor and initiate the ignition.

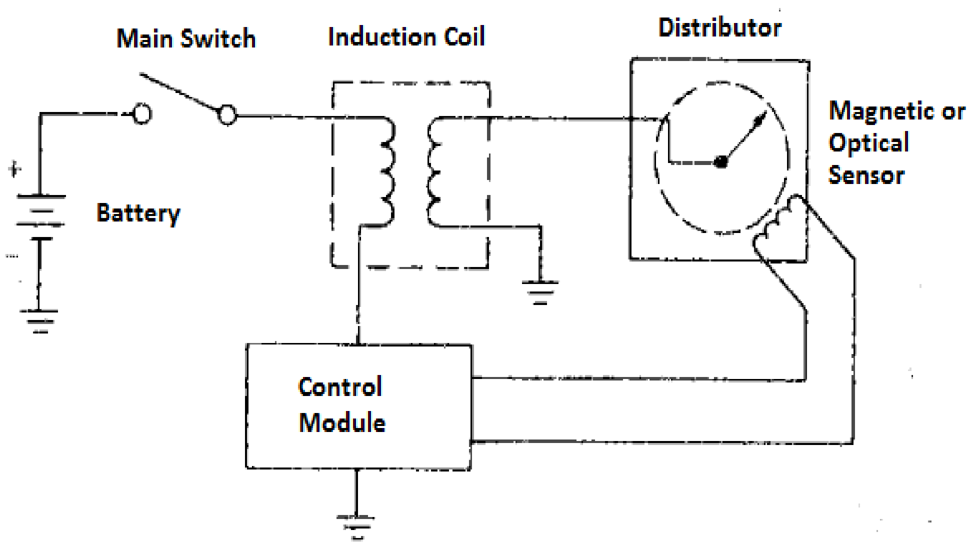


Figure 1.4: Schematic view of sensor triggered transistorized ignition system

1.2.4 Capacitive –Discharge Ignition(CDI) Systems

With this type of ignition system, a capacitor rather than an induction coil is used to store the energy necessary for ignition; this is the main difference of the system. Commercial development of CDI happened around the mid 1960's and it was tested on a 90cc Kawasaki motorcycle, but application in automotive was introduced by Bosch with “Bosch Motronic” in 1979. The system includes charging device, pulse shaping circuit, control unit, thyristor and ignition transformer. The working principle of the system is as follows. The transformer in charging device steps up the battery voltage to 400-600 volts and charges main capacitor. When control unit receives ignition timing signal, the capacitor is discharged rapidly via thyristor, voltage of primary winding of the ignition coils rises up to 400-600 volts, this voltage induces high voltage, around 40 kV in the second winding this is the necessary voltage for spark generation. Because of fast capacitive discharge, the spark is strong but short. This can lead to ignition failure at operating with very lean or dilute. This type of ignition is widely used in outboard motors, chainsaws, motorcycles and racing cars.

1.2.5 Distributorless Ignition Systems

Ignition systems with a distributor have been used for many years; but advances in semiconductors allow people to construct small chips to control most of the operations which was controlled mechanically in the past. After the replacement of mechanical or vacuum advance assembly in distributor with a microcontroller based operation, the size of distributors got smaller. To eliminate voltage losses during distribution, increase the accuracy of ignition point and decrease the cost, the distributor is replaced with control circuit and position sensors in 1980`s, this type of ignition systems are called distributorless ignition systems(DIS). As it is seen in Figure 1.5, engine control module receives the position signals from camshaft and crankshaft position sensors and it uses these signals to detect cylinder positions and ignite the right cylinder at the right time, there is an igniter circuit this circuit works as follow. It receives ignition timing signal and number of ignition coil which will be ignited from engine control unit and ignites related spark plugs. There are various sensors such as engine load, cooling water temperature and knock sensor, engine control unit receives all the outputs of these sensors to control injection, advance etc. In the ignition systems with distributor, there is one ignition coil and all spark plugs are ignited from this coil, but in distributorless ignition systems there is one ignition coil for each spark plug or one ignition coil for two spark plugs.

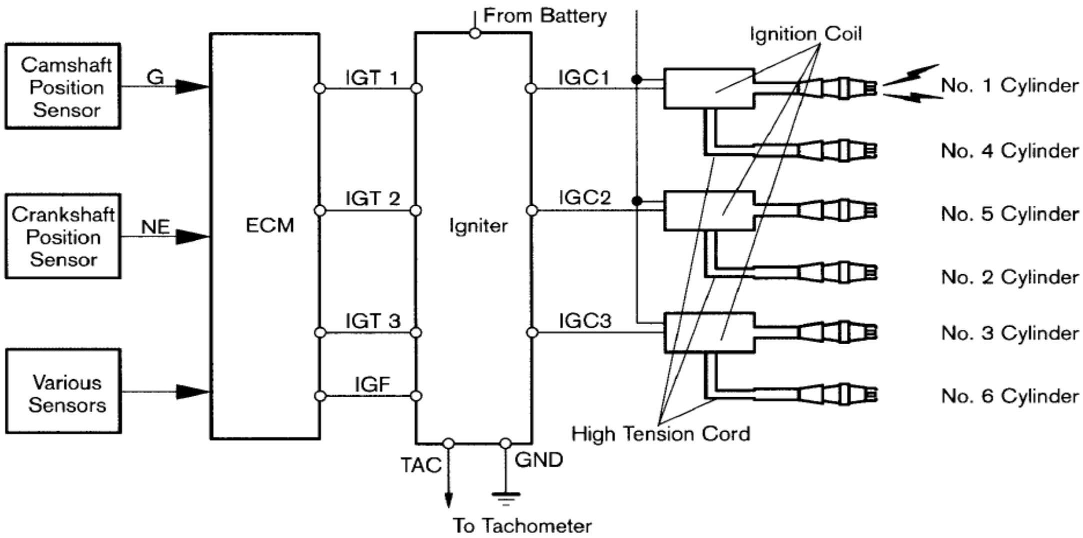


Figure 1.5: Schematic view of distributorless ignition system

There are many distributorless ignition systems in the market, for example General Motors Corporation held a patent related to distributorless ignition system [15], it is one of former versions. In this ignition system, there are two gear wheels on the crank shaft and two magnetic sensors. One of the gear wheel has only one tooth, this gear wheel is used to sign reference position, the other gear wheel has many teeth according to cylinder number as a choice and it is used to determine crank shaft angle, one of the sensor is used to count the teeth on this gear wheel and determine engine speed, and the other one is used to detect reference point. Firstly, the control circuit of the system detects reference position and determines position of the first cylinder (reference cylinder) signal then it counts the teeth with binary counters and determines position of the other cylinders. The system determines cylinder positions as mentioned above, it determines advance and dwell angle by using registers which was already adjusted according to engine speed on itself.

1.2.6 Direct Ignition Systems

Nowadays, this is the most popular ignition system. Operational principle of this system is the same with distributorless ignition system, but the place of ignition coils is different. Ignition coils are directly mounted on the spark plugs in this ignition system. By this way, ignition cables and electromagnetic interference caused by ignition cables are eliminated. In distributorless wasted spark ignition systems, the working life of spark plugs is shorter compared to direct ignition systems. In some direct ignition systems, igniter circuit is integrated on ignition coil. Figure 1.6 shows schematic view of positions of ignition coils in direct ignition system.

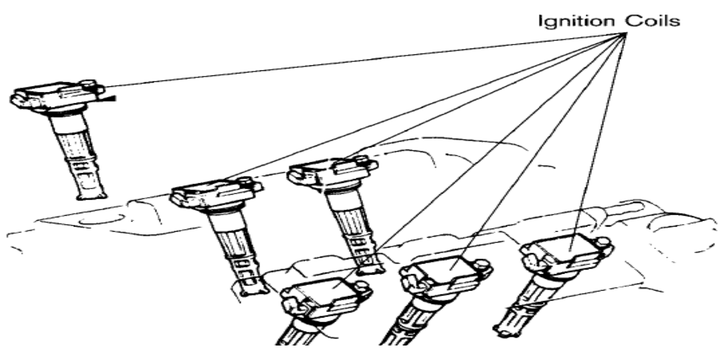


Figure 1.6: Positions of ignition coils in direct ignition system

There are many patents about direct ignition systems which are held by big companies, one of them is held by Fiat Auto S.p.A.[19]. In this system, to generate ignition sparks in the correct sequence, there is a need to get a stage signal which defines the stroke of selected cylinder as seen in Figure 1.7. This stage signal is supplied by a sensor associated with a timing member; the timing member is inlet-exhaust valves operating shaft. This stage sensor (7) may be placed anywhere, but important point is that for a 4 stroke cycle engine the shaft on which the stage sensor is assembled shall have a rotation ratio ½ according to crank shaft. In Figure 1.7, there is a phonic wheel with part number 7, this wheel is used to detect engine shaft rotation and determine top dead center of cylinders. As seen in Figure 1.7, the phonic wheel (7) has four regularly arranged notches and two notches; because this system is related to five cylinders engine, and two notches give the top dead center position of reference cylinder and the other four notches give the top dead center position of the other cylinders. Top death center position does not give the stroke of a cylinder it may be compression or exhaust, so to differentiate strokes, engine control unit use stage signal. If the system use wasted spark method, there is no need to look at the stage sensor, because the control module initiates spark for all of the cylinders which are at the top dead center position, combustion takes place in the cylinder which is at the compression stroke, the other cylinder will be at the exhaust stroke and spark will not affect anything.

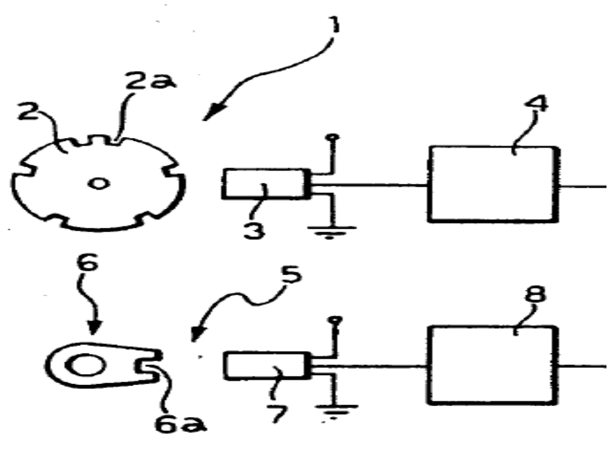


Figure 1.7: Sensors and disk used to determine cylinder positions in Fiat direct ignition system

This ignition system uses wasted spark ignition, too. To overcome the disadvantage of extended starting times due to the fact that sparks are generated during the first revolution of the engine and until correct stage of the ignition occurs, wasted spark ignition method is used during starting the engine, then control unit of the ignition system detects stage signal when correct stage signals start to come, control module shifts ignition system to direct ignition method.

There is another patent which is held by another big company, Robert Bosch GmbH [20]. The operating system of this ignition system is the same with the ignition system which is told above, the only difference is that a hall sensor is used as a stage sensor instead of a magnetic sensor.

CHAPTER 2

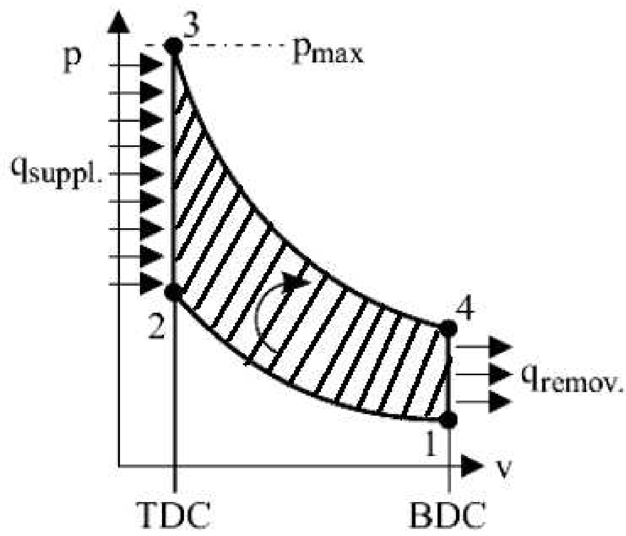
THE NEW DESIGN ENGINE

This thesis was studied to design and construct a microcontroller based electronic ignition system for a new design engine. So, the first step of our study is examining the new design engine. To understand its working principle and advantageous sides; firstly, we should learn the possible ways to optimize engine efficiency which are not used in conventional internal combustion engines and its different sides than similar engine designs.

2.1 Some Possible Ways of Optimizing Efficiency

2.1.1 Constant Volume Combustion

Many studies were conducted on position of spark plugs, shape of combustion chamber and swirl angle of intake charge to increase combustion efficiency in the cylinder. But, there is another way to increase thermal efficiency, this is constant volume combustion. This way is based on keeping constant the volume of combustion chamber during combustion; if you can keep the volume of combustion chamber constant, you can get higher combustion pressures. Actually, Otto cycle considers constant volume combustion, but it assumes combustion process is so rapid and piston does not move during combustion. Figure 2.1 shows ideal Otto cycle pressure versus volume diagram. As it is seen in Figure 2.1, ideal Otto cycle proposes constant volume combustion (2-3). The shaded area of figure gives the useful work which is converted from available energy during combustion process as it is given by the formula in the figure, so it is a representation of thermal efficiency. If we can increase this shaded area we increase thermal efficiency of process.



$$\frac{W}{\text{cycle}} = \int p\,\mathrm{d}V$$

Figure 2.1: P-V diagram of ideal Otto cycle

The peak pressure at point 3 in Figure 2.1, can be increased by keeping volume constant during combustion process, so it will increase the shaded area and the work done during combustion will increase. But this is too difficult with conventional crank shaft engines. Because, the crank shaft rotates continuously, and staying at TDC of pistons is too short and dependent on engine speed. At higher engine speeds, the volume of combustion chamber increases faster, so combustion pressures cannot reach their theoretical peak pressures.

Figure 2.2 shows a piston path for a conventional crank shaft engine; as it is seen in the figure the piston stays at TDC and BDC for too short time interval, so constant volume combustion process is valid for very short time interval.

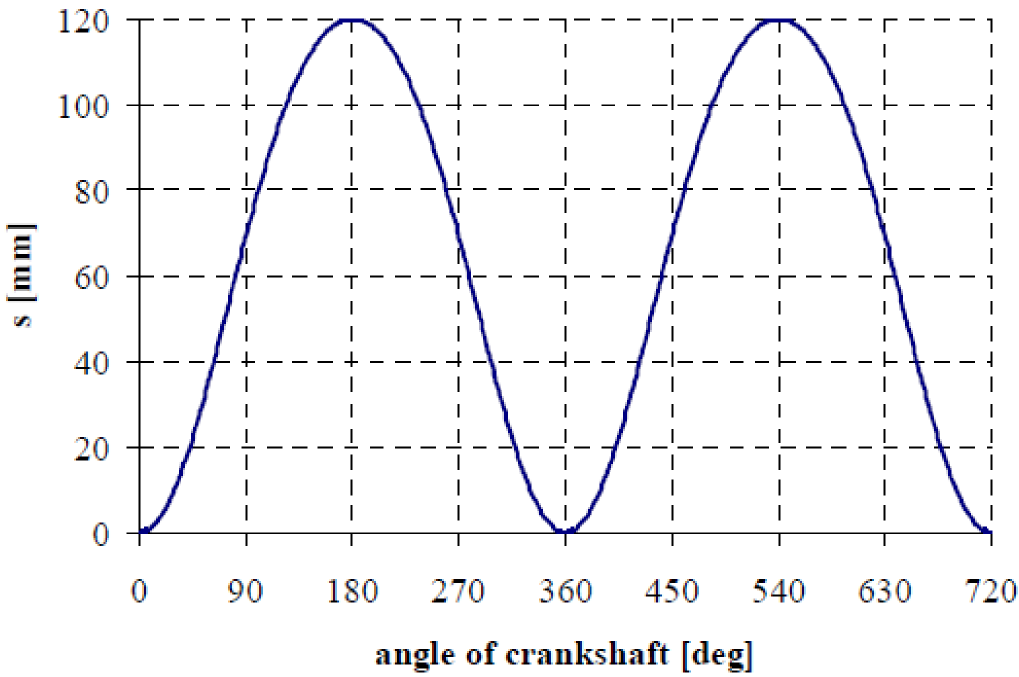


Figure 2.2: Path of a conventional crank shaft engine piston

As it is stated before, to achieve constant volume combustion with conventional crank shaft engine is not possible, there is a study about constant volume combustion in the literature it will be helpful to understand physics of achieving constant volume combustion, it is based on changing kinematic of conventional IC engine crank shaft and giving pause or dwell at the top dead center (TDC) and bottom dead center (BDC) while crank shaft still rotates about 20º. With this dwell at TDC, the author proposed to have constant volume for combustion, so higher combustion pressures and higher thermal efficiency. The piston path of this unconventional engine is shown in Figure 2.3, as it is seen in the figure, piston position stays at the same position while crank shaft keep rotating, so this provides condition for constant volume combustion.

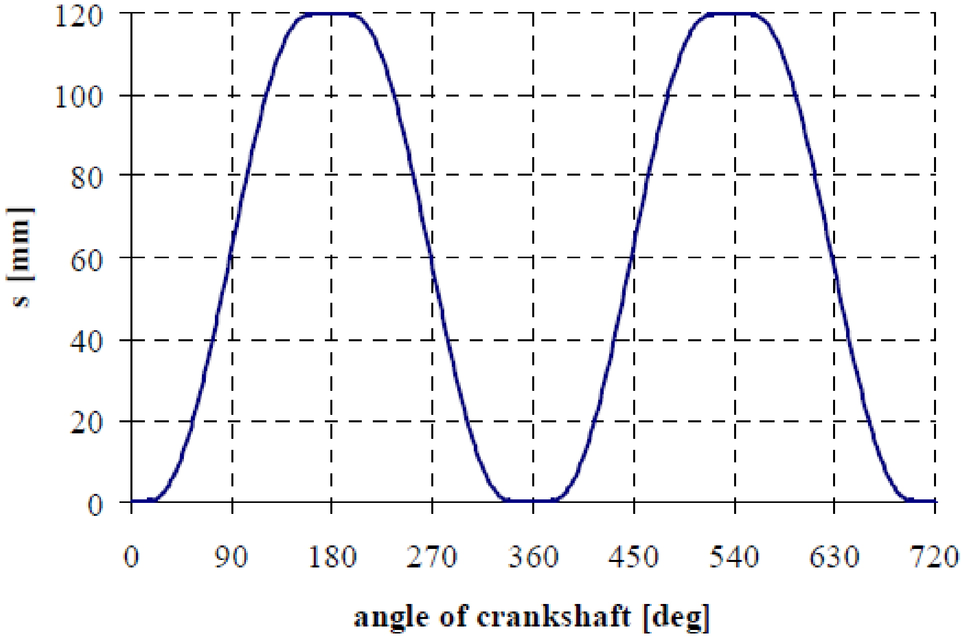


Figure 2.3: The piston path of engine with modified kinematic

This modified engine had been simulated for full throttle conditions to prove the effect of constant volume combustion on efficiency, the result is shown in Figure 2.4. As it is seen in the figure, higher combustion pressures and efficiency were realized.

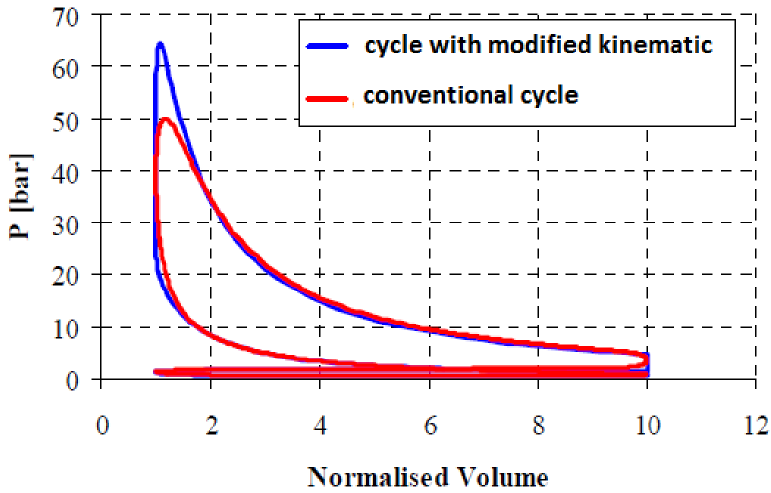


Figure 2.4: Comparison of conventional cycle and cycle with constant volume combustion

Constant volume combustion is one of the most effective ways to increase combustion efficiency, but it also has some drawbacks. The temperatures during constant volume combustion increases with increasing pressure and efficiency and it triggers formation of NO_x emissions, because NO_x formation increases with high temperature, so you may need extra exhaust gases treatment. The compression ratio can be reduced to eliminate high temperature caused by constant volume combustion; it also reduces the compression work, frictional losses and temperature and mechanical wear caused by friction, so the useful life of the engine is increased. Also, tendency to spark knocking increase with constant volume combustion, so to avoid knocking the swirl of air/fuel mixture should be satisfying. Also, ignition timing should be arranged to avoid knocking and back pressure on the piston.

2.1.2 Hyper-Expanded Cycle

As it is stated in previous part, to increases thermal efficiency we should expand the shaded area in Figure 2.1. One of the ways to expand the area is to apply constant volume combustion as stated before; there is another possible way, hyper-expanded cycle. The point 4 in Figure 2.1 is the end of expansion stroke, and as it is seen in the figure, the pressure at point 4 is relatively high; it is around 3 atm [27], it means: there is a potential to produce useful work. The common way to use this relatively high exhaust pressure is to use a turbocharger. In naturally aspirated engines, intake air goes into cylinder by vacuum of downward motion of piston, but the cylinder is not filled fully. The ratio of gas flow into the cylinder to the theoretical mass of gas that can be inducted in ideal conditions is called as volumetric efficiency. The aim of using turbocharger is to increase volumetric efficiency by increasing the mass of intake air by increasing pressure so the density, by compressing intake air. To operate this compressor (turbocharger), the exhaust gas is used. Another way to utilize relatively high exhaust pressure is to increases the length of expansion stroke, so the relatively high exhaust pressure at the end of expansion stroke of a conventional crank shaft engine can keep doing work against the piston; this process is called the hyper-expanded cycle. But this may be impossible with conventional crank shaft engines which have the same compression and expansion stroke, because high compression ratio increases tendency to knocking, so this limits compression stroke and expansion stroke. The hyper-expanded cycle can be shown as in figure 2.5; the work result of conventional crank shaft engine cycle is the area within the points 1-2-3 and 4’, the work result of hyper-expansion cycle is the area within the points 5-2-3 and 4’. The area so the useful work of hyper expansion cycle is bigger than conventional crank shaft engine cycle, it means higher thermal efficiency. The hyper-expansion cycle was applied in some engines in the past, although the method decreased fuel consumption and increased thermal efficiency; the overall result was not satisfactory because of following reasons: in hyper-expansion cycle piston travels longer strokes compared to conventional cycle, so hyper-expansion cycle takes longer time it may cause lower power. Actually, for some throttle conditions exhaust pressure at the end of expansion stroke may drop below ambient pressure and it may produce negative work on the piston. So an optimum point for hyper-expansion should be selected.

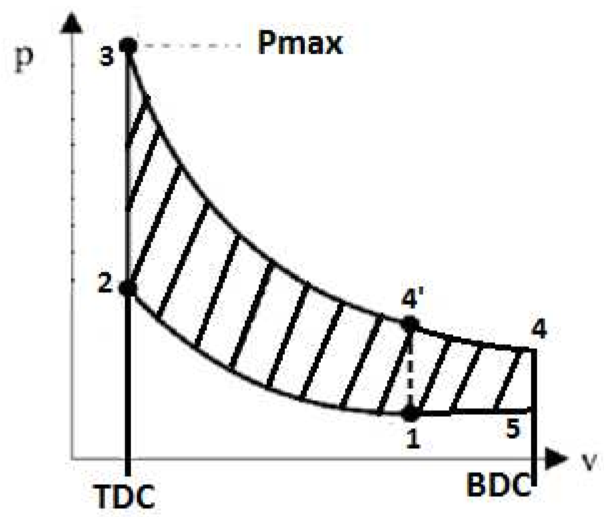


Figure 2.5: Hyper-expanded cycle

2.1.3 Modification Of Gas Exchange Process

There is another point which will be considered to optimize engine performance and used a design point in our new design engine; it is modification of gas exchange process. In conventional engines, the piston moves within the same limits and when it reaches to its upper limit, the TDC, for exhaust stroke, there is still remaining volume as seen in Figure 2.6. At the end of exhaust stroke, there will be exhaust gas in that volume, and this residual exhaust gases will try to prevent fresh air/fuel mixture to go into cylinder in intake stroke and decrease the density of the gas entering the cylinder by heating it. And this will cause to decrease in volumetric efficiency.

There are some studies in the literature about this residual gas problem; one of them is valve overlap method. When the piston reaches to the upper limit, TDC, both of the two valves are open and exhaust gas with relatively low pressure helps fresh air/fuel mixture with relatively high pressure to goes into cylinder; the pressure difference between intake and exhaust manifolds initiate gas flow and helps residual gas to flow out of cylinder, but it may cause some amount of fresh air/fuel mixture to escape into exhaust manifold and increase in fuel consumption, and to create pressure difference between intake and exhaust manifolds, there is need to design special massive manifold systems [27]. There are some engine designs in the literature to eliminate residual gas at the end of exhaust stroke by mechanically such as Atkinson engine. In that engine design, piston moves further position than a conventional engine by a special linkage mechanism and there is a little amount of residual exhaust gas at the end of exhaust stroke it means there is larger free volume for fresh intake charge and increase in volumetric efficiency.

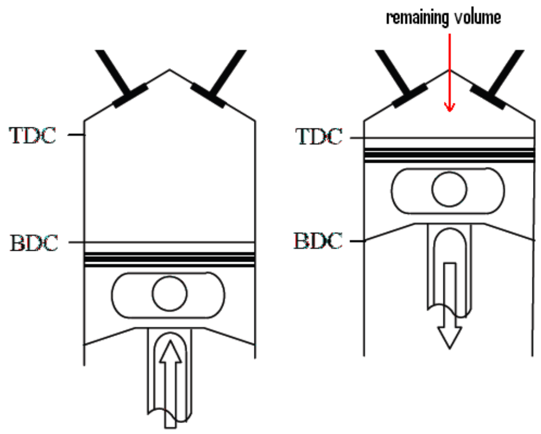


Figure 2.6: Piston working limits in a conventional engine

2.1.4 Alternative Valve Systems

Another point, which will be considered in new design engine to optimize efficiency, is valve system. In conventional internal combustion engines, poppet valve system is used. As seen in Figure 2.7, a conventional poppet valve blocks the port and the flow itself; as a result quality of swirl, which is very important effects on combustion efficiency, decreases [27]. There are some alternative valve systems in the literature as follows: rotary valves, slide valves and sleeve valves. One of them may be used to attain greater flow area and better gas dynamics, but they have also some drawbacks.

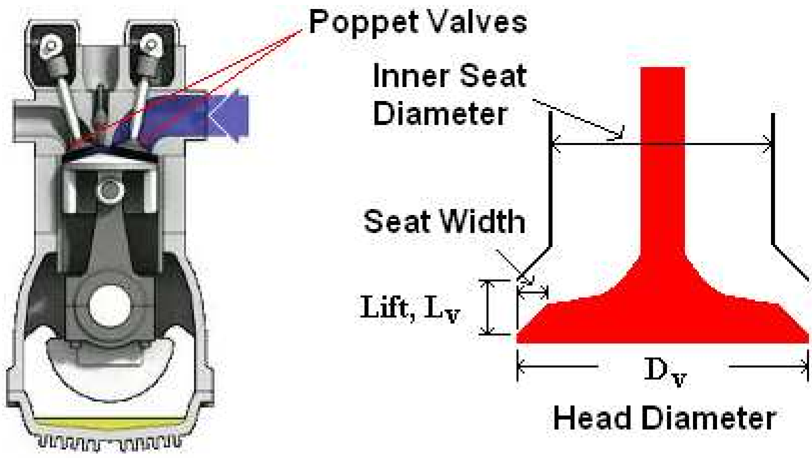


Figure 2.7: IC engine with poppet valve and a poppet valve in port

Figure 2.8 shows the rotary type valve system, in this system the valve block is driven by the crank shaft at a constant ¼ of crank shaft speed and rotates around the axis of the ball bearing shown in the figure. As seen in the figure, the ports are fully open and there is not any part of valve system to block or disturb the gas flow. One of the most important drawback of the system is the friction surface is larger than poppet valve system, so lubrication is a problem. Also, to avoid gas leakage the system needs highly satisfactory sealing because of large contact surface. In poppet valve system, high exhaust and compression pressures act on poppet seats and help to avoid gas leakage, but in this system all pressures act on valve system this is another disadvantage of the system.

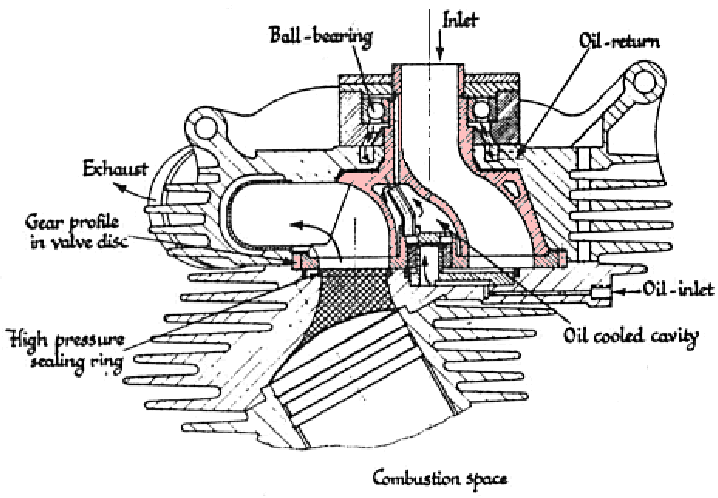


Figure 2.8: Rotary valve system

Another alternative valve system is sleeve valve system, in this valve system a sleeve, having inlet and outlet holes on itself, locates between cylinder wall and piston. And the inlet and exhaust ports of the cylinder are at the side of the cylinder different than conventional poppet valve system. The sleeve is driven by camshaft and it slides and opens inlet or exhaust port according to stroke. The same drawbacks except pressures acting on the valve system and advantages which are stated in rotary valves are valid in this valve system, too. Figure 2.9 shows a drawing of a sleeve valve system.

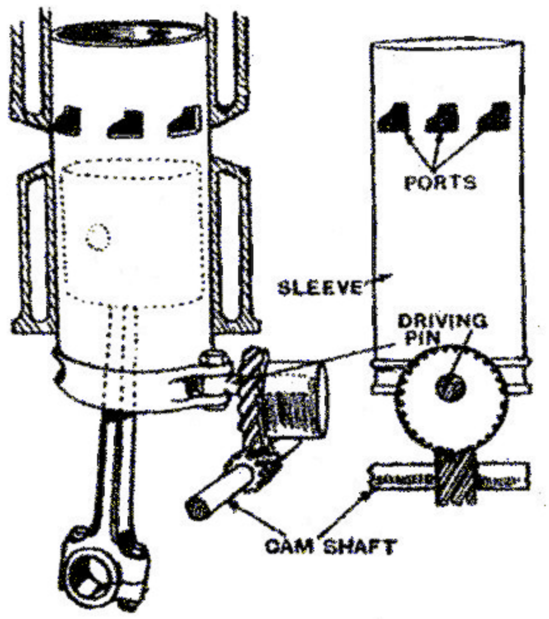


Figure 2.9: Sleeve valve system

The other alternative solution for the valve system is slide valves, this valve system has the same working principle, advantages and drawbacks with sleeve valve system, but slide valve does not cover all cylinder surfaces; so it has less friction surface than sleeve valve, this may be stated as an advantage over sleeve valves. Figure 2.10 shows slide valve system.

As stated above, with alternative valve systems higher volumetric efficiency, better gas dynamics and as a result higher combustion efficiency can be attained, but they have important drawbacks such as high friction, difficulty in sealing and lubrication problems.

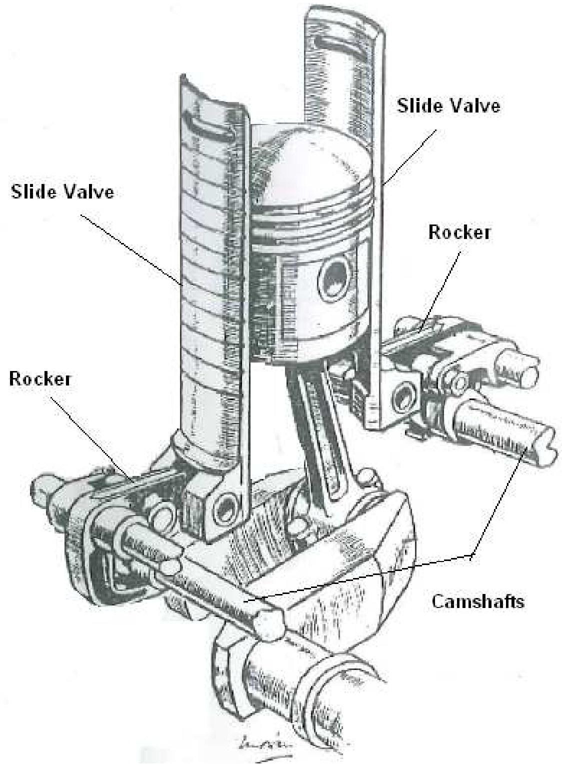


Figure 2.10: Slide valve system

2.2 Engine Designs Similar With the New Design Engine

There are some engine designs which have used the methods to optimize efficiency, mentioned above. To look at that designs and examine their advantages and disadvantages will be helpful to understand the new design engine, but this part will not cover all engine designs similar with our new design engine.

In conventional Otto engines, the compression and expansion strokes are the same, and tendency to knocking limits compression stroke and expansion stroke, so the hyper-expanded cycle which plays an important role on engine efficiency is not applicable. But in 1882, Atkinson introduced its four-stroke engine with hyper-expansion concept for the first time which has higher thermal efficiency than Otto cycle. The first version of Atkinson engine was composed of two opposed pistons. The four strokes of the operation are occurred for the one revolution of crank shaft by the help of complex linkage mechanism. The most important feature of the engine is that the engine has different stroke lengths by the help of its complex linkage mechanism; this eliminated the effect of knock tendency on hyper-expanded cycle which is stated before, and increased thermal efficiency by utilizing relatively high exhaust gases at the end of expansion stroke of conventional Otto engines. Also, by the help of increased exhaust stroke, there is negligible amount of residual exhaust gas in the cylinder; it means more free volume for fresh air/fuel mixture, so increased volumetric efficiency. The Figure 2.11 shows Atkinson engine, its linkage mechanism and strokes with different lengths. As seen in the figure, the engine completes its cycle for the one rotation of crank shaft.

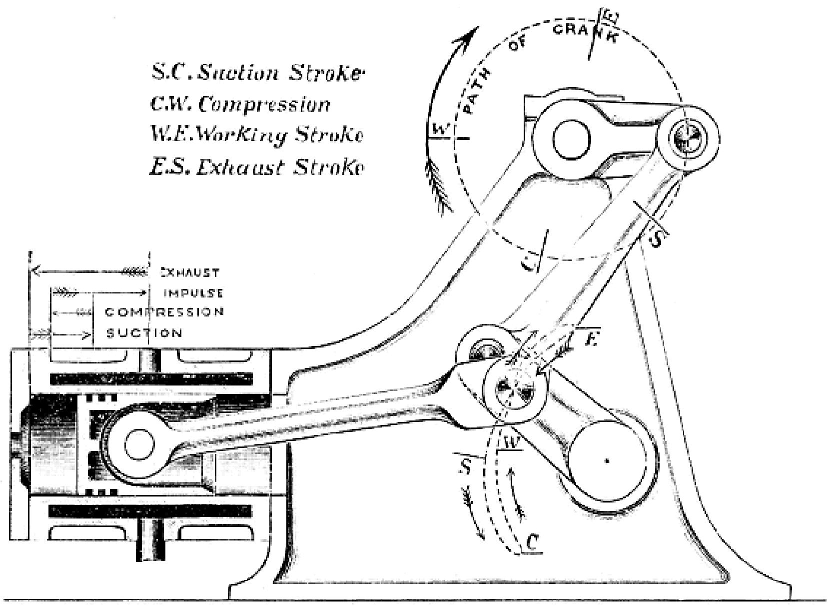


Figure 2.11: Atkinson engine

Although Atkinson engine had higher thermal efficiency, it was heavy, complex and its speed was limited compared to four-stroke Otto cycle engine. So, it couldn`t find wide commercial application. Another design which is similar with Atkinson`s opposed piston engine, was introduced by Woolson in 1931. In this design, two cams are used to operate the opposed pistons which are located in common cylinders. Fresh air/fuel mixture is taken into cylinders from the inlet port located on one end of the common cylinder and compressed between two pistons, and exhaust gas is sent to exhaust port located on the other end of common cylinder after expansion. In the engine operation, two pistons are used to create one combustion volume. Higher volumetric efficiency is proposed in this design, but any change on the cycle is not introduced. This engine design is important, because axial cams are used to operate pistons for the first time. The Figure 2.12 shows drawing of Woolson engine, its strokes and its two cams which operates the pistons.

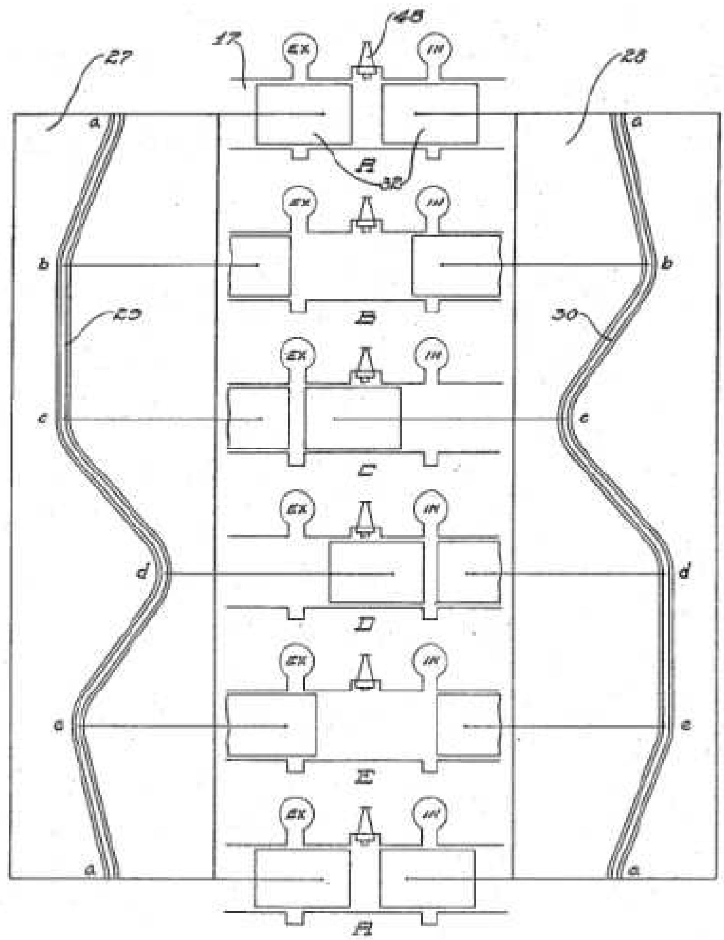


Figure 2.12: Woolson Engine

Another engine design which is axial cam operated is Tibbets engine. Operation of this engine looks like Woolson engine, two opposite pistons are operated by two axial cams in a common cylinder and the gas exchange process is held by ports on the cylinders. There are two inlet ports and one exhaust port for each cylinder, the exhaust port is located in the middle of the common cylinder. There are two combustion volumes which are created by combination of two opposed pistons and engine completes two cycles for each revolution by the help of different axial cam profile. Figure 2.13 shows drawing of Tibbets engine. Another engine design which has axial cam operated opposed piston in a common cylinder is Kristiansen engine, this engine design was introduced in 1986. This design is the most similar engine design to our project engine [27], it introduces hyper-expanded cycle and constant volume combustion which are mentioned as ways of optimizing engine efficiency in Part 2.1. Hyper-expanded cycle was also introduced by Atkinson, this engine differs from Atkinson`s because the expansion to compression ratio is adjustable in this design. The pistons are driven by axial cams and the movements of pistons dependent on cam profiles, so the movements of pistons and expansion to compression ratio can be adjusted by changing the cam profiles. In this design, there are one common inlet port, one common exhaust port and one ignition point. There are some engine designs with axial cams which are stated above, but operation of Kristiansen engine is different. In this design, the axial cams are stationary and the block containing the cylinders with two opposed pistons rotates around the centerline of axial cams. The rotating parts have big inertia compared to the other engine designs, so the forces acting on cylinder surfaces result of centrifugal forces during rotation is too much, and this can damage the engine. Also, the gas dynamics in cylinders and combustion efficiency may be affected by high centrifugal forces.

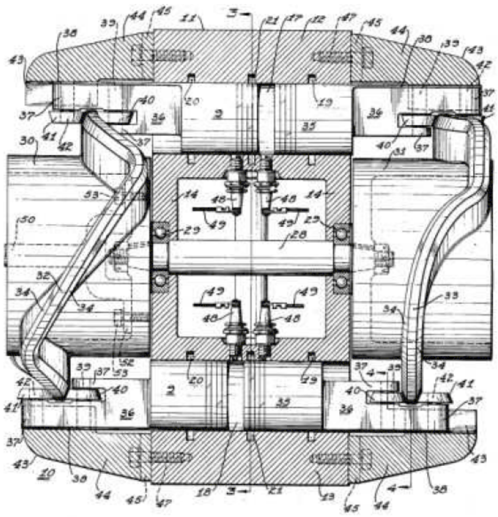


Figure 2.13: Tibbets engine

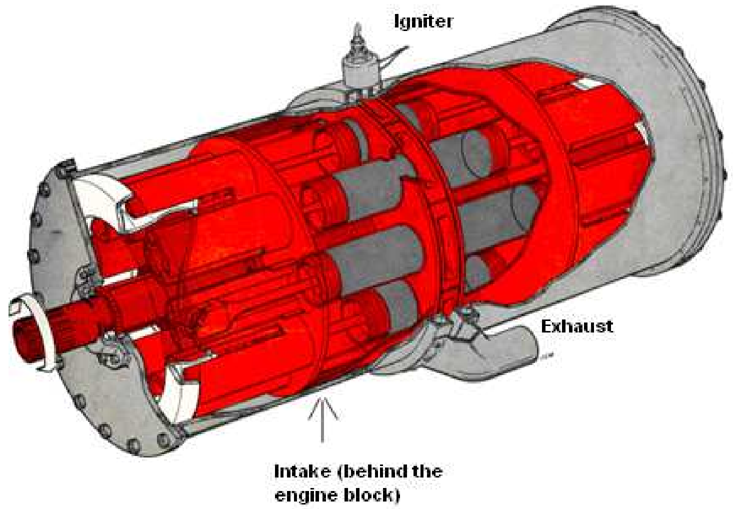


Figure 2.14: Kristiansen engine

2.3 Features of the Project Engine

The similar engine designs are stated above; the ways to increase engine efficiency which are mentioned in previous parts are tried on those engines. For example, hyper-expanded cycle and modification of gas exchange process are stated in Atkinson engine, constant volume combustion and hyper-expanded cycle were stated in Kristiansen engine, also alternative valve systems instead of conventional poppet valve were stated. As stated before, to increase engine efficiency using alternative crank shaft system is necessary, alternative crank shaft system is used in the engines given above as similar engines. The mostly mentioned method to drive pistons instead of conventional crank shaft engine is to use two axial cams to drive pistons. Also, axial cams to drive piston are used in our project engine, too. Figure 2.15 shows drawing of such type of engine. As you see in the figure, there are two cams which are mirror twin of each other. The opposed pistons travel on the special profile of opposed cams, while traveling on the profile the pistons come closer or go further, and initiate four strokes of engine. Profile of the cams determines the piston paths, so to change the piston path or keep the piston stationary during combustion (constant volume combustion) is possible with this kind of piston drive method, this may be stated as the most important advantage of axial cams.

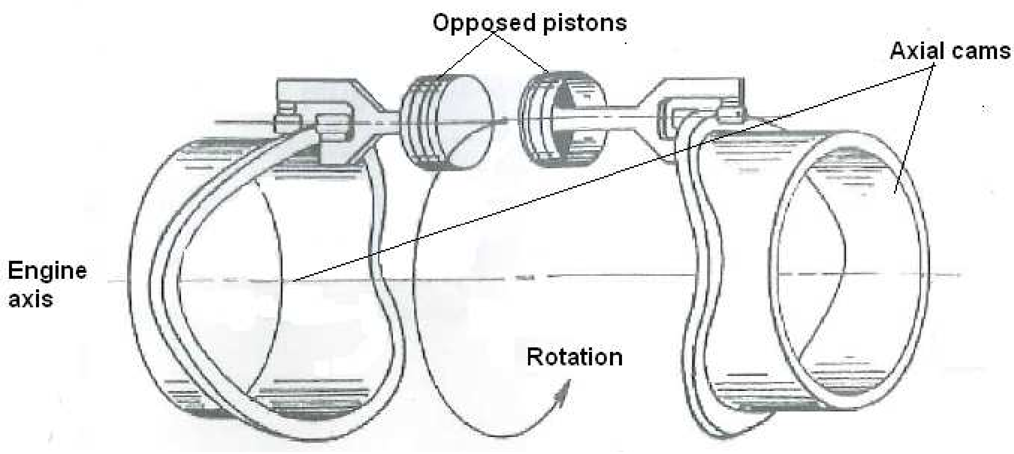


Figure 2.15: Drawing of an engine with axial cams and opposed pistons

The axial cams which are used in our project engine look like the cams in the figure, but they are mounted with 180˚ difference, so the same stroke is initiated by the pistons which located 180˚ difference on the engine and all strokes take place for all pistons in each revolution of the engine; it means all strokes take place in 180˚ revolution of engine for one piston. The project engine contains 16 pistons, 8 cylinders and 2 axial cams. Two opposed pistons work in a common cylinder and these pistons are driven with rotating axial cams. The Figure 2.16 shows the axial cams in the project engine and stroke positions on the cam. As it is seen in the figure, the axial cams are mounted with 180˚ difference and all strokes are completed in 180˚.

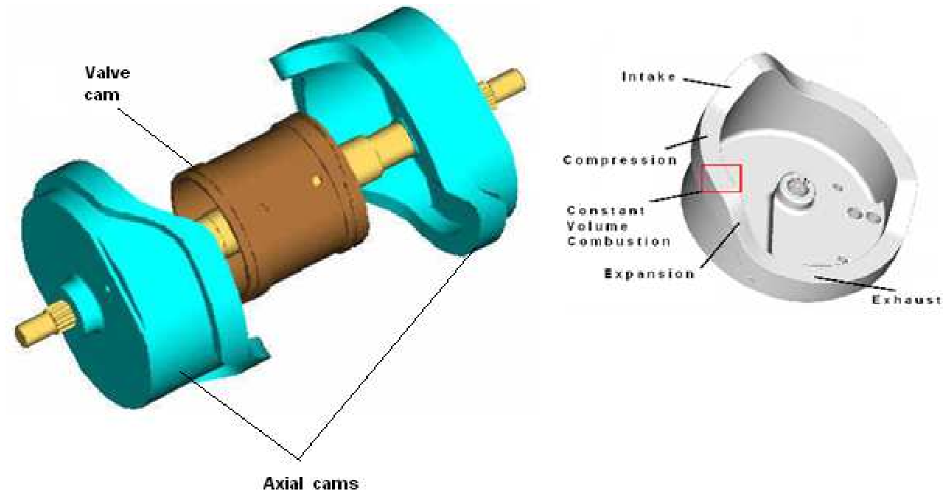


Figure 2.16: The axial cams, stroke positions on the cam and valve cam of the project engine

As stated above, there are 8 common cylinders, and 2 opposite pistons are located in a common cylinder. The positions of common cylinders can be shown as in Figure 2.17. By the help of special design 2 axial cams, there are two complete cycle in all common cylinders. And there are two combustions at the same time, so there are 8 combustion points. The combustions which are at the same time, take place in the cylinders located 180˚ difference. The positions of pistons and combustion points can be shown as in Figure 2.18.

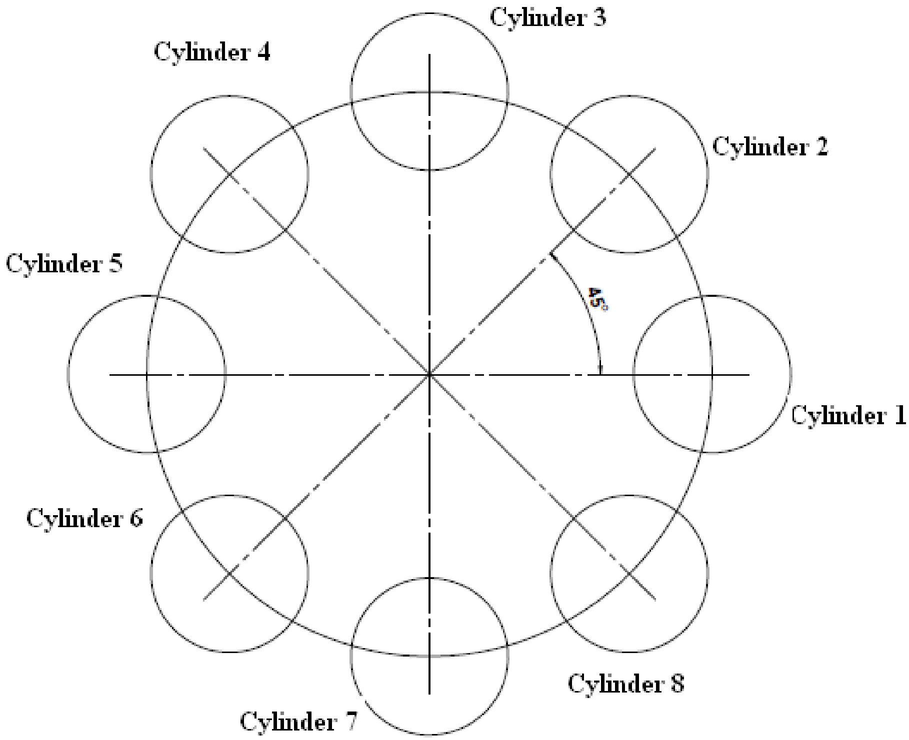


Figure 2.17: Locations of the common cylinders on the engine block

The cylinder pairs which are located with 180˚ difference are cylinders 1-5, 2-6, 3-7 and 4-8. The same strokes take place in cylinder pairs as it is seen in Figure 2.18.

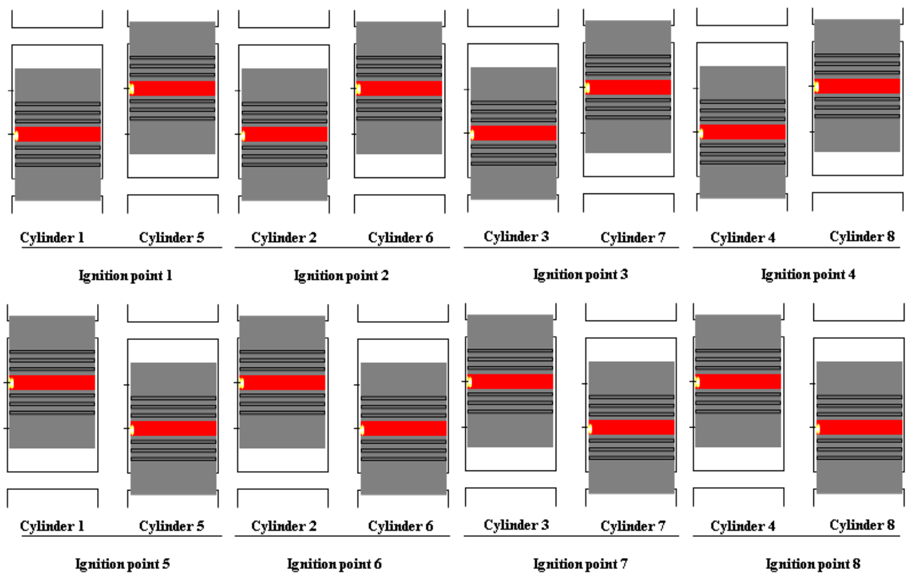


Figure 2.18: Ignition points and positions of the pistons.

To complete the cycle in 180˚ is initiated by combination of motions of the two axial cams, to examine the cycle for a piston stroke by stroke will be helpful to understand their working principle and visualize the motion of opposed pistons in the common cylinder. Figure 2.19 shows four strokes of a piston (the piston and axial cam on the left side in the figure are called as piston 1 and cam 1; the other piston and axial cam are called as piston 1' and cam 2) and the position of the pistons and axial cams. In the intake stroke, the profile of axial cam makes piston 1 travel to the axial cam 1 side of engine and create vacuum to let the fresh air/fuel mixture come into the cylinder while piston 1' is staying stationary. In the compression stroke, while the piston 1 is traveling on the flat part of the cam profile and staying stationary; the cam 2 pushes the piston 1' and makes it to travel to cam 1 side of engine and compress the air/fuel mixture. After compression stroke, both pistons stay stationary that means constant volume for combustion which is one of the most effective ways to increase efficiency. In expansion stroke, the expanded volume in the combustion chamber makes piston 1 travel to axial cam1 side of the engine while the piston 1' is traveling on the flat surface of the axial cam 2 and stays stationary in horizontal direction. At the end of expansion stroke, the piston 1 stays stationary, and the cam 2 pushes piston 1' against piston 1 and makes exhaust gases flow to atmosphere. As it is seen, the strokes of a piston is completed by combination of two piston motions, so it creates a chance to complete all strokes in 180˚ for one piston.

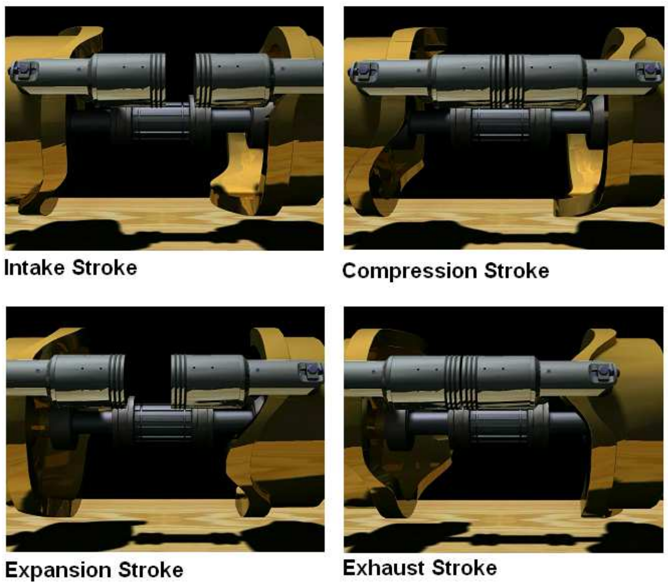


Figure 2.19: Four strokes of a piston in the project engine

In part 2.1.1, the effects of constant volume combustion on engine efficiency are given and a study from the literature [29] is given. In that study, the conventional motion of crank shaft and connecting rod is modified and pauses are created at the end of compression and expansion stroke while the crank shaft keeps rotating as seen in Figure 2.3, plot of piston path. Also, the increase in engine efficiency is stated in that study. It is possible to plot such a graph for our pistons and examine piston motion, constant volumes and gas exchange process. As it is seen in the Figure 2.20, there is 20˚ difference between the end of compression stroke and the beginning of expansion stroke with constant volume; this area is given as "constant volume combustion" in the figure. The ignition process can be initiated at any point of this area, but this ignition point should be determined after some calibration tests. But it is obvious that the project engine is able to initiate constant volume combustion easily by the help of its axial cams with special profile.

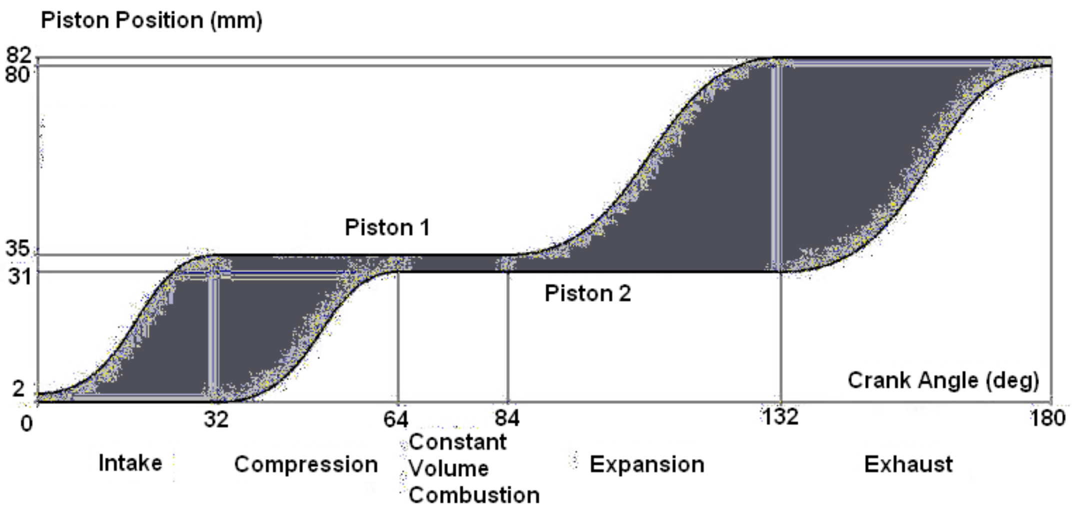


Figure 2.20: Opposed pistons paths in 180˚ rotation

Another way to increase engine efficiency is hyper-expanded cycle. With this cycle, we can use relatively high pressure exhaust gas at the end of expansion stroke of a conventional crank shaft engine. In conventional crank shaft engines, all stroke lengths are the same, so if you increase expansion length the compression length increases, too. But knock tendency is increases with increasing compression ratio; this is a limiting factor to apply hyper-expanded cycle in conventional crank shaft engines. In Atkinson engine, a complex linkage mechanism is used to apply hyper-expanded cycle; in that engine all stroke lengths are different, so knock tendency is eliminated. In Kristiansen engine and our project engine, piston motion is dependent on profile of the axial cams and stroke lengths do not need to be the same, so we can arrange the piston path and stroke lengths by changing profile of the cams easily. To apply hyper-expanded cycle, the profile of the cams is designed to have 50% longer expansion stroke than compression stroke. The hyper-expanded cycle can be seen in figure 2.20; in compression stroke the piston 2 travels from 0 to 31 mm while the other piston is stationary, but in expansion stroke, piston 1 travels 47 mm, from 35 mm to 82 mm, while the other piston is stationary, it is about 50% longer than compression stroke (31 mm). Another point which is considered in the project engine design is modification of gas exchange process. As it is stated in part 2.1.3, piston works within some limits TDC and BDC as in Figure 2.6. And there is a remaining volume, which piston cannot reach to, at the end of exhaust stroke. Some residual exhaust gases stay at that volume and reduce the volume which will be filled with fresh air/fuel mixture, so it causes to drop in volumetric efficiency. In Atkinson engine, piston goes further than a conventional crank shaft engine by the help of its complex linkage mechanism and decreases the volume of residual gas in the cylinder, and increases volumetric efficiency. The profile of axial cams is designed to reduce the volume at the end of exhaust stroke to eliminate residual gas and drop in the volumetric efficiency in the project engine. This feature of the project engine can be seen in the exhaust stroke in Figure 2.20, there is 2 mm difference between pistons (about 5.7 cc for 60 mm inner diameter of cylinder) at the end of exhaust stroke.

Another issue to be considered in the design of project engine is valve system. In conventional engines, poppet valves are used as inlet valves and exhaust valves. In poppet valve systems, gas leakage or sealing is not a problem because the pressurized gas in the cylinder pushes the valves against the valve seats and tries to close the valves; this situation may be stated as an advantage of poppet valve system. Also, poppet valve system some disadvantages as stated in part 2.1.4. As it is seen in Figure 2.7, poppet valve stays in front of the port and blocks the flow and disturbs the swirl even it is fully open. This may cause poor swirl, poor combustion and low volumetric efficiency. The conventional poppet valves are driven by a cam shaft, the sinusoidal motion of cam driven system causes the valves to open or close slowly. They come to fully open condition at the middle of the stroke; this causes a drop in the volumetric efficiency or drop in the useful work. In the project engine, an alternative valve system seen in Figure 2.21 is used. As it is seen in the figure, there are two slots: exhaust and intake slots. This valve can move 8 mm forward or backward, and opens the cylinder to exhaust port or intake port by using those slots according to stroke. The flow area of these valves is 35% larger than a conventional poppet valve and it can open or close 4.7 times faster than a conventional valve. The positions of exhaust and intake slot are different, so two cylinders can use the same intake or exhaust ports on the engine block. There are compression rings on the piston heads, and these rings are located between piston and valve, so they avoid leakage from cylinder to ports via the slot.

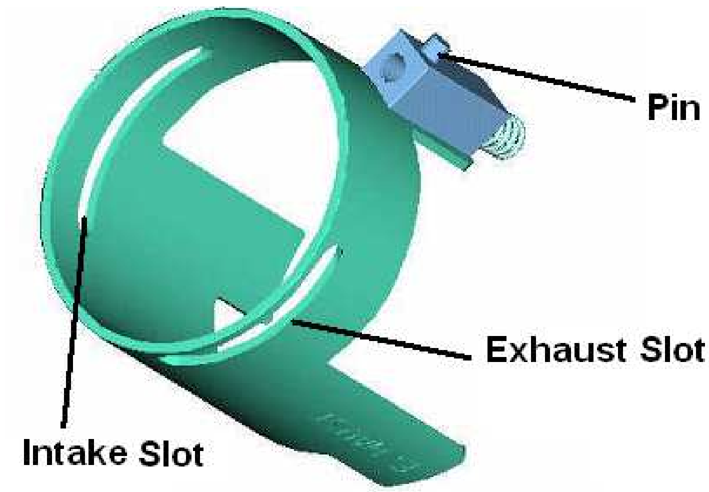


Figure 2.21: Valve used in the project engine

The philosophy behind the motion of these valves is similar with the motion of pistons. As seen in Figure 2.16, there is a valve cam, which is a hollow cylinder, mounted on the axis of the engine. This part is used to move valves and, arrange the exhaust and intake timing. To move the valves, the cam has motion profiles which are specially designed to move the valves according to piston stroke and arrange valve timing; the pin of the valve seen in Figure 2.21 travels on this profile.

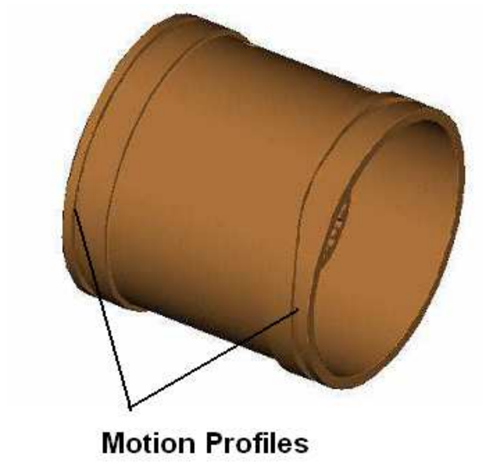


Figure 2.22: Valve cam of the project engine

To understand the working principle of these valves, we should see them on the pistons. Figure 2.23 shows the condition of these valves during intake and exhaust stroke. As seen in the picture on the left hand side of the figure, piston 1 is at the beginning of the intake stroke and the intake slot is fully open to intake port, the same situation is valid for exhaust stroke. As it is stated before, conventional poppet valve comes to fully open condition at the middle of stroke, but the valve system used in the project engine is fully open at the beginning of stroke, this is one of the most important advantages of the valve system.

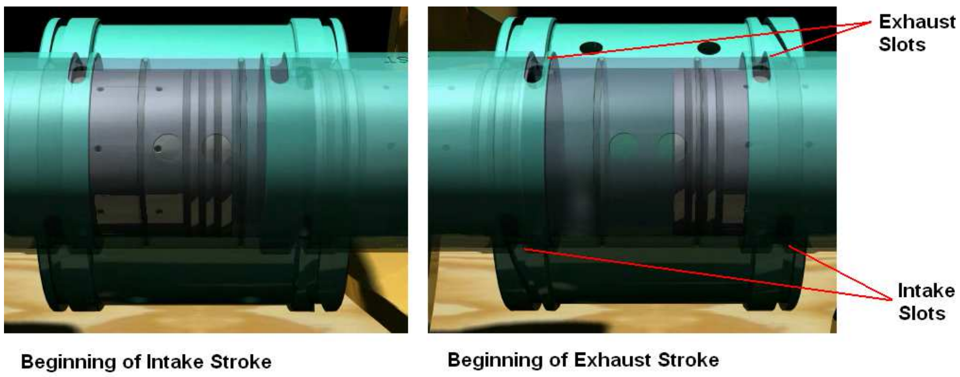


Figure 2.23: Position of valves during intake and exhaust stroke

Some possible ways to increase engine efficiency are stated in part 2.1 and some engine designs which try to apply those possible ways are also stated. In our project engine, all of those possible ways are considered and applied on the engine as mentioned above. Besides, it also has some advantages by the help of its working principle and geometry. In conventional crank shaft engines, component of the force, which is applied by crank shaft on connecting rod and piston head, acts on the cylinders wall; this affects compression rings and oil film between piston head and cylinder wall. But in the project engine, the pistons are driven with axial cams, and these axial cams apply force on pistons perpendicularly, so there is no force component acting on the cylinder wall, this will increase useful life of compression rings and engine. Conventional crank shaft engines work with vibration and noise because of the nature of crank shaft and connecting rod motion; but in the project engine, the pistons travel on the smooth profile of the axial cams, so there is no vibration caused by motion of pistons and cams. Also, combustion takes place in the cylinders with 180˚ difference, so the engine is in balance in radial direction. As it is stated before, the pistons travel on the profile of the axial cams, there is not a connecting rod or the other parts which are used in conventional crank shaft engines to assemble the piston to crank shaft, so the pistons used in the project engine are lighter than the pistons in conventional crank shaft engines; this is a factor which can affect engine efficiency. The engine blocks of conventional internal combustion engines are commonly manufactured with casting process. But the block of project engine can be manufactured by a CNC milling machine. Also, the components of the engine can be assembled easily. These features of the project engine can be stated as its advantageous sides.

CHAPTER 3

EXPERIMENTAL SETUP

In this chapter, the designed and constructed test set-up for special engine that was mentioned in previous chapter will be introduced. Each subcomponent in the set-up and their working principle will be told step by step. Figure 3.1 shows the overall test set-up.

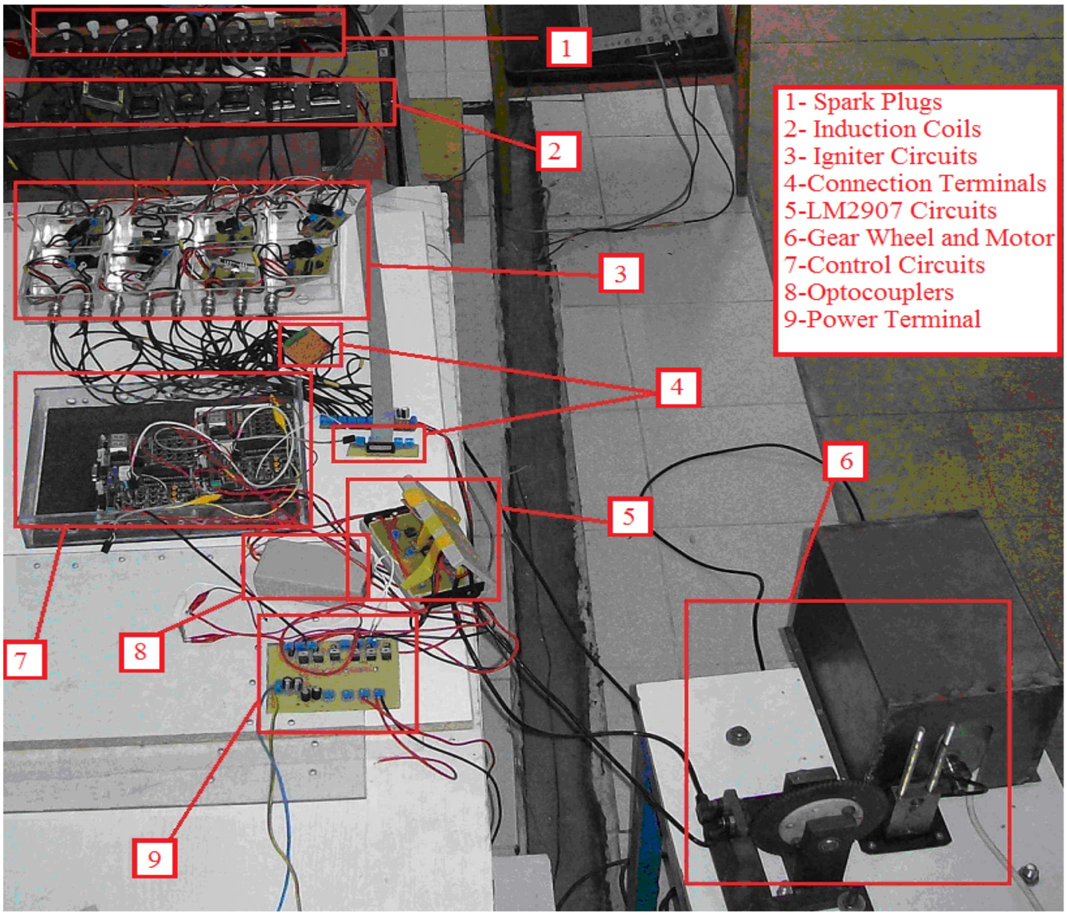


Figure 3.1: Experimental set-up

3.1 Induction Coils, Ignition Cables and Spark Plugs

3.1.1 Spark Plugs

There are many ignition types which are used now or was used in past, they can be grouped by their high voltage creation or their voltage distribution. Whatever ignition type is, spark plug plays vital role in petrol engine. It is responsible for ignition of air-fuel mixture. The quality of ignition directly affects several factors which have great importance for both quality of the driving experience and the environment. This includes starting, smooth running, general engine performance and efficiency as well as reduction of harmful emissions. When we consider a spark plug must ignite air-fuel mixture between 400 and 4000 times per minute, it becomes clear how difficult the spark plugs job is and how important the contribution of spark plug technology is for adherence to current emission standards and to the reduction of fuel consumption.

A spark plug is composed of different parts as seen in Figure 3.2: Connection terminal, insulator, current leakage barriers, gasket, inner seals, metal shell, centre electrode, resistor and ground electrode. Connection terminal is the top part of the spark plug, it is a barrel shaped or 4mm thread. The high tension ignition lead or pencil coil is plugged onto the terminal. This connection allows the high voltage to be transferred to firing end of spark plug. The ceramic insulator has two tasks. The main function is to provide a high degree of electrical insulation preventing the high voltages discharging to earth externally via the engine block to other components. It also allows efficient transfer of the heat of combustion from the firing end to cylinder head. The current leakage barriers on the outside of the insulator prevent the leakage of electrical energy to the vehicle body earth. They do this by increasing the length of the path that the current would travel to reach the earth point provided by the metal shell. This in effect is like having a significantly taller insulator section ensuring that electrical energy takes the path of least resistance through the centre electrode. The gasket ring prevents any possibility of combustion gas leaking past the spark plug due to the extremely high combustion pressures. In doing this it prevents any cylinder pressure losses. Another important function is that provides good conduction of heat to the cylinder head. The inner seals create a gas-tight connection between insulator and metal housing. The seal is made from talcum ring enclosed between two additional stainless steel sealing rings. During production of spark plug the talc ring is compacted tightly ensuring a perfect gas tight seal. The metal housing or shell also plays an important role in the thermal conductivity of the spark plug as it is part of the mechanism of transferring heat away from the insulator to the cylinder head. The centre electrode of a standard spark plug is comprised mostly of a nickel alloy. From the end of this electrode the spark must jump over to the earth electrode. Some spark plugs have a copper core, which significantly improves the thermal conductivity preventing overheating. The resistor is used to limit high voltage to ensure electromagnetic compatibility (EMC). And thus the fault-free operation of the onboard electronics, a ceramic resistor is used inside the spark plug as an interference suppression device. This resistor is composed of carbon and glass compounds which form a solid component within the spark plug. The last part is ground electrode, this part is made of a special nickel alloy, it provides opposite electrical pole to central electrode and high voltage jumps over this part.

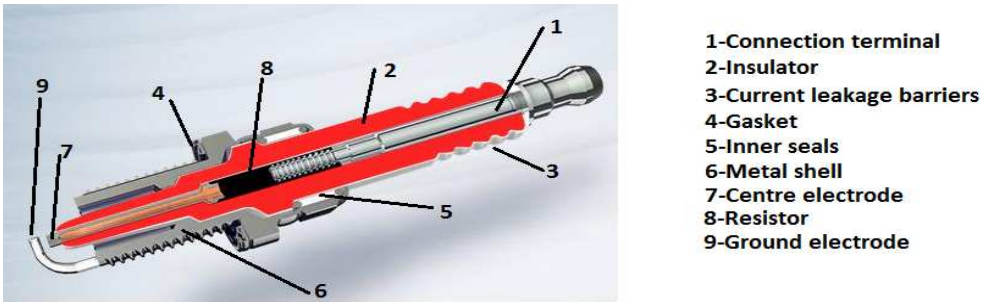


Figure 3.2: Parts of a typical spark plug

In our system, standard NGK spark plug is used. This is spark plug of choice in millions of vehicles, because of its consistent performance and OEM quality. Figure 3.3 shows the spark plug which is used in our system.

Figure 3.3: Standard NGK spark plug which is used in our system.

3.1.2 Ignition Cables

Another main component of ignition systems is ignition lead. It is responsible for conducting necessary voltage for spark to spark plug connection terminal as little loss as possible. Since the ignition voltage rises up to 36000 volts which is very high voltage range, the ignition leads have to be protected accordingly against over voltage. The ignition voltage must never flow to ground, since this could cause misfiring, so there should be good insulation. As any component on the engine, they should be designed to resist hard working environment. They should be resistant to becoming brittle and cracked even at high temperatures and in contact with oil or petrol. The parts of ignition cable can be shown as in Figure 2.4 there are some kinds of ignition cable in the market, they have different color, resistive material, insulation, but they have the same principle. Ignition leads are connected to ignition coil and spark plug with its two terminals, its metal contacts touch the contact of ignition coil and connection terminal of spark plug; and high voltage flows through the core of ignition cable. There are a inner insulation used to prevent high voltage to jump to ground, a metal bread to eliminate magnetic field and a outer jacket to protect ignition lead from working conditions and provide extra insulation.

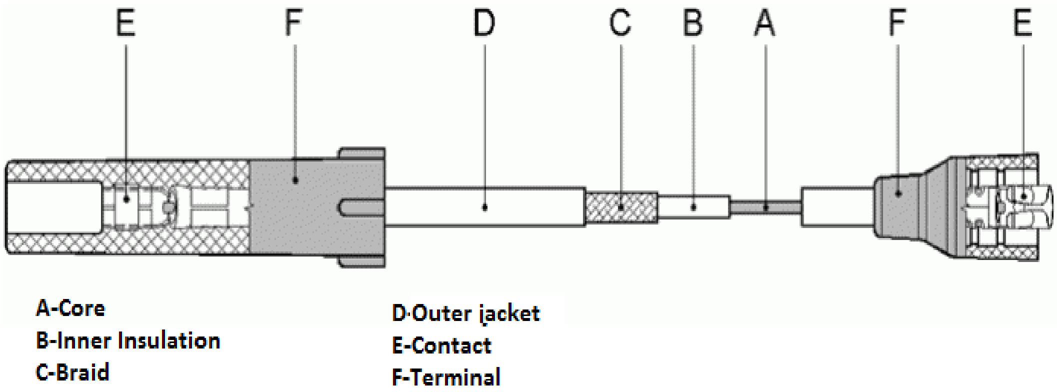


Figure 3.4: Parts of an ignition cable

As mentioned in the part related to spark plugs, electro-magnetic compatibility is an issue should be worked on in ignition cables, too. Wherever electric current flows, electromagnetic fields are formed, as for example in mobile phones and radio waves. Such electromagnetic fields also occur during ignition. They increase considerably in intensity at the time of each “spark breakaway” on the center electrodes of spark plug which results in strong voltage peaks along the lead. However, since strong electromagnetic fields can cause disturbances in electronic devices-such as the radio, engine or transmission control units or the ABS-they have to be kept within a non-damaging range, to lower electromagnetic field magnitude, the ignition leads are equipped with electrical resistors, to limit voltage peaks during spark breakaway and discharge of the ignition coil. The new design engine which is used in our test set-up is suitable for the direct ignition system, so the usage of ignition cable and electromagnetic interference caused by the ignition cables can be eliminated.

There are different types of ignition leads, they differ according to the materials used for the conductor and the type of resistor required for interference suppression. As seen in Figure 3.5, there are kinds of NGK ignition leads, they are copper ignition leads with interference suppression resistor in the connector, carbon resistor ignition leads and ignition leads with inductive resistor.

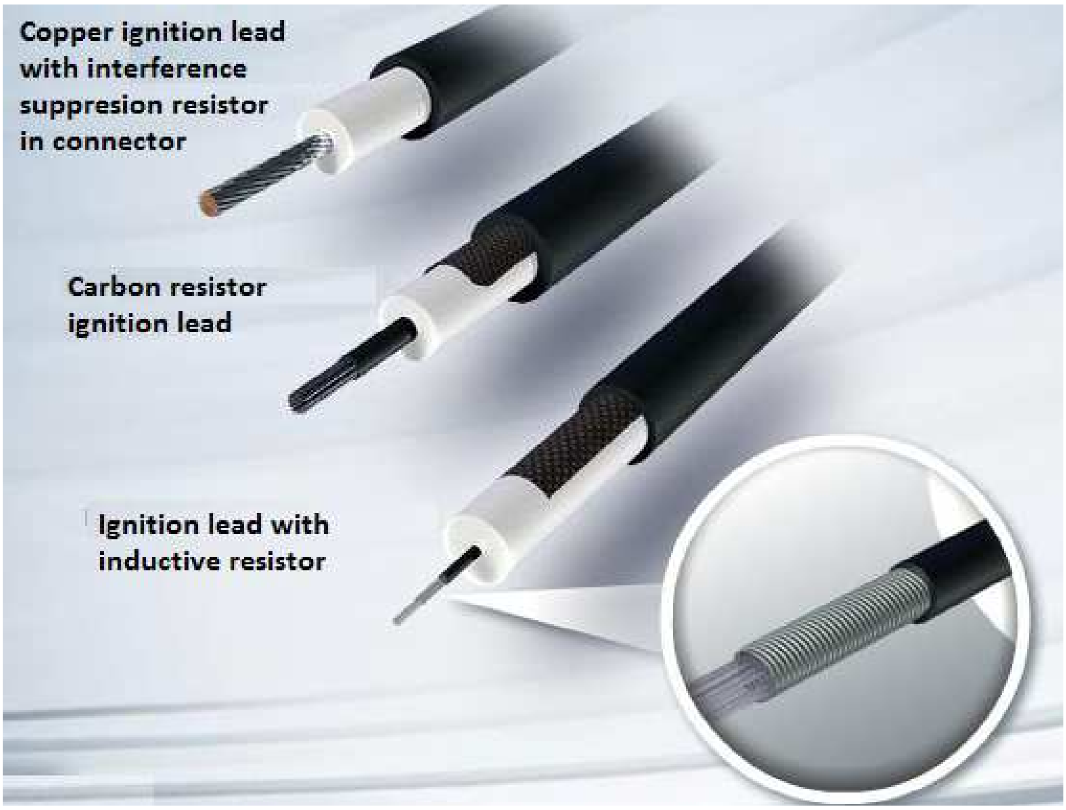


Figure 3.5: NGK ignition lead types

In the ignition leads with copper core, the copper formed as tin-plated, this form protects the copper from oxidation. The core is enclosed in a silicone shell for increased electrical insulation to prevent misfiring. The outer insulation increases insulation and protects the lead against temperature, oil and petrol. These types of ignition leads are not equipped with their own interference suppression resistor, but it contains a resistor in the spark plug and coil connector. Its resistance is between 1 and 6.5 kΩ. Another ignition lead type is carbon resistor ignition lead. Inside of this type ignition leads; there is braided carbon impregnated fiberglass. This fiberglass core is surrounded by two silicone layers and fiberglass fabric. The inner insulation made of silicone provides for stability and electrical insulation. The fiberglass fabric increases the tensile strength, the outer insulation which is made of silicone can withstand high temperatures and resistant to petrol and oil. This type of ignition leads have interference suppression resistance is usually between 10 kΩ -23 kΩ per meter. The last ignition lead type is ignition lead with inductive resistor. This type of ignition leads also have a fiberglass core, over the fiberglass core there is a conductive and magnetic silicone layer, around which stainless steel wire is wound. As in a coil, inductive voltage occurs here; the coil wire picks up and delivers energy. As a result the inductive voltage is internally cancelled through the lead. And they have silicone and fiberglass layers to increase electrical insulation; they also have outer insulation to withstand high temperature, oil and petrol. This type of ignition leads have 1,8 to 2,2 kΩ suppression resistance range.

In our system, Bougicord Class B ignition leads are used. The properties of our ignition lead is black color, Ø7mm outer diameter, maximum working temperature 100 ºC, minimum working temperature -30 ºC, silicone outer jacket and 5,6 kΩ resistance. This type of ignition lead is used for general applications and easy to find in the market. The properties are pretty good and enough for our application.

3.1.3 Induction Coils

A spark can arc from centre electrode to ground electrode only if a sufficiently high voltage is applied. In a typical spark discharge, the electrical potential across the electrode gap is increased until breakdown of intervening mixture occurs. Ionizing streamers then propagate from one electrode to the other. The impedance of the gap decreases drastically when a streamer reaches the opposite electrode; and the current through the gap increases rapidly. This stage of the discharge is called as “breakdown phase”. The next main phase is “arc phase”, in this phase thin cylindrical plasma expands largely due to heat conduction and diffusion and, with inflammable mixtures; the exothermic reactions which lead to a propagating flame develop. The final phase is “glow discharge”, in this phase the ignition coil dumps its energy into the discharge circuit. There are also some minor phases; such as predischarge and transition phase. As it can be easily understood, they are transition phases between main phases. The figure below shows voltage current variation simply during spark discharge. too small time interval for the phase. The glow discharge phase has the lowest power level (~10W), but the highest energy (30 to 100 mj), due to its long discharge time.

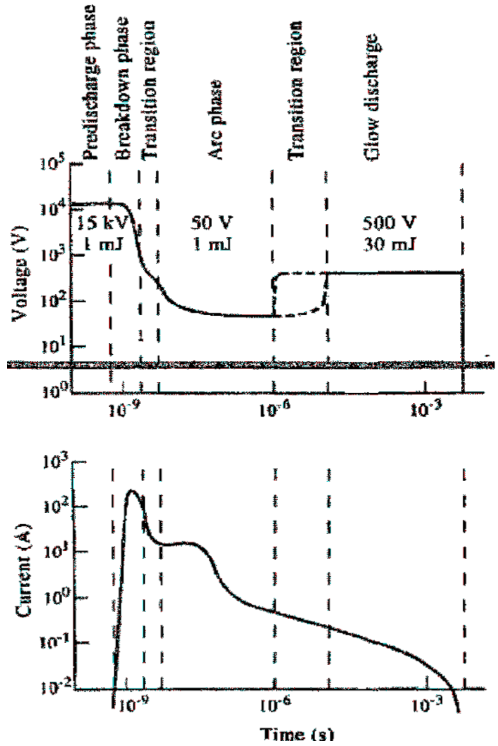


Figure 3.6: Variation of voltage and current during spark generation

As seen in the Figure 3.6, there is a need of high voltage around 18000 to 24000 volts to initiate spark discharge. To achieve this high voltage there is a special part, induction coil. An induction coil is formed by two coils of insulated copper wire wound around a common iron core. The first coil, called “primary winding” is composed of around few (tens or hundreds) turns of coarse wire. The second coil called “secondary winding” is composed typically of many (thousands) turns of fine wire.

Their working principle is based on Faraday`s Law. According to the law, any change in the magnetic environment of a coil of wire will cause a voltage(emf) to be induced in the coil. No matter how the change is produced, the voltage will be generated. If any current flows through the primary winding, it creates a magnetic field. Because of the common core, most of the primary's magnetic field couples with the secondary winding. The primary winding behaves as an inductor, storing energy in the associated magnetic field. When the primary current is suddenly stopped, the magnetic field rapidly collapses. This change in the magnetic field cause a high voltage pulse to be developed across the secondary terminals through electro-magnetic induction. Because of the large number of winding turns in the secondary coil, the secondary voltage pulse is typically many thousands of volts compared to the first winding. Figure 3.7 below shows an old fashioned ignition coil.

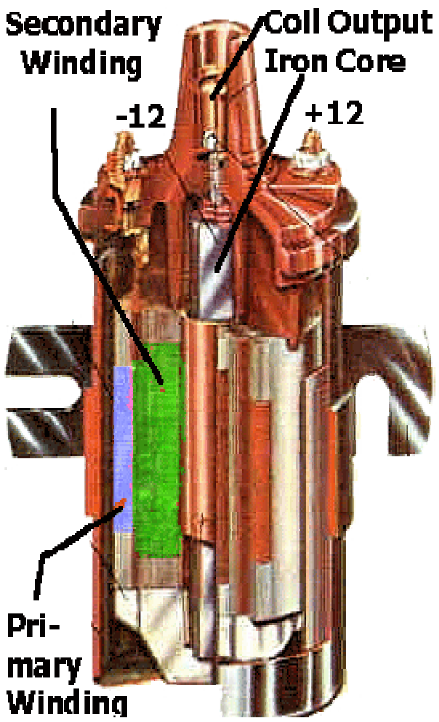


Figure 3.7: Old fashioned Ignition Coil

Figure 3.8: Delphi Pencil Coils

As you see in the figure, primary winding is on the outside; the secondary one is on the inside and has a longer length. And there is a common center core with two open ends; it also increases magnetic flux losses. This ignition coil is an old fashioned one, now there are many types of ignition coils in the market. All of them have different shapes according to their design considerations, but all of them are based on the same working principle. In modern ignition systems, the ignition coils are getting smaller to achieve more compact engine sizes. These new generation ignition coils can be directly mounted on spark plug while eliminating ignition leads; they are called pencil coils and plug top coils. These types of coils have some benefits such as magnetic noise reduction, increases reliability, high accuracy, lower mass and sizes etc. These ignition coils on the left side, Figure 3.8 are example of new generation ignition coils; their design consideration is taking advantage of unused space found above conventional spark plug.

Their compact size enables them to fit on spark plug hole which varies between 22mm to 29.1 mm. Their energy rates also changes between 35 mj to 80 mj according to their sizes. Another new generation ignition coil type is plug top coil. This type of coil is designed to be used when packaging constraints prevent the use of pencil coils (spark well inside diameter <22 mm), also their energy ranges are higher than pencil type coils, between 35 mj to 100 mj. Figure 3.9 shows plug top coils.

Figure 3.9: Delphi Plug Top Coils

These two types of new generation coils are good example to understand design consideration of new generation ignition coils. Another design consideration is ease of control of the system, in wasted spark systems; one coil serves two spark plugs (Two coils for 4-cylinder engines; three coils for 6-cylinder engines.). In this arrangement the coil generates two sparks per cycle to both cylinders. The fuel in the cylinder that is nearing the end of its compression stroke is ignited, whereas the spark in its companion that is nearing the end of its exhaust stroke has no effect. The wasted spark system is more reliable than a single coil system with a distributor and less expensive than coil-on-plug. Where coils are individually applied per cylinder, they may all be contained in a single molded block with multiple high-tension terminals. This is commonly called a coil-pack, Figure 3.10 shows an example coil pack designed for a 4-cylinders engine with wasted spark ignition system.

Figure 3.10: Delphi Waste Spark Pencil Coil Pack

In our test set-up we have used wasted spark ignition coil, they had been designed to serve two spark plugs at the same time. Our ignition system is not a wasted spark ignition system but we have two cylinders at compression cycle at the same time so we need two sparks simultaneously. The ignition coils which are used in our system are Mako ignition coil is used, as in the Figure 3.11 it is designed for wasted spark ignition systems. There are some materials which are used in ignition coils to provide insulation; this ignition coil is filled with epoxy resin to provide insulation. This ignition coil is used in the system because it is widely used in automotive industry, so it is cheap and easy to find in the market.

Figure 3.11: Mako ignition coil which is used in our system

3.2 Igniter Circuits

As mentioned before, ignition coils are composed of two coils, they are primary and secondary windings. When a current flows through the primary winding, it creates a magnetic-field; if the current s suddenly stopped the magnetic field rapidly collapses. This change in the magnetic field cause a high voltage pulse to be developed across the secondary terminals through electromagnetic induction, this is the working principle of our ignition coils. To suddenly stop the current, we need a breaking system. Though there are different types of ignition system, the use of a breaking system is consistent.

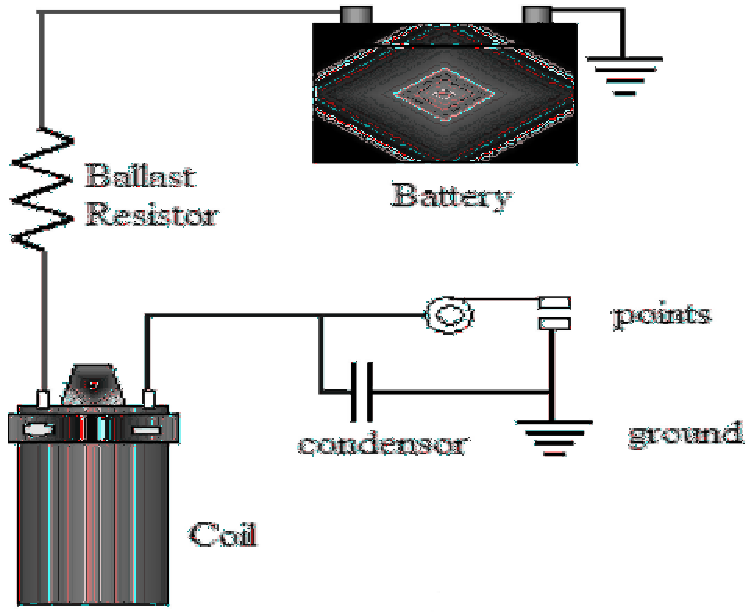


Figure 3.12: Typical point type ignition system

The Figure 3.12 is a typical point type ignition. The conventional breaker point-type ignition system has been in use since the early 1900s. In this system primary circuit of the ignition coil receives power from the battery through a resistor. The power is grounded through closed ignition points in the distributor. Current flows through the windings of the primary coil, creating a magnetic field. When the points are opened by the distributor cam. By touching of the distributor cam, the current's electrical circuit is broken, collapsing the magnetic field. The force from the collapse crosses the windings of the secondary coil and creates an electrical current within them. The current flows into the distributor cap and eventually into the spark plugs, all in a split second. As it can be understood from the Figure 3.12, the early ignition systems uses mechanical contacts to stop the current in the primary winding, there are some disadvantages of this system such as maintenance, difficulty in adjustment; wearing caused from arc and mechanical contact, poor ignition timing and unreliability. For this reason advance in the ignition systems have replaced mechanical contacts with various sensors, such as camshaft position sensor and crankshaft position sensor and some dedicated IC`s. Figure 3.13 shows a schematic view of a new generation distributorless type ignition system working principle.

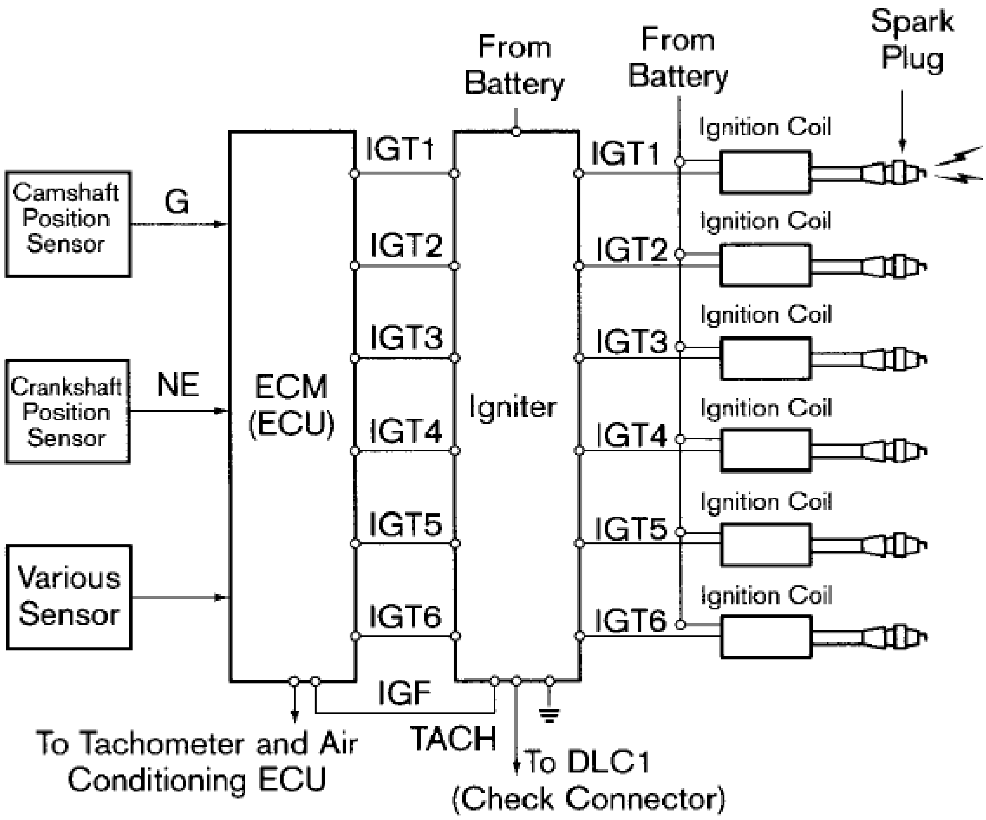


Figure 3.13: Toyota 1 MZ-FE 94 Direct Ignition System (DIS).

As seen in the Figure 3.13, there is a circuit called igniter, it receives ignition timing signals from ECU for each ignition coil and open or close the current to primary winding of ignition coil. The igniter circuits use transistor, mosfet or dedicated IC`s to trigger primary voltage of the ignition coil. In our system, the igniter circuit is based on microcontroller, PIC16F628A and the other main components are mosfet, IRF540N and optocoupler, 4N35. The commercial igniter circuits have duties such as receiving ignition timing signals from ECU, drive ignition coils and ignition detecting, for these purposes to use a microcontroller will be beneficial. Some properties of PIC16F628A are important for our application, it have such properties: 20MHz maximum operating frequency, 2048 words flash program memory, 224 bytes memory, 128 eeprom memory, 3 timer modules, 2 comparators, 1 capture/compare/PWM module, USART serial communication protocol, 10 interrupt sources and 16 I/O pins [2], these properties are given in Table 3.1. The most important properties of optocoupler for our application is turn-on and turn-off time, they are typically 7 us (max 10 us), Table 3.3.The properties of IRF540N related to our application is: continuous drain current at 10 volts gate-source voltage is 33 A, turn on delay time is typically 11 ns, turn-off delay time 39 ns and rise time 35 ns [3] as given in Table 3.2. These properties are pretty good for our application.

Table 3.1: The related features of PIC16F628A

Max. Freq.	Flash Memory	RAM	Timer	Capture/ Compare/ PWM	Serial Com.	Interrupt Sources	I/O	Eeprom Memory	Comparator
20 MHz	1024 Words	224 Bytes	3	1	USAR T	10	16	128 Bytes	2

Table 3.2: The related features of IRF540N

Continous Drain Current(Vgs @10V)	Turn-on Delay Time	Turn-off Delay Time	Rise Time
33 A	11 ns(typ.)	39 ns(typ.)	35 ns(typ.)

Table 3.3: The related features of 4N35

Turn-on Time	Turn-off Time
10 us (max)	10 us(max)

There are eight igniter circuits in our ignition system, they receives ignition timing signal from the main circuit. The ignition timing signal is in the form of 0-5V square wave and the igniter circuits are triggered on the rising and falling edges of the signal. To create a spark, the ignition coils should be charged for a while this is our dwell time, it begins with the rising edge of the ignition timing signal ends with the falling edge. The triggered mcu, PIC16F628A, uses the optocoupler to drive the mosfet, so we can isolate the microcontroller from high voltage driving mosfet. The igniter circuit which is used in the system is shown in Figure 3.14

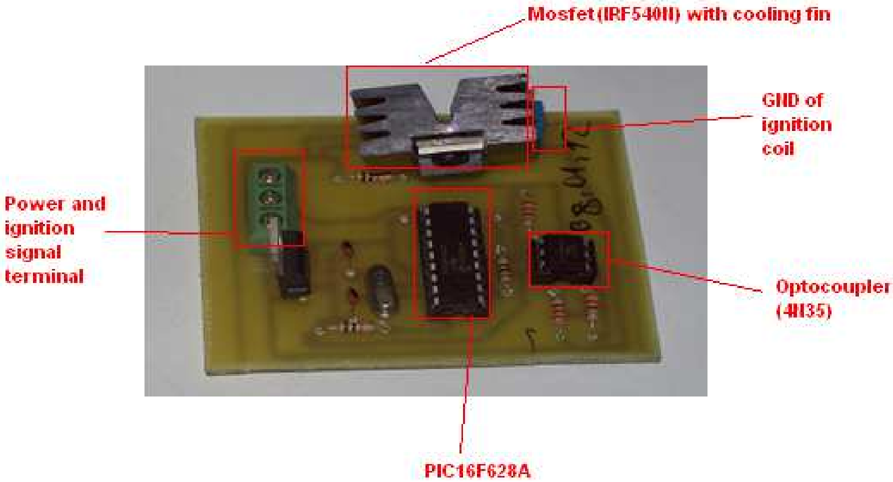


Figure 3.14: Igniter Circuit

Figure 3.15 shows the schematic view of igniter circuit which is designed with ORCAD 9.0; it will be beneficial to understand working principle of the circuit. The microcontroller unit which is soldered on the igniter circuit is programmed to detect ignition timing signal on pin B5 continuously. When it detects the high state of pin B5 (it means it is the start of ignition), it can trigger the optocoupler to drive the mosfet, pin B0 is used to drive optocoupler via 330 Ω resistor. It keeps pin B5 at high state until the falling edge of the ignition timing signal. Optocoupler works as follows. When enough current flows through the anode and cathode pins, it lets the current flow from the collector pin to the emitter pin. The current which should flow through the anode and cathode pins is so small, so a microcontroller unit can supply this current. This working principle of optocoupler is used to supply 12V to the base of the mosfet which is required to drive the mosfet. The collector pin of the optocoupler is connected to 12V; and when the current flows through anode and cathode pins (this current is supplied by PIC16F628A via pin B0), 12V flows to base of the mosfet (pin 3 in the Figure 3.15) via collector and emitter pins of the optocoupler, and this is the starting point of the spark generation process. The induction coils which are used on the system are connected as in Figure 3.14. Positive terminal of the primary winding is directly connected to +12V; and ground of the primary winding is controlled by the igniter circuit with mosfet. When the required voltage which is 12V in the igniter circuit, is applied to base of the mosfet, it lets current flow through the primary winding. As seen in Figure 3.15, the igniter circuit has a connector to connect the GND terminal of the induction coil; the connector is connected to the drain pin (pin 1 in Figure 3.15) of mosfet and when the mosfet is triggered, it will let the current from drain pin to GND of the system [4]. This flowing current is relatively high so a cooling fin is assembled on the mosfet as seen in Figure 3.15. And, the PCB layout of the igniter circuit is given in Figure 3.16. (The figure is the bottom layer and board edge of the PCB and the PCB is one sided.)

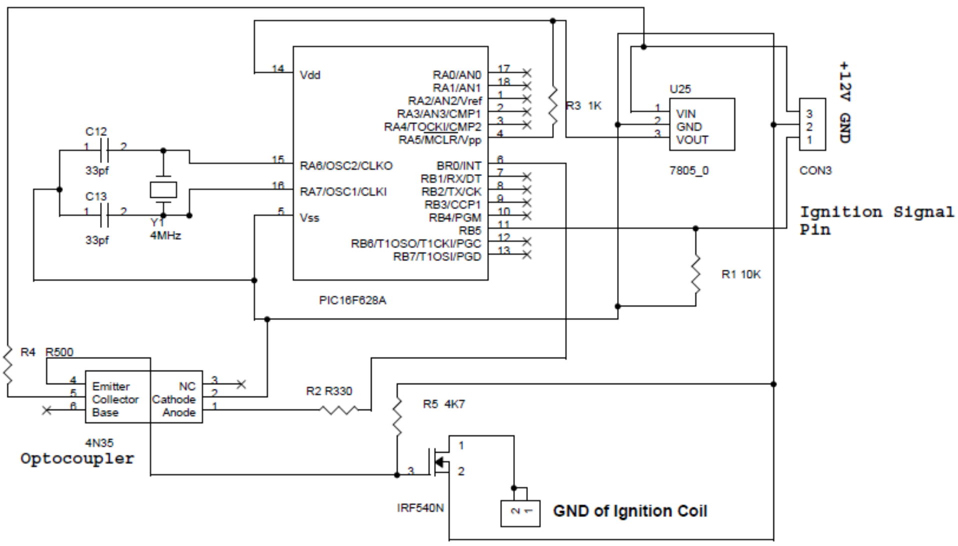


Figure 3.15: Schematic view of igniter circuit

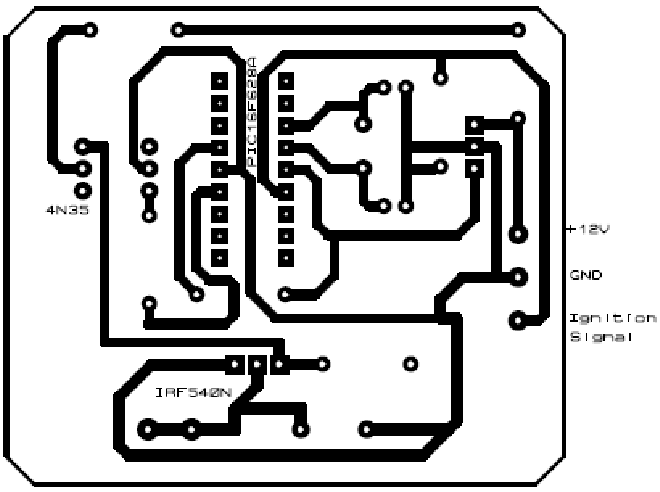


Figure 3.16: PCB layout of the igniter circuit

3.3 Control Circuits

As it is understood, the igniter circuits are slave circuits, they start ignition when an ignition signal comes from the main circuit (ECU) as seen in Figure 3.13, Toyota 1 MZ-FE 94 Direct Ignition System (DIS). In our system, we have a PIC16F877A based master circuit, to control the other slave circuits. The most important component of the circuit is PIC16F877A, it is a high performance risc cpu by Microchip [1], and it is very popular it means there are thousands of source codes related to this microcontroller on the internet. The important specifications of the mcu for our application are given below in Table 3.4.

Table 3.4: The features of PIC16F877A

Max Operating Frequency	Flash Program Memory	Data Memory (bytes)	EEPROM Memory (bytes)	Interrupts	I/O Ports	Timers	Serial Communication	10-bit ADC
20 MHz	4K	368	256	15	Ports A, B, C, D, E	3	MSSP, USART	8

As seen in the Table 3.4, it can work at 20 MHz frequency it means 5000000 cycle/second (200 nanosecond instruction executions). Also it has five I/O ports, serial communication modules and eight analog to digital conversion channels, these features are enough for our application.

In our system, the rpm value and cooling temperature will be used as inputs to determine advance angle and initiate ignition. These values will be read in analog forms, so the main circuits should have connections for analog channels. The control circuits will communicate with each other via master slave serial communication, so the control circuits will have RX and TX connections. (RX and TX pins of microcontrollers are used for serial communication) [26]. Also, those pins should be connected to RS-232 port via max232, because we may need to communicate the control circuits with PC to upload advance angle data. The igniter circuits will be triggered by logic ignition timing signals of control circuits, so the control circuit should also contain I/O pin connections and light emitting diodes to debug the source codes which are written for control circuits. Engine control circuits have external eeproms to store advance angle data, so the control circuits should have an external eeprom memory. In the light of required features which are stated above the control circuits are designed, there are two identical control circuits (they are designed identically to reduce cost and time required for designing), but their duty, so their source codes will be different (these control circuits will be called as main control circuit and secondary control circuit according to their duty). Figure 3.17 shows schematic view and Figure 3.18 shows PCB layout of the control circuits. As seen in the Figure 3.17, there are three analog channels; these channels will be used to measure analog rpm value and cooling water temperature. The circuit has max232 and serial communication port which may be used to communicate with PC; and has RX and TX pin connections, these pins will be used to communicate the control circuits with each other. The circuits have external eeprom memories which are used to store advance angle data as look-up table. In our system, 24C64 series eeprom is used to load look-up advance table, the 24C64 eeprom provides 65536 bits electrically erasable and programmable read only memory, it means we can write 8 bit advance data to 8192(13 bit) addresses. Also, it supports I2C and SPI communication protocols. Main circuit uses cooling water temperature and rpm value as inputs to figure out the advance angle. The cooling water temperature is measured via one of the analog input pins shown in Figure 3.17 and converted into digital form by 10-bit analog to digital conversion module of the main control circuit. The source code of main control circuits is written to read rpm value in 8-bit digital format via serial communication, so there is a need for a circuit to measure rpm value and format it into 8-bit form. Our secondary circuit is dedicated to measure rpm and formats it into 8-bit form. The secondary control circuit sends rpm value to the main circuit via serial communication with RX and TX pins, the mcu PIC16F877A has Universal Synchronous Asynchronous Receiver Transmitter (USART) module which is one of the two serial I/O modules. (USART is also known as a Serial Communications Interface or SCI.) [26]. This module can be configured as a full-duplex asynchronous system that can communicate with peripheral devices, such as CRT terminals and personal computers or it can be configured as a half-duplex synchronous system that can communicate with peripheral devices, such as A/D or

D/A integrated circuits, serial EPROMs, etc. In our system synchronous mode communication is used, this is a one way communication because the secondary circuit receives no data from the main circuit. When we look at the communication mode, the main circuit is set as slave, the secondary circuit is set as master, and it means secondary circuit transmits data, the main circuit receives that data, but this communication starts whenever the main circuit sends a ready signal to the secondary one.

Actually, the main circuit and the secondary circuit have the same hardware except 24C64 eeprom, because reading advance angle value from a look-up table is the duty of the main control circuit(secondary control circuit also has connections for 24C64, but it will not use the eeprom memory during operation). As seen in the Figure 3.18, the external eeprom is connected to PIC16F877A with its SDA and SCL pins. SDA is serial data I/O pin and SCL is serial clock input of the external eeprom [26]. Those pins are connected to pin C4 which is used as serial data I/O and pin C3 which is used as serial clock output of PIC16F877A. The connection which is given above will be used to read data from external eeprom memory via I2C protocol of MSSP module. The secondary control circuit will count the square wave output of position sensors to determine crank shaft angle and receive ready signal from the main control circuits, so the D0, D1 and D2 pins which is seen in figure 3.17 will be used for these purposes. The control circuits have connection port for PORTB and light emitting diodes connected to PORTB. The PORTB of main control circuit is used to send ignition timing signals to igniter circuits. The leds connected to this port will be used to simulate ignition timing signals and debug the source code.

The PCB layout of control circuits is given in Figure 3.18; these control circuits are manufactured by ironing method (commonly used by amateurs to manufacture circuit board). These circuits are also used to test control codes to check if they succeeded, but for the final design more professionally assembled and manufactured PCBs may be used. The PCB layout which is given in Figure 3.18 can be manufactured by professionals or standard PIC16F877A development circuits can be used. There is such a PIC16F877A development board (Altas yayincilik) in the market as seen in figure 3.19. The development board has all the necessary pins, connections, leds and external eeprom connection which we need in the control circuits. To use this development board as control circuit will be beneficial because this circuit is professionally assembled and tested.

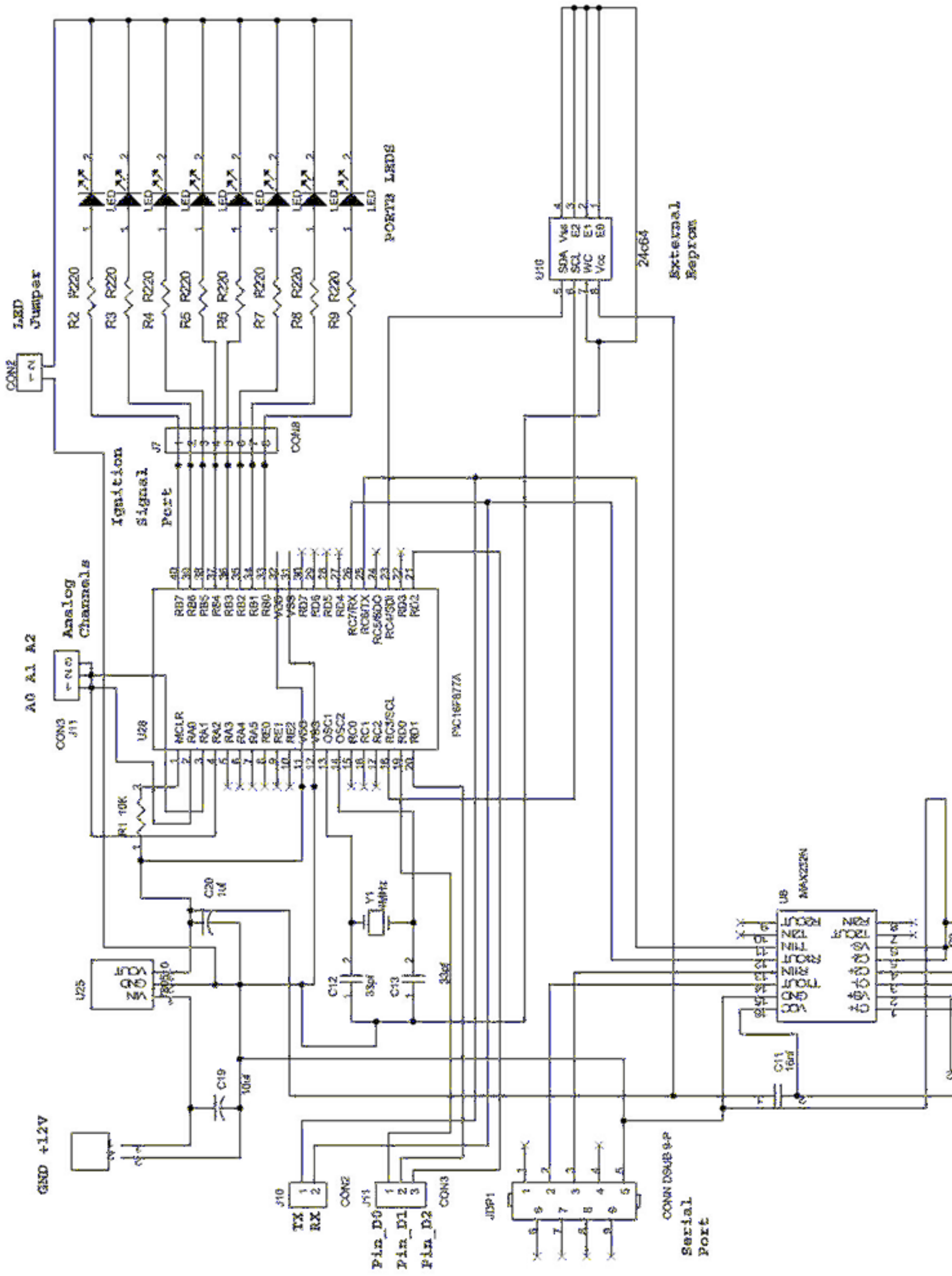


Figure 3.17: Schematic view of the main control circuit

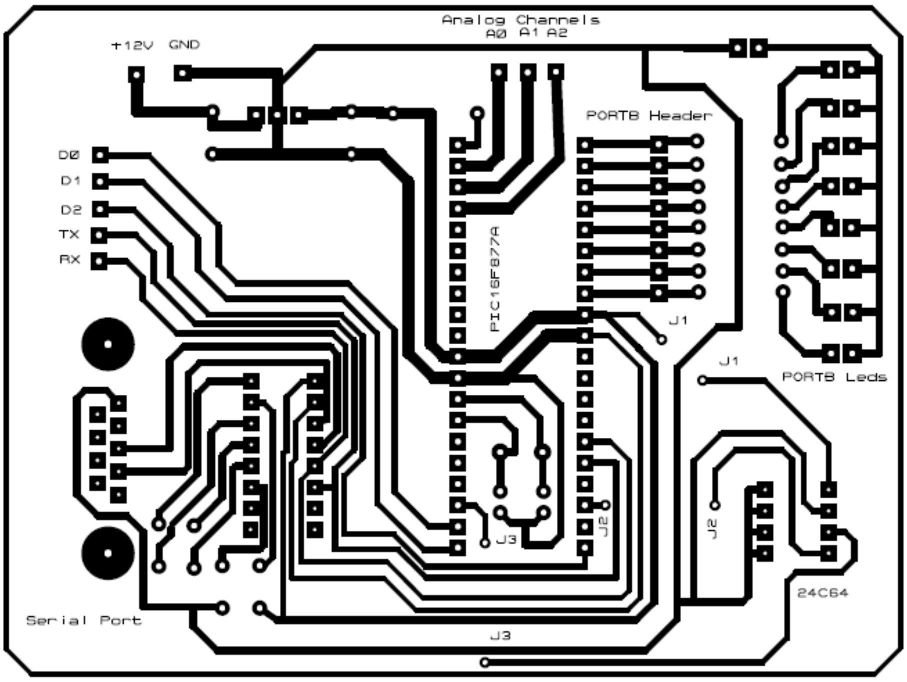


Figure 3.18: PCB layout of the main control circuit

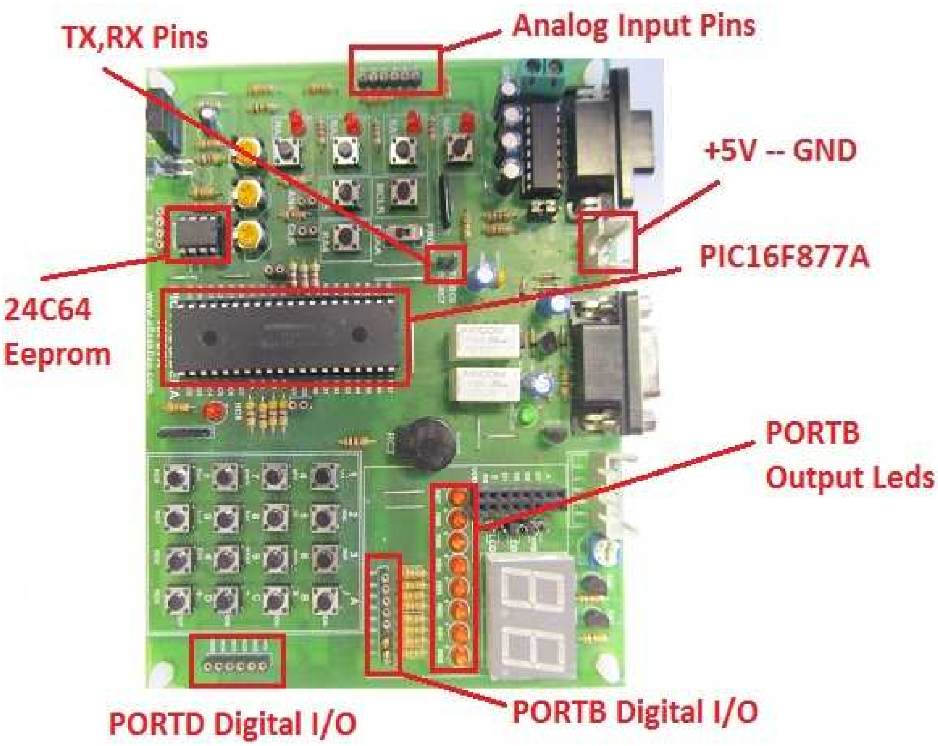


Figure 3.19: Main control circuit

3.4 Speed Measurement and Cylinder Identification

3.4.1 Magnetic Pick-up

The rpm value is measured with a sensor which is a variable reluctance magnetic pick up, Figure 3.20, it is a commercial product and it can be found easily as a spare part in the market.

Figure 3.20: Magnetic pick-up which is used in our system

This sensor is widely used in automotive industry because of its enduring structure and easy working principle. As seen in Figure 3.21, it is composed of a permanent magnet, a pole piece metal and a coil, the working principle is if a metal piece closes to the pole piece part it causes a change in the magnetic field and it induces a voltage in the coil, this induced voltage is observed with the signal wires as a AC form [30].

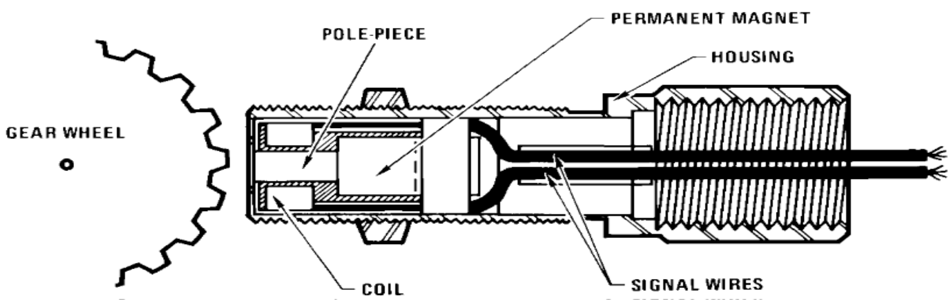


Figure 3.21: Typical Magnetic Pick up

3.4.2 Frequency to Voltage Converter Circuit

As stated before, the output of magnetic pick-up sensor is a useless ac signal, so to use the output you should shape it into square wave form or you should use frequency to voltage converter to get an analog signal. There is an integrated circuit in the market which is called LM2907, frequency to voltage converter; it is an 8-pins small integrated circuit. This integrated circuit is widely used in the automotive industry to get analog signal from the ac output of the magnetic pick up sensors. Figure 3.22 shows an example circuit of frequency to analog signal converter [30], this example circuit is the same with the circuit used in our application. After converting the ac signal to analog signal, the secondary control circuit converts it into 8-bit digital form by using A/D conversion module.

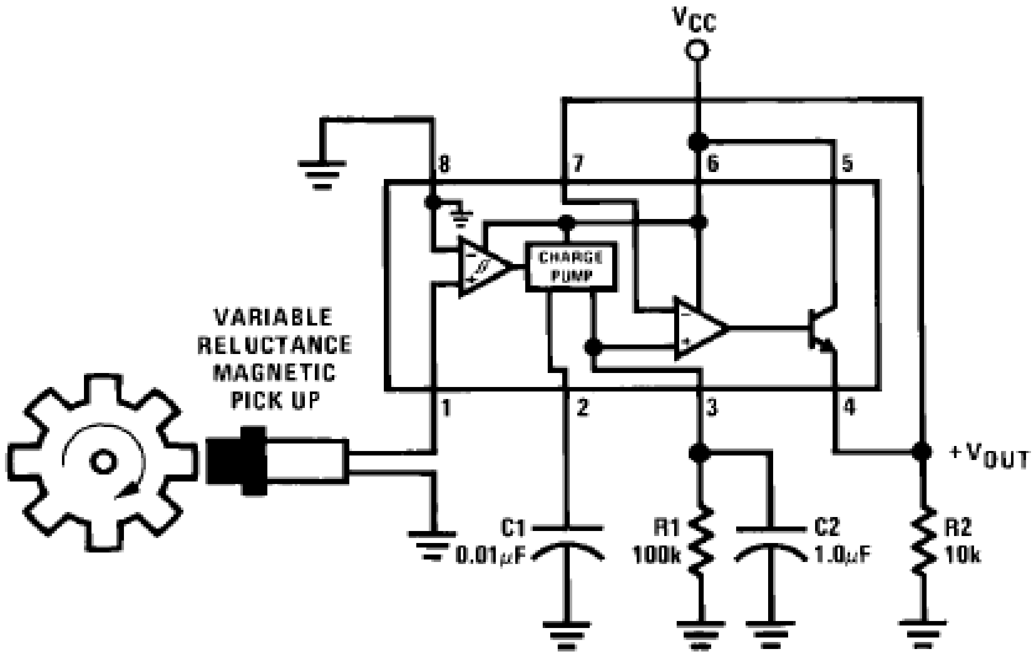


Figure 3.22: Basic Frequency to Voltage Converter.

Sensor, power, capacitor and resistor connections are shown in Figure 3.22, but the output voltage will be different for different capacitor and resistor combinations in the datasheet of LM2907 this situation is defined with an equation as follows [30].

$V_{out}=V_{cc} \times f_{in} \times C1 \times R1 \times K$ (K is the gain constant and typically 1)

Eqn. 3.1

In frequency to voltage converter design, the resistor, capacitor and supply voltage is chosen to keep output voltage within 0-5V. So, according to Eqn. 3.1 circuit is designed in ORCAD 9.0 as in figure 3.23. The maximum output voltage is calculated around 4.8 V for 3000 rpm (4000 Hz for gear wheel with 80 teeth) in the design. This designed frequency to voltage converter circuit is manufactured with the PCB layout which is given in Figure 3.24 with ironing method.

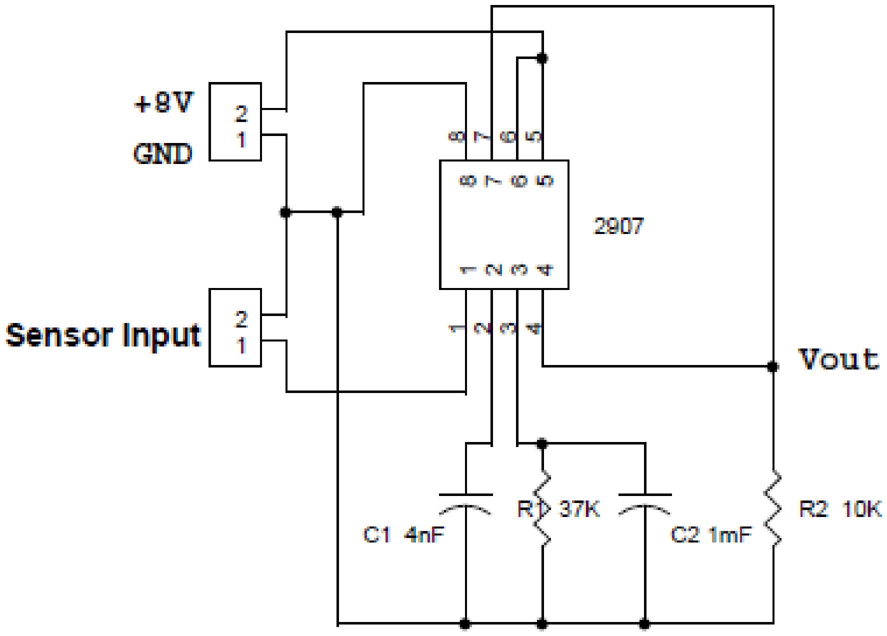


Figure 3.23: Schematic view of frequency to voltage converter circuit

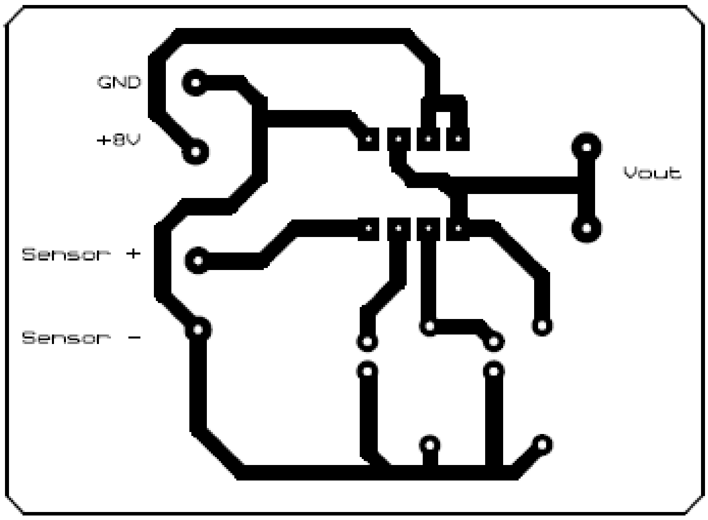


Figure 3.24: PCB layout of frequency to voltage converter circuit

3.4.3 Generation of Cylinder Position Signals

Another duty of the secondary control circuit is to send cylinder position signal to the main circuit, to do this job there are 2 secondary LM2907 circuits, these circuits converts the ac output signal of the magnetic pick up sensor to square wave, then the secondary control circuit easily counts square waves to determine crank shaft angle. There are two secondary LM2907 circuits which convert AC signals to square wave in our system; one of them is used to determine crank shaft angle as stated above and it is called secondary LM2907 circuit 1; the other one is used to detect first piston position and it is called secondary LM2907 circuit 2. The application circuit of LM2907 to convert AC signals to square wave [30] is shown in Figure 3.26.

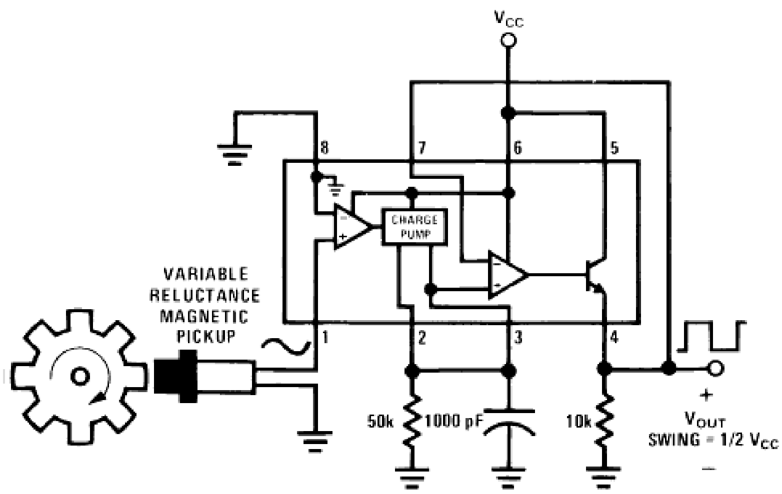


Figure 3.25: Square wave signal generator circuit (secondary LM2907 circuit)

As it is understood from the Figure 3.25, the magnitude of square wave is dependent on supply voltage. So the secondary LM2907 circuit is designed to have 0-5V square wave as in Figure 3.26.

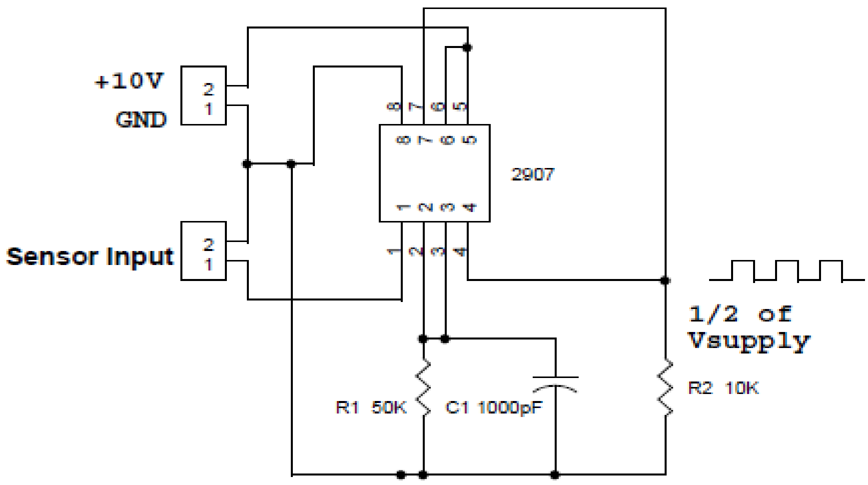


Figure 3.26: Secondary LM2907 circuit

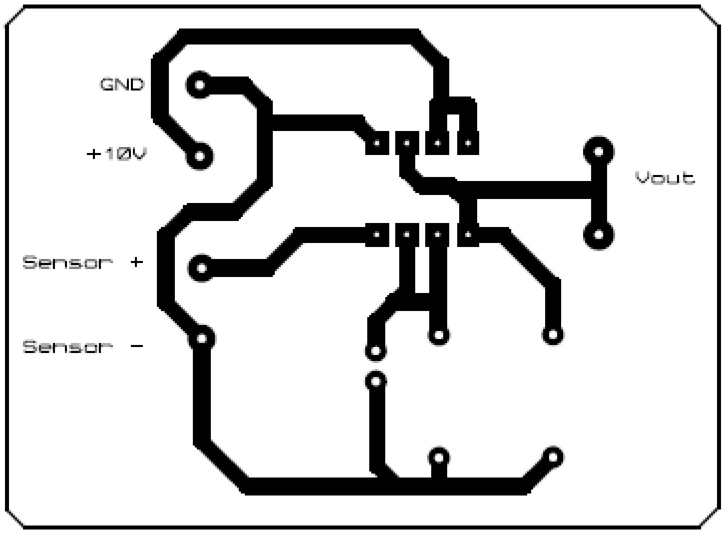


Figure 3.27: PCB layout of the secondary LM2907 circuit

There is a gear wheel which triggers the magnetic pick-up sensor as you see in figure 3.28, this gear wheel is used to determine engine speed and piston positions, the gear wheel which has eighty teeth to simulate an actual engine, and it means ten teeth per cylinder. There is a metal part mounted on the gear wheel it is an additional tooth and it is used to determine first piston position.

Figure 3.28: Gear wheel and driving system figure

The frequency to voltage converter circuit which is told in part 3.4.2 uses this gear wheel and outputs of crank shaft position sensor in Figure 3.28 as input. As seen in figure 3.28, gear wheel is driven with a belt and a motor, this motor is 0.36 kW AC motor and it is driven by Delta VFD 004L11A series ac motor driver. It is very useful for laboratory works because it has many parameters to change control settings and gives the operator permission to change these settings. For example you can control this driver with its digital keypad, its potentiometer, 0-10V input voltage, 4-20 mA input current or RS-485 communication port. Among these options to control motor speed, 0-10V input voltage option is suitable for us because we have a data acquisition card having analog output channels.

3.5 Data Acquisition and Control System

3.5.1 Data Acquisition Card and Its Accessories

One of the most important parts of the experimental set-up is data acquisition and control system. It contains a computer, control software, Advantech PCI 1716 data acquisition card, Advantech PLC-10168 wiring cable, PLCD-8710 wiring terminal board and a transmitter/receiver circuit.

The computer in the experimental set-up is a standard personal computer, we don`t need a special computer for this set-up, all we need is a computer which it can run Delphi 4.0 software and has a PCI bus. The data acquisition card on the set-up is Advantech PCI-1716 100kS/s, 12-bit, 16-ch Universal PCI Multifunction Card, it has

16 channels single-ended or 8 channels differential or a combination of analog input, 12-bit A/D converter with up to 100 kHz sampling rate, programmable gain, automatic channel/gain scanning, onboard FIFO memory, 2 12-bit analog output channels, 16 channels digital input and 16 channels digital output and onboard programmable counter. These properties are acceptable for an experimental work.

The data acquisition card is a PCI type card, Figure 3.29, so we need special cable with connector and a terminal board for I/O connections. PCL-10168 cable and PCLD-8710 industrial wiring terminal board is used on the set-up, Figure 3.30. These are accessories for this card supplied by Advantech.

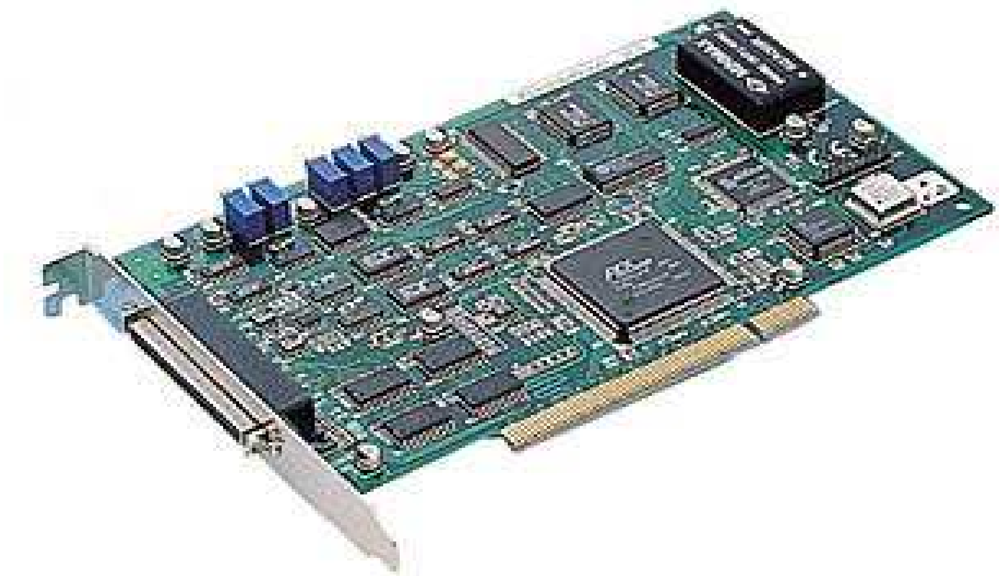


Figure 3.29: Advantech PCI-1716

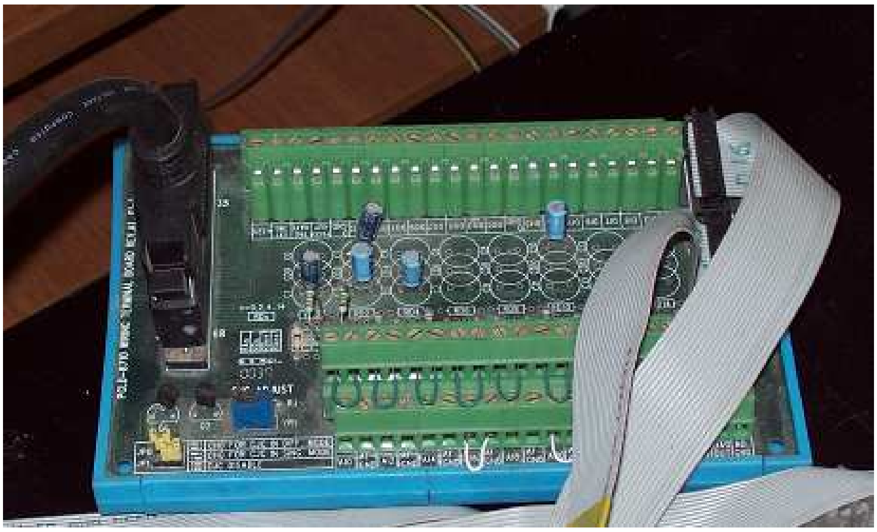


Figure 3.30: Connection terminal box and connector cable

The data acquisition card 16 digital outputs and 16 digital outputs as stated before, but to use these inputs and outputs in your experimental set-up you need another circuit because digital outputs are not enough to drive inductive loads and you should isolate digital inputs from bad signals, there is an interface circuit for this purpose. The circuit has four 74LS245 IC`s, this IC is a octal bus transmitter/receiver, they are used to isolate the data acquisition card from bad input signals. There are 16 relays on the circuit, they are driven by ULN2003A high voltage, and high current Darlington arrays each containing seven open collector Darlington pairs with common emitters. These integrated circuits are triggered by output signals of the data acquisition card, with these interface circuit our data acquisition system have 16 isolated digital inputs and 16 relay outputs which is capable of driving inductive loads. Figure 3.31 shows interface circuit.

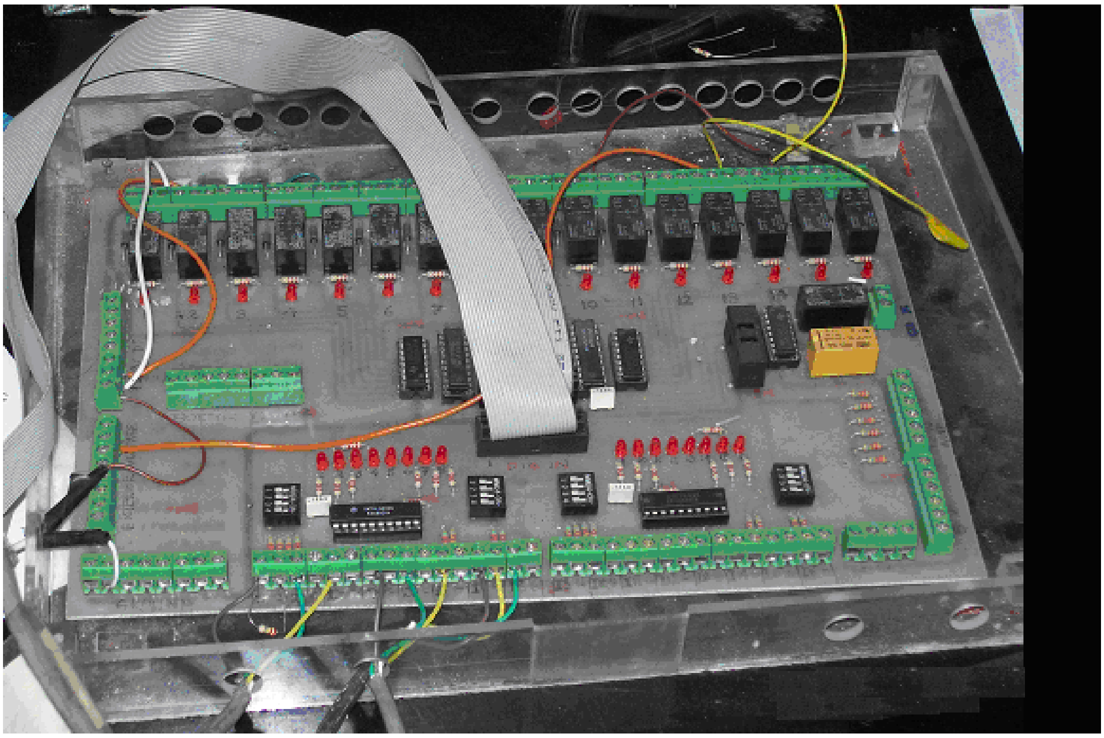


Figure 3.31: Interface circuit

Interface computer program which is necessary to control the hardware told above was developed with Delphi 4.0, this interface program is used for different experimental set-ups in the laboratory, so our program was added on the existing program. Figure 3.32 shows opening view of the program.

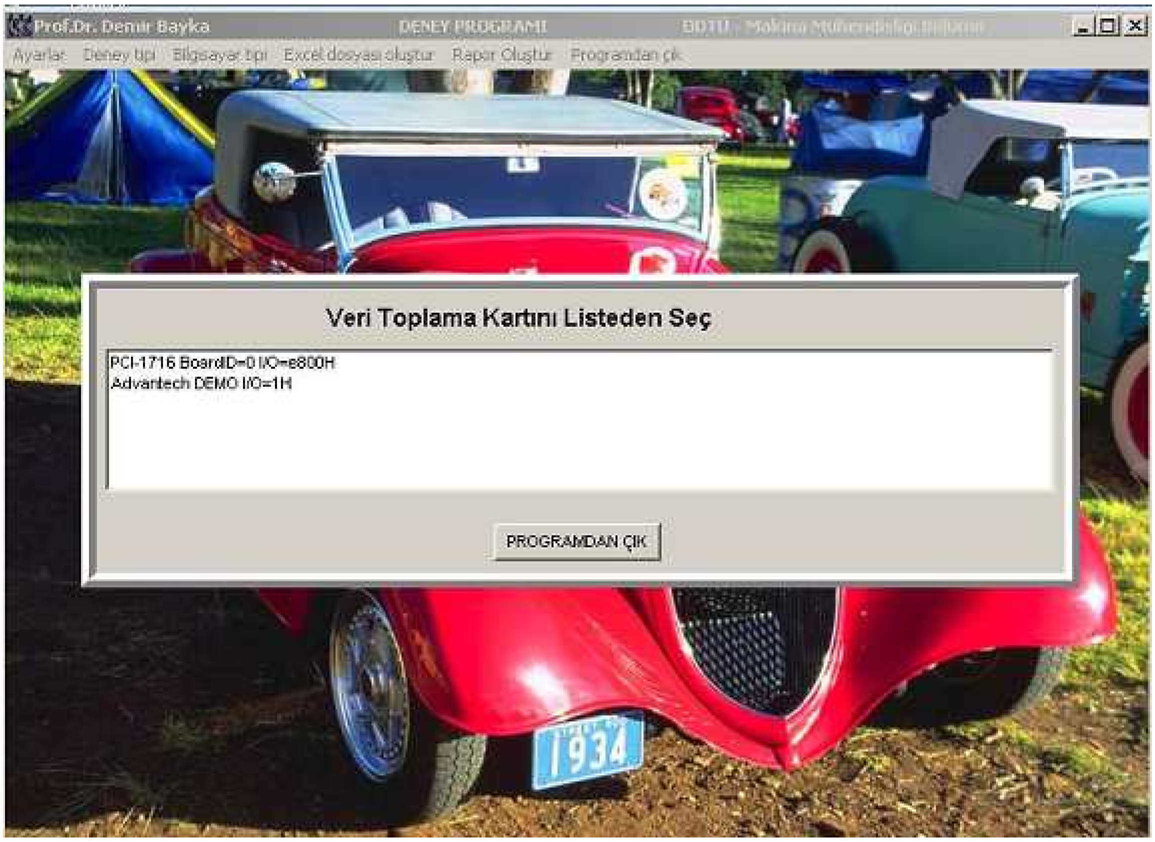


Figure 3.32: Opening view of the interface program

As it is used various experimental set-ups, there is a option to choose data acquisition card, our card is PCI-1716. The next step is choosing our experimental set-up; Figure 3.33 shows how we open our main page.

Figure 3.33: The next step to open our set-up page

Figure 3.34 shows how our main page looks like, we can control speed of the motor, scan digital inputs and play animation of our ignition system via this interface.

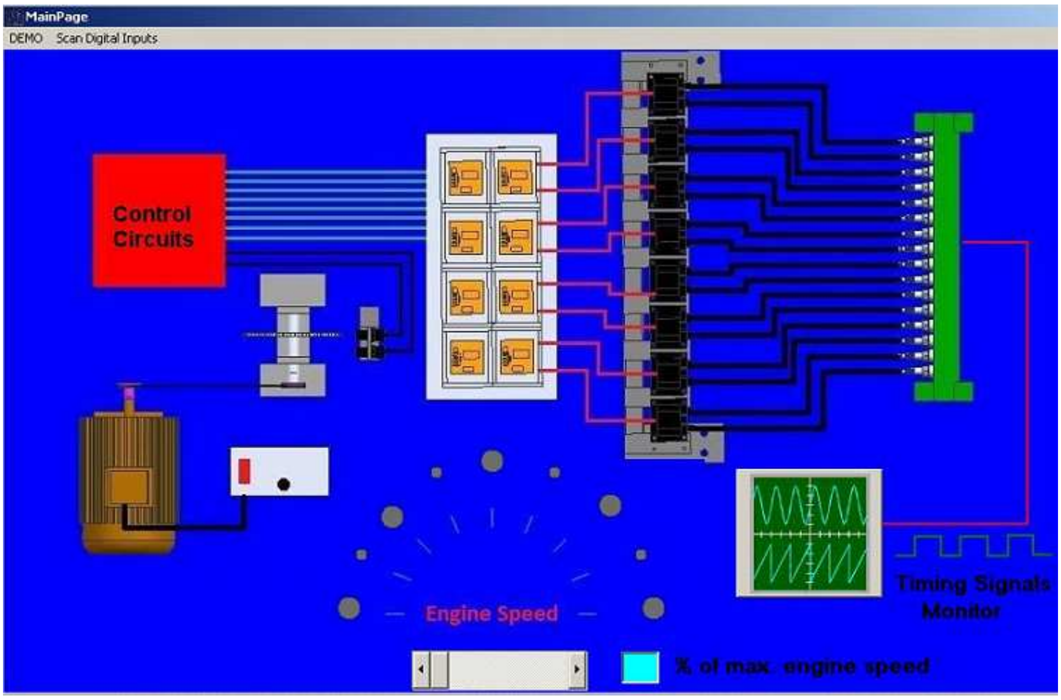


Figure 3.34: Main page of our control software

CHAPTER 4

EXPERIMENTAL METHOD

In this part of the thesis, experimental method and how the elements of the set-up which are told in previous chapter are used together will be stated. There are many circuits and their working principle, schematic view and PCB layout are given in the previous chapters, it will be helpful to review their working principles and duties in the set-up. There are 3 LM2907 circuits, one of them is designed as a frequency to voltage converter and the others are designed as square wave generator circuits. There are 2 position sensors; they are crank shaft position sensor and reference point sensor. The crank shaft sensor is connected to frequency to voltage converter LM2907 circuit; the aim of this connection is to measure engine speed as voltage. The crank shaft position sensor is also connected to one of the square wave generator LM2907 circuits. This connection is used to create 0-5V pulse for each tooth of the gear wheel in Figure 3.28. So, control circuits count the pulses and determine the crank shaft angle and identify the cylinder positions. We should have a reference point to start to count the pulses; this is held by reference point sensor and the other of square wave generator LM2907 circuits. Control circuits detect the output of that square wave generator circuit to start to count the pulses. The reference point is the position of the first cylinder. Secondary control circuit is dedicated to measure the speed by using output of the frequency to voltage converter circuit and send rpm value in 8-bit format to the main control circuit and identify cylinder positions (by detecting the reference point and counting the output pulses of square wave generator circuit) and send them to the main control circuit. The duty of the main control circuit is to detect the cylinder position signals (0-5V pulses) coming from the secondary control circuit and add advance angle value to the cylinder position signals and trigger the igniter circuits. The connections for all the circuits are given in Figure 4.6, and examining this figure will be beneficial for understanding the connections and duties of the circuits.

4.1 New Design Engine

It will be helpful to state important points of the study and test engine. This ignition system set-up is constructed for a special kind of engine, so the first step is to understand the working principle of the engine. The engine has 8 cylinders arranged radially on the engine, and there are 2 pistons for each cylinder it means there will be ignition at respective sides of common cylinders. The engine has 2 special axial cams at the each side of the engine. Another important point is ignition order of the spark plugs, each side of the cylinder has ignition for each revolution of the engine unlike a conventional four strokes one, because there is one ignition in a cylinder for every two revolutions in a conventional 4-stroke cycle engine as in Figure 4.2. In other words, crank shaft angle of the new design engine gives which piston is at which stroke. Figure 4.1 shows parts of our new special engine.

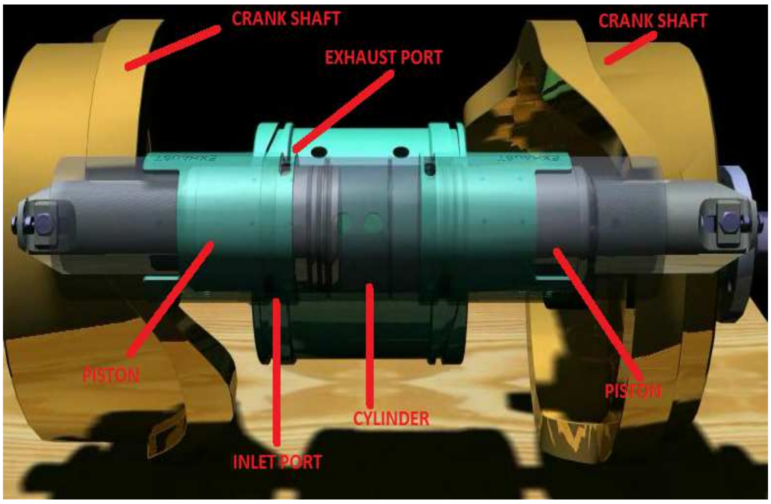


Figure 4.1: Engine for which the ignition system set-up was constructed

Figure 4.2 shows four stroke cycle of a conventional internal combustion engine, as shown in the figure it is impossible to determine the firing order with only crank shaft angle (except wasted spark ignition). For example, the crank shaft angles of compression stroke and exhaust stroke are the same in the figure. So to determine the correct ignition order there will be need to another sensor output.

Our study is based on a special type of engine and its firing order is different but physics of a combustion process is the same so the different part of our ignition system is about firing order and its determination.

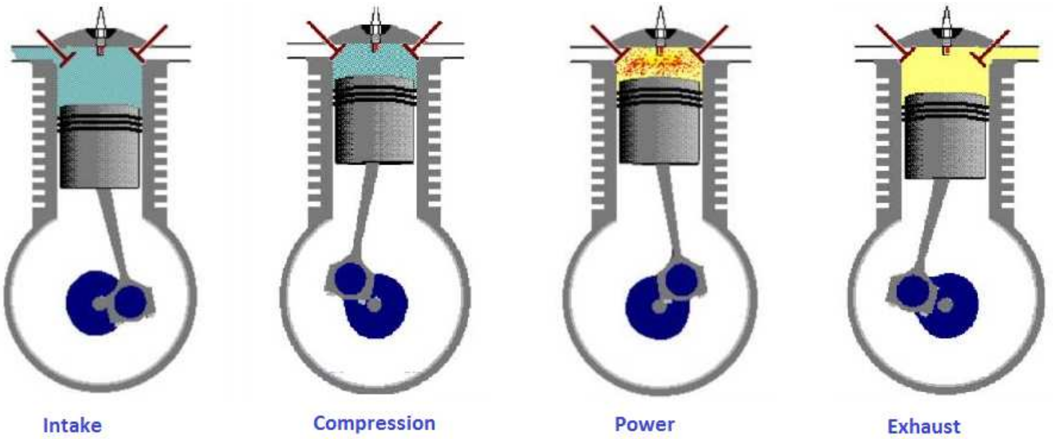


Figure 4.2: Four strokes of an internal combustion engine

4.2 Working Principle of the System

In this part of the thesis, the working principle of the system is going to be given. The duties of the circuits and their relations with the other circuits are going to be shown and told. The working principle is not going to be given operation by operation, the operations are going to be grouped according to the circuits realizing the operations, but it is going to be in an order. To follow the operations easily, it will be helpful to look at Figure 4.3 the flowchart of the control algorithm of the system.

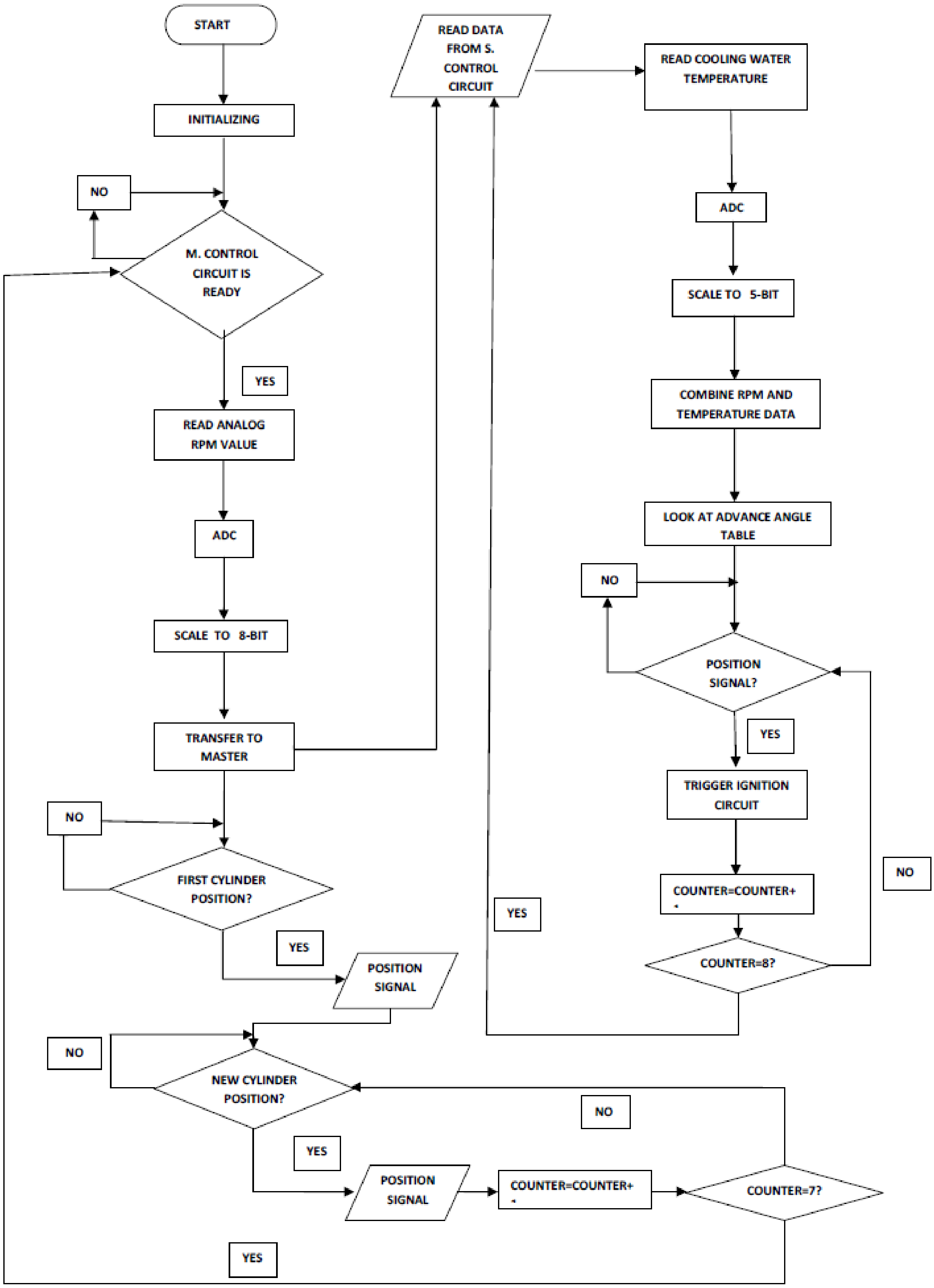


Figure 4.3: The flowchart of the control algorithm of the system

The connection diagram in Figure 4.4 shows the exact connection of the circuits, they are not symbolic connections. It will be helpful to understand the control algorithm, operation order and the circuits in relation.

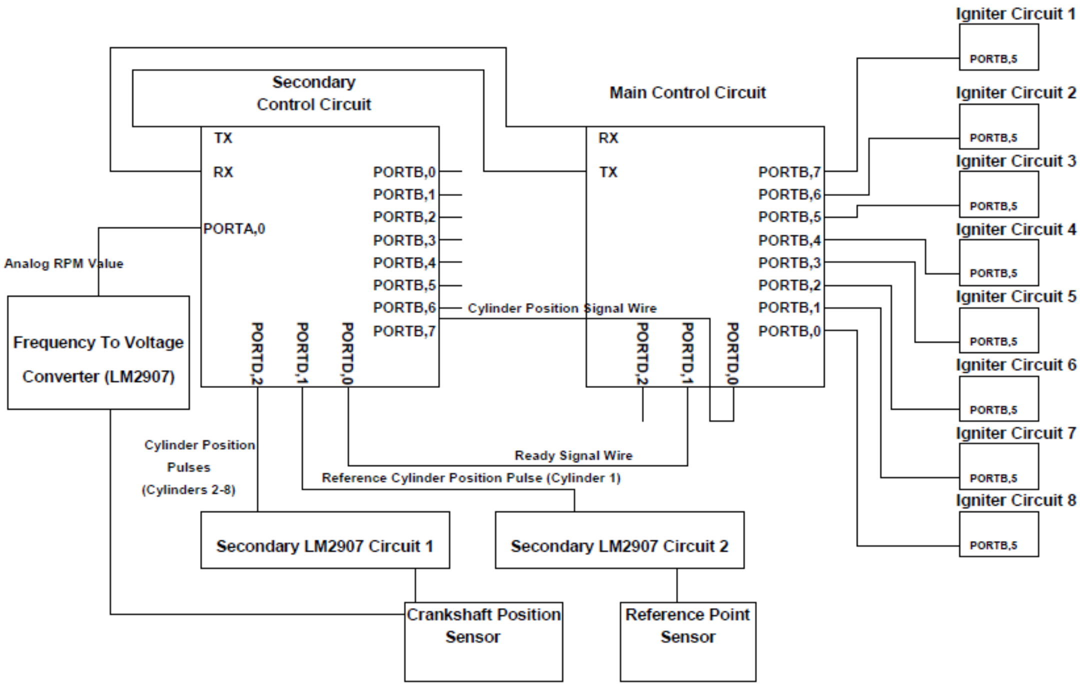


Figure 4.4: Connection diagram of the circuits

Figure 4.5 shows the operation order and the circuits realizing the operations. The system should be examined operation by operation, the operations and their order can be followed with Figure 4.5 and the algorithm of the operation can be seen in figure 4.3; and the wire connections for the operation can be seen in Figure 4.4, so the Figure 4.3, 4.4 and 4.5 should be examined together.

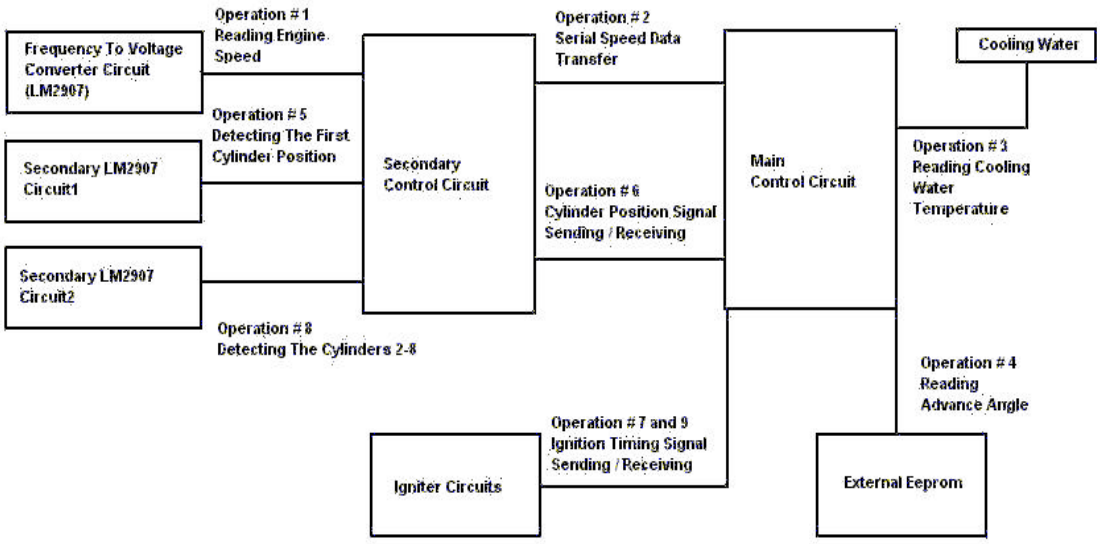


Figure 4.5: The operation order and the circuits realizing the operations.

4.2.1 Speed Measurement and Piston Position Determination

4.2.1.1 Position Sensors

Figure 4.6 shows a four stroke four cylinders combustion engine and its front view; there are a gear wheel with a missing tooth on the crank shaft and a pick-up coil type sensor. These components are used to determine position of the crank shaft and speed of the engine.

Figure 4.6: A Four cylinder demo engine and its front view

As stated before, the crank shaft position sensor is not enough to determine the correct ignition order, so we need another sensor output; this sensor is camshaft position sensor. Figure 4.7 shows typical outputs of crank shaft position sensor and camshaft position sensor in a conventional crankshaft engine.

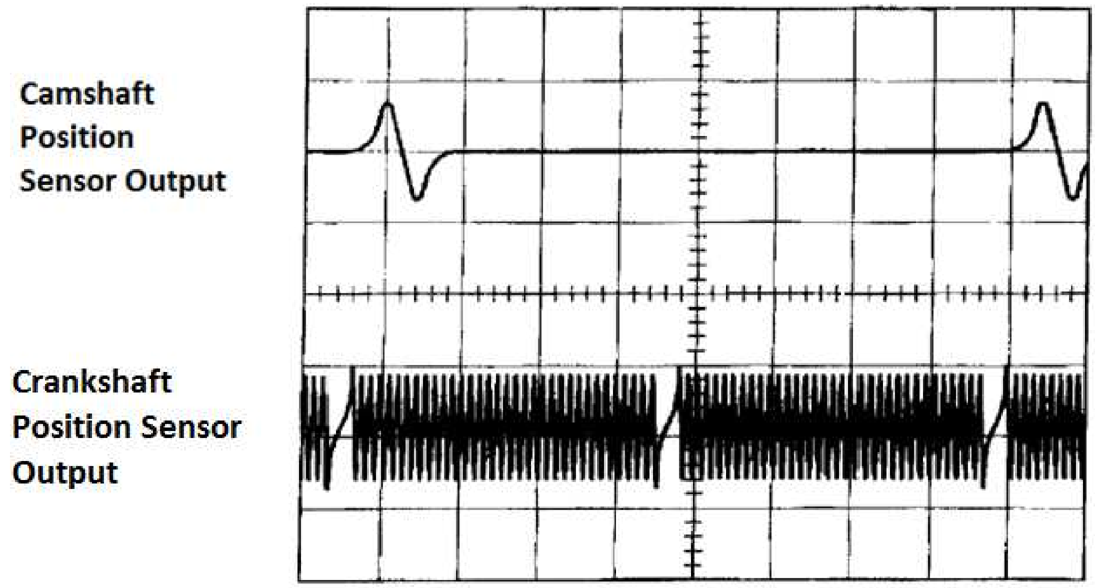


Figure 4.7: Typical outputs of position sensors

The periodic gap in the crankshaft position signal is because of the missing tooth in the gear wheel. The gap is used by control unit as a reference of the crankshaft position. When it is combined with the camshaft position signal, cylinder position and stroke can be determined. In our case, a missing tooth in the gear wheel will be enough to determine cylinder positions and strokes because the all strokes are completed in one revolution of the engine by the help of two axial cams, so the same operation is going to take place at the same crank angle in every revolution.

We have used an additional tooth instead of the missing tooth; the source code of control circuits will be simpler by this way. Figure 3.28 shows gear wheel, additional tooth and sensors. There are two sensors, crank shaft position sensor and reference point sensor. Outputs of position sensors in our system are shown in Figure 4.8, as you see in the figure there is no periodic gap in the crankshaft position sensor because we do not have any missing tooth. This signal is used to determine engine speed and crankshaft angle as told in the previous chapter.

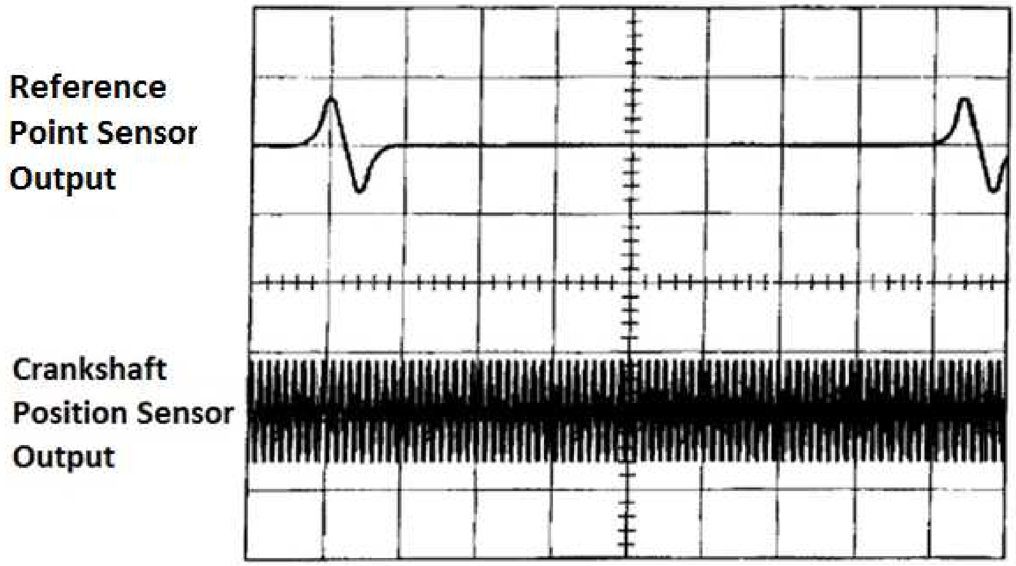


Figure 4.8: Outputs of position sensors in our system.

4.2.1.2 Speed Measurement

There are many steps in ignition process and, they repeat in each revolution of the engine. The first step is reading rpm (revolution per minute) and transferring it to the main circuit in required format, the output of crank shaft position sensor is used to read rpm value by using LM2907, frequency to voltage converter, based circuit as mentioned in previous chapter. Figure 4.9 shows typical application circuit of LM2907 to measure the engine speed. This circuit uses the crankshaft position sensor output as input, and converts it into voltage shown in Figure 4.9 as Vout.

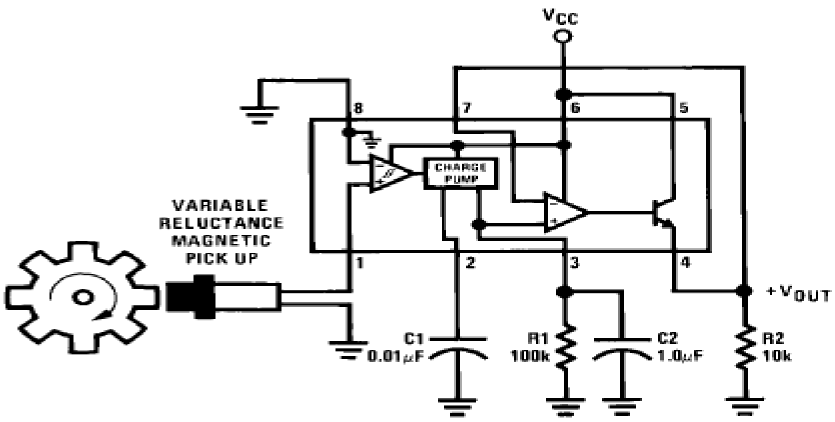


Figure 4.9: Typical application circuit of LM2907 to measure speed

The most important advantage of this circuit is that its output is in analog form, so whenever you want to read rpm the only thing to do is analog to digital conversion, you do not need to count any pulses or store any data to read speed. To determine speed of engine you may use sensors with digital output and count the teeth of gear wheel assembled on crankshaft, but you should count the teeth continuously it means another extra circuit. The main control circuit manages every operation in the system, so reading rpm voltage operation starts with ready signal of the main control circuit, the main circuit makes the pin high, PORTD,1 it means the main control circuit is ready for data transfer, after the secondary control circuit see the ready signal , it reads analog rpm signal (output of LM2907 circuit) and converts it into digital form, as given in the previous chapter the main and secondary control circuits are both based on PIC16F877A microcontroller, and it has 10-bit analog to digital conversion module, so analog to digital conversion of rpm signal gives two 8-bit variables. The main control circuit needs rpm value in 8-bit format, so the secondary control circuit makes required mathematical operations; they are 16-bit division and subtraction, to scale two 8-bit variables into one 8-bit form. Then the secondary control circuit sends 8-bit rpm data with USART synchronous master/slave communication with 500 kHz baud rate.

The main control circuit manages every operation in the system but during the serial communication it acts like slave because it just receives data. The serial communication takes place with the TX and RX connection as seen in Figure 4.3. The Figure 4.10 shows the operational view of the engine speed measurement

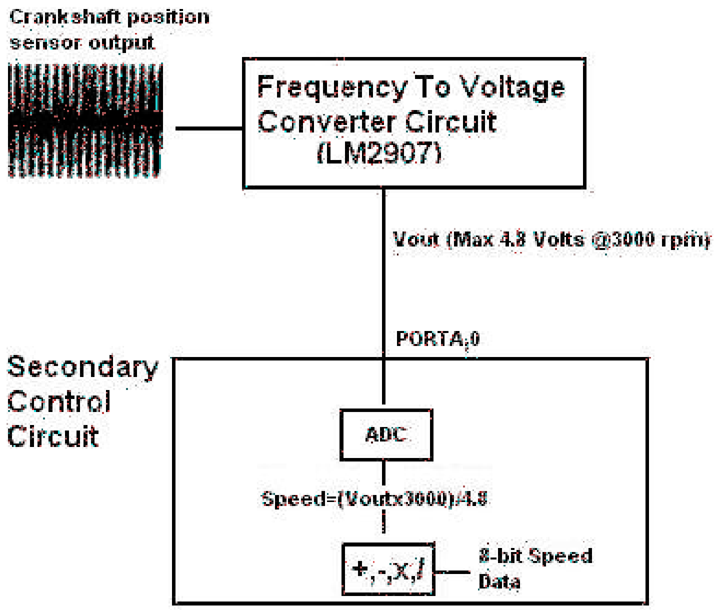


Figure 4.10: Operational view of the engine speed measurement

4.2.2 Piston Identification and Crankshaft Angle Measurement

The output of position sensors are low level analog signals, we shape it into square wave form to use them as a trigger signal in our microcontroller based secondary circuit. This job is done by secondary LM2907 circuits; this application of LM2907 is shown in Figure 4.11. There are two identical circuits in the system, one is for reference point sensor output, and another is crankshaft position sensor output which is also used to determine engine speed as seen in Figure 4.4.

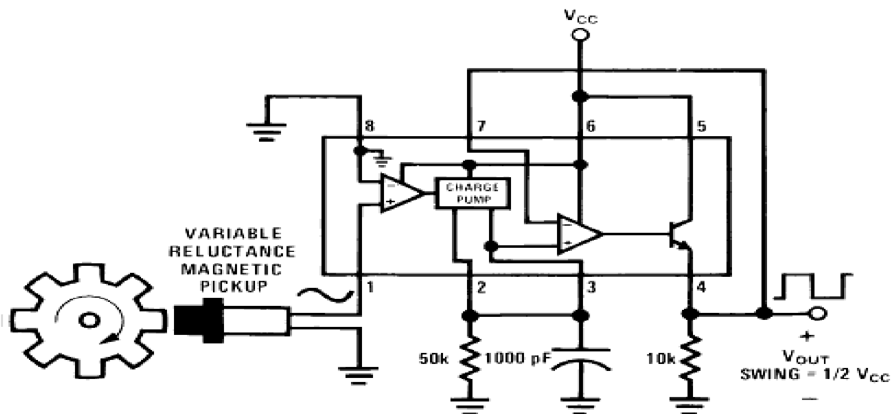


Figure 4.11: Secondary LM2907 circuit

The outputs of secondary LM2907 circuits are square form of the ac analog signals as seen in Figure 4.11. After the secondary control circuit sends the engine speed data to the main circuit in 8-bit format, it goes to the second step. This step is to find the reference point of the crankshaft and crankshaft angle, it starts with the reference point detection, because firing of spark plugs start with a reference point and continues sequentially. As stated before, reference point is our additional tooth and it is detected with reference point sensor. The pin PORTD,1 of the secondary control circuit is dedicated to detect reference point signal, when it receives the signal, the secondary control circuit makes PORTB,7 high for 20 µs this is first cylinder position signal; Pin PORTB,7 is connected to pin PORTD,0 of the main control circuit, as seen in figure 4.3 and it is triggered at the falling edge of cylinder position signal. Then secondary control circuit starts to count square waves of crankshaft position signal, PORTD,2 of the secondary circuit is dedicated for this purpose, if it counts ten pulses, ten pulses mean 45 º rotation of crankshaft because the gear wheel has 80 teeth for 8 cylinders, it makes high PORTB,7 for 20 µs this is position of second cylinder, the secondary circuit repeats this process for seven times, then it goes to the initial point and wait ready signal from the main circuit for the next revolution. As it is told above, the main circuit communicates only with the secondary circuit for engine speed and piston identification.

Main control circuit uses cylinder position signals to create ignition timing signals. The gear wheel will be mounted on the engine as rotated 22.5˚, it means the cylinder position signal gives the middle point of two cylinder. And the advance value will be added on this point to find the required position of the ignition. Figure 4.12 shows the operational view of the piston identification and crank angle measurement.

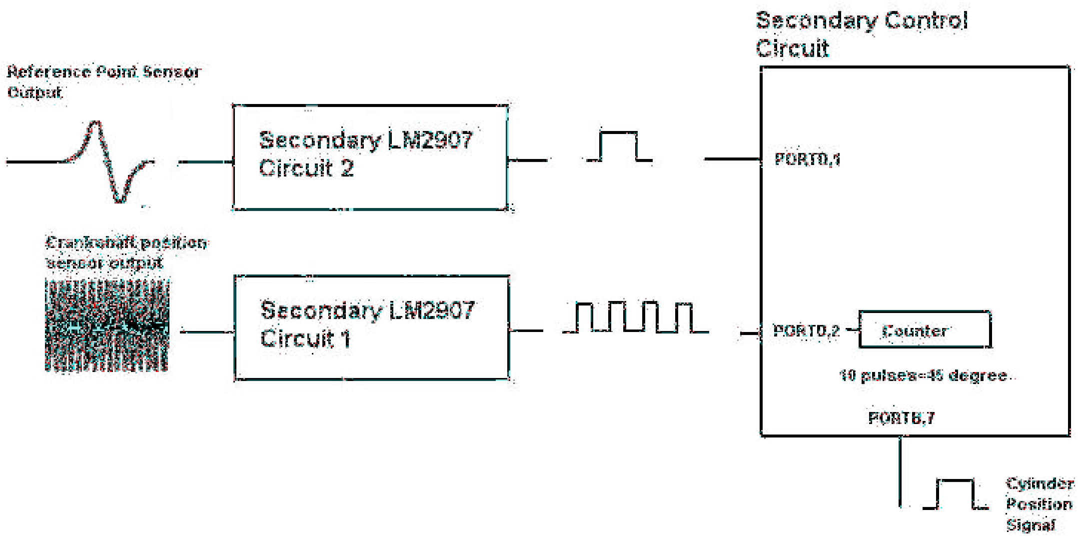


Figure 4.12: Operational view of the piston identification and crank angle measurement

4.2.3 Receiving Speed Data and Reading Cooling Water Temperature

There are many factors such as engine load, speed, temperature, richness of air-fuel mixture etc. which affect the combustion process in the cylinder. Ignition system shall be designed to adapt itself to changes in these variables; our ignition system set-up is designed to use engine speed and temperature to arrange ignition point. There are many parameters which can be used as input to arrange ignition point such as pressure of the inlet manifold or exhaust gas temperature, but for the time being engine speed and cooling water temperature is enough to develop ignition control system for the laboratory.

The first thing which the main control circuit does after initialization is sending ready signal to the secondary circuit with its pin PORTD,1 and waiting for data transfer, if there is a problem in the secondary circuit or data transfer wiring, the main circuit will keep waiting for data transfer, but a timer can be used to limit waiting time for the data transfer and if there is not data transfer during that time, previously transferred data can be used. After receiving engine speed data, it reads cooling water temperature sensor output and it converts it into digital form by using analog to digital conversion module, this module has 10-bit resolution and our system uses cooling water temperature in calculations as 5-bit format, so the main circuit makes necessary 16-bit calculations to scale digital cooling water temperature data into 5-bit.

4.2.4 Selection of Advance Angle and Ignition Timing Signals

The main duty of the main circuit is to determine the ignition timing and send the ignition timing signals to the slave igniter circuits. The main control circuits receive cylinder position signals at pin PORTD,0 from the secondary control circuit. In our system, cylinder position signal shows the middle point of the two cylinders; this is our reference point to calculate ignition point. The ignition timing signals are advance angle added form of the cylinder position signals. Figure 4.13 shows the physical meaning of the advance angle value, the advance angle value is the required time to travel from the cylinder position to the ignition point. There are 16 ignition points in our new design engine, but the two ignitions take place at the same time, so we need 8 position signals as seen in Figure 4.13. The two ignitions taking place at the same time are generated by the induction coils with two high voltage output, so 8 igniter circuits and 8 induction coils are used in the system.

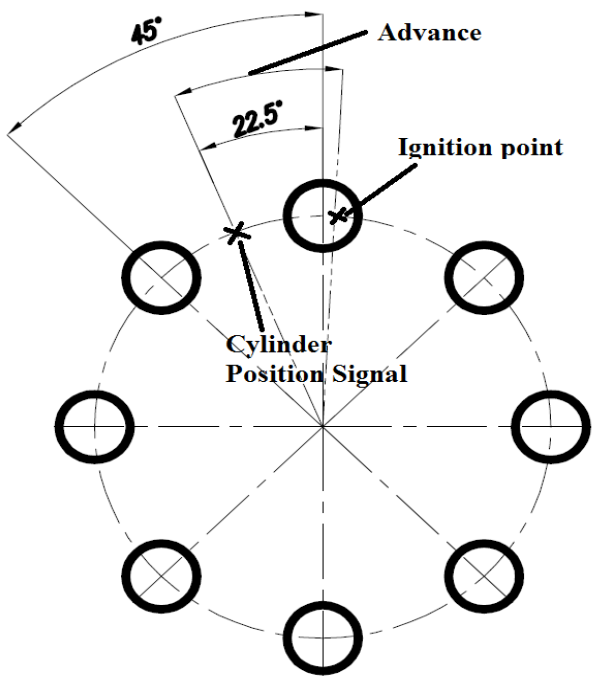


Figure 4.13: Advance angle value

Ignition advance is the number of degrees before or after top-dead-centre (TDC) that a spark occurs in conventional crank shaft engines. The reason for ignition advance is that the spark needs to be timed so that the point of peak combustion pressure is when the piston is just beyond TDC.

If the point of peak combustion pressure is too early and before TDC the pressure wave will slow down the speed of the piston traveling up towards it, and may cause detonation (knocking) which is very damaging to the engine. If the point of peak combustion pressure is too late, the pressure wave will chase the piston as it travels back down the cylinder in the combustion stroke and most of the energy will be lost. This advance angle changes during the engine operation due to engine load, engine speed, fuel, temperature etc., for example as the speed of the engine rises, the ignition advance angle needs to increase. The philosophy behind this: because the time to burn an unchanging air/fuel mixture is approximately constant. If the ignition advance angle were kept the same, the point of peak combustion pressure would move further and further into the combustion stroke losing more and more power. Therefore the ignition advance needs to be increased to bring the point of peak combustion to just beyond TDC. The ignition advance decreases while engine load increases, because the amount of time taken for a fuel/air mixture to burn mainly depends on the richness of the fuel mixture. When the engine is under low load with a lean air/fuel mixture the degree of ignition advance will need to be large to allow for the slow combustion of this mixture. Conversely when the engine is under load a richer air/fuel mixture is used to provide more power. This richer mixture has a faster combustion time so the degree of ignition advance needs to be reduced to keep the peak combustion pressure just beyond TDC, the temperature also do the same effect with the engine load. Those possible problems are valid for conventional crank shaft engines, because the combustion process in the new design engine takes place in constant volume, one of its advantageous sides, and the advance angle should be calculated to find the ignition point in the constant volume area. But, the parameters which affect the advance angle will also affect the advance angle of the new design engine.

As it is stated above, the ignition advance angle is dependent on a few variables; during the operation it is impossible to calculate advance angles due to these variables. So in modern engines look-up tables are used to select suitable advance angle for specific engine operation conditions. These look-up tables contain experimental advance data and they are loaded to eeprom memories. Figure 4.14 shows advance angle map which is dependent of engine load and engine speed.

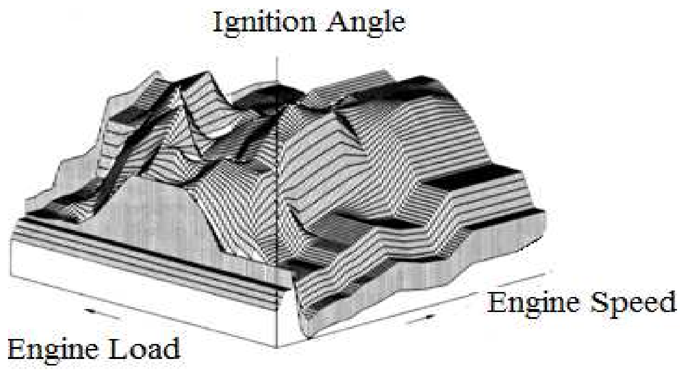


Figure 4.14: Advance angle map

In our system, 24C64 series eeprom is used to load look-up advance table, the 24C64 eeprom provides 65536 bits electrically erasable and programmable read only memory, it means we can write 8 bit advance data to 8192(13 bit) addresses, 13-bit address is divided as 8 bit + 5 bit in our application according to importance on advance. As seen in figure 4.15, the main circuit uses rpm value and cooling water temperature as eeprom address to select suitable advance angle from the look-up table, rpm value is the 8-bit address part (ADDRESSL) and cooling water temperature is the 5-bit address part (ADDRESSH) [26].

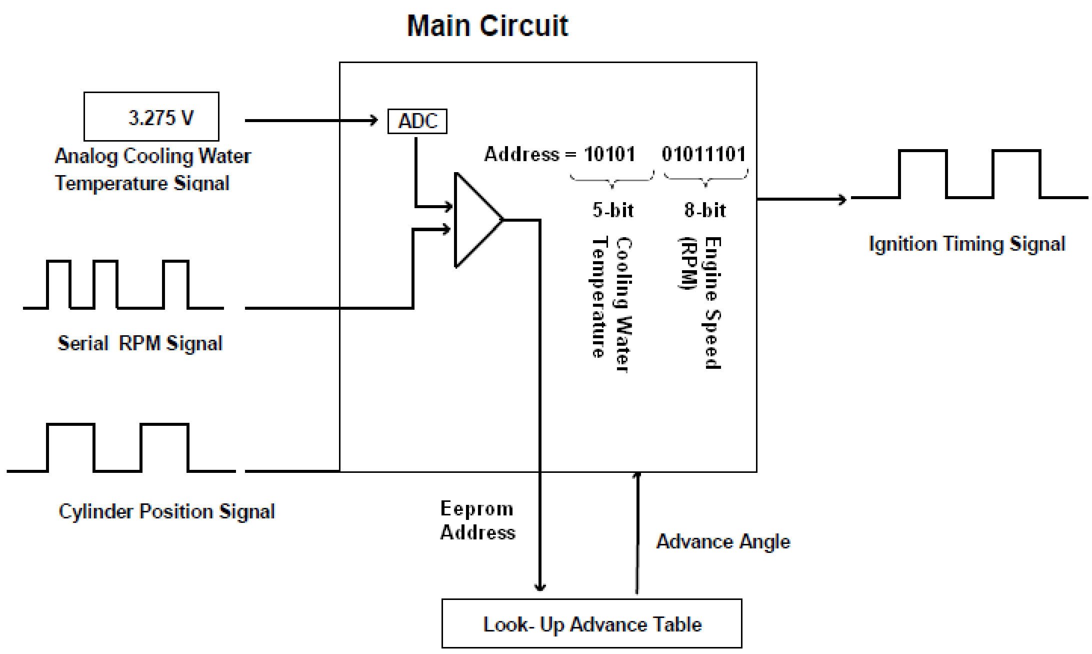


Figure 4.15: Operational View of the Main Circuit

(The values 3.275 V and 10101 01011101 are symbolic numbers). The required advance angle value for the engine speed and cooling water temperature in the address which the advance angle value will be read from, was loaded into that address before, this is the philosophy to load advance angle map into eeproms.

Selection of advance angle according to engine speed and cooling water temperature is told above, the advance angle value which is read from the eeprom is a time delay and this delay is added to cylinder position signal. The main control circuit program goes to wait for position signal of the first cylinder after it reads the advance angle value. When it detects the falling edge of the first cylinder position signal it waits for a moment, this moment is advance angle value which is read from eeprom memory, and then it sends ignition point (the falling edge of the ignition timing signal) to the first igniter circuit, and it repeats this process for eight times.

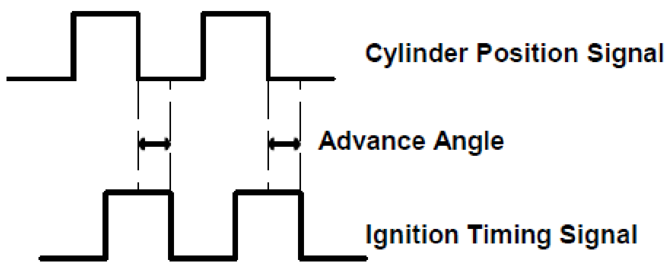


Figure 4.16: Ignition timing signals

The ignition timing signal is a square wave, when the main control circuit receives the cylinder position signal it makes its related pin high (ignition mode_0), after advance delay it makes the pin low and creates the spark with the igniter circuit. The point at which the pin is made high changed according to the engine speed, it is called dwell angle and it is going to be told in part 5.5.

For the time being, it is impossible to determine advance values, because advance angle values are determined after series of tests which is called calibration tests.

4.2.5 Receiving Ignition Timing Signal and Firing Spark Plugs

As stated in previous chapter, there are eight PIC16F628A based igniter circuits which are dedicated to receiving ignition timing signals and trigger induction coils. Ignition timing is determined by the main circuit according to advance angle, as seen in Figure 4.16, it is a square wave. In signals which are in square wave form, there are two reference points, rising edge and falling edge. Our igniter circuit detects its related input pin continuously to catch the rising edge of ignition timing signal, when it catches the rising edge it opens the way of current which flows through the primary winding of induction coil by driving mosfet via optocoupler. Then it starts to detect the related input pin continuously to catch the falling edge of ignition timing signal, when it detects the falling edge, it closes the way of the current suddenly to induct high voltage in the secondary winding of induction coil.

This high voltage jumps to ground via spark plug as a spark and ignition occurs. Figure 4.17 shows operational view of the igniter circuit.

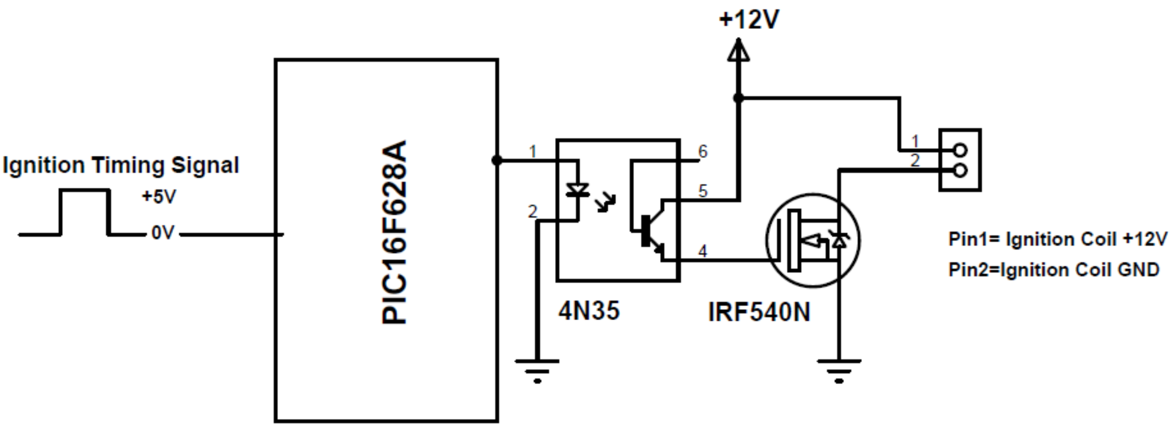


Figure 4.17: Operational view of the igniter circuit

CHAPTER 5

DESIGN CALCULATIONS

Control circuits which are used in our system are based on PIC microcontroller and the microcontroller units on the circuits are programmed in assembly language. Ignition is a fast process, so our ignition system should be fast enough to initiate ignition at the required time. In the circuits 4 MHz crystals are used as an oscillator; it means our circuits are able to make 1000000 operations per second; this operational speed is suitable for our application, but the control circuits convert analog speed signal and cooling water temperature to digital value, and read ignition advance angle value from an external eeprom these are time consuming operations, so the registers related to operational speed of these operations should be set according to time requirements.

5.1 A/D Conversion Calculations

5.1.1 Acquisition Time

Before the analog to digital conversion starts, the charge holding capacitor (C_{HOLD}) must be allowed to fully charge to input channel voltage level. Analog input model of PIC microcontroller unit is given in Figure 5.1; according to analog input model the source impedance (R_S), internal sampling switch impedance (R_{SS}) and interconnect resistance (R_{IC}) directly affect the time required to charge the capacitor (C_{HOLD}).

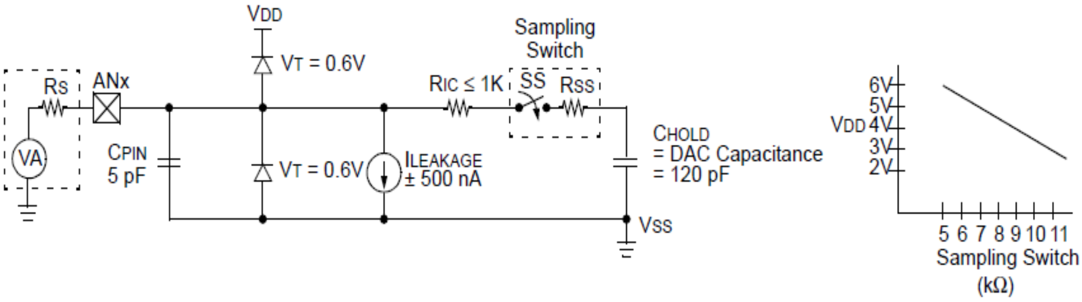


Figure 5.1: Analog input model

Another parameter affecting acquisition time is amplifier settling time, internal amplifier of the microcontroller unit is set before the conversion. Also working conditions especially temperature affects acquisition time of the microcontroller unit. The acquisition time of mcu can be stated as follows [1]:

T_{ACQ} = Amplifier Settling Time + Hold Capacitor Charging Time + Temperature Coefficient (**5.1**)

$= T_{AMP} + T_C + T_{COFF}$

$= 2\ \mu s + T_C + [(\text{Temperature} -25\ ^oC)*(0.05\ \mu s/\ ^oC)]$

$T_C = C_{HOLD} *(R_{IC} + R_{SS} + R_S)* \ln(1/2047)$

$= -120\ pF\ (1\ k\Omega + 7\ k\Omega + 10\ k\Omega) \ln(0.0004885)$

$= 16.47\ \mu s$

$T_{AMP} = 2\ \mu s$

$T_{ACQ} = 16.47 + 2 + (75\text{-}25)*0.05$

$= 20.97\ \mu s$

The result of equation 4.1 gives the acquisition time of voltage, it may be assumed as a delay before the A/D conversion. The order of magnitude of acquisition time is microsecond; it is acceptable for our application.

5.1.2 Selecting the A/D Conversion Clock

The analog to digital conversion time per bit is defined as $T_{AD.}$ The analog to digital conversion requires a minimum 12 T_{AD} per 10-bit conversion process. For correct A/D conversion operation, the A/D clock must be selected to ensure a minimum T_{AD} 1.6 µs [1]. The source of the analog to digital conversion clock is software selected and there are six options for T_{AD}:

- 2 T_{OSC}
- 4 T_{OSC}
- 8 T_{OSC}
- 16 T_{OSC}
- 32 T_{OSC}
- 64 T_{OSC}

Note: T_{OSC} is period of oscillator. The oscillator on the control circuits is 4 MHz crystal:

Frequency (f) = 1/ Period (T)

5.2

4 MHz = 4000 000 Hz

$4000000 = 1/T_{OSC}$

$T_{OSC} = 0.25$ µs

As stated before, T_{AD} should be selected as minimum 1.6 µs.

$X*T_{OSC} = 1.6$ µs X*0.25 µs = 1.6 µs so X = 6.4(minimum)

So it is selected as $8T_{OSC.}$ Conversion time can be calculated as $12*T_{AD}$

12*1.6 = 19.2 µs required time for 10-bit conversion.

5.1.3 A/D Conversion Resolution

As it is stated before, PIC16F877A has 10-bits A/D conversion module it means it can sense $4.8876x10^{-3}$ volts.

Resolution = $(Vref^{+} - Vref^{-}) / (2^{10}-1)$

5.3

= (5-0) / 1023

$=4.8876x10^{-3}$ volts

5.2 Serial Communication Rate

In our system synchronous serial communication method is used. Minimum operating time is selected for analog to digital conversion operation, but it is about 20 µs. There is no specific limit for serial communication rate, but it can be select as equal to the analog to digital conversion rate. The required time for serial communication will be selected as 16 µs (for 8-bit). Operational speed of serial communication is defined with baud rate; it is numbers of bits transferred per second; and it is set by SPBRG register. For synchronous serial communication [1]:

Baud rate = F_{OSC} / (4*(SPBRG+1))

5.4

1/Baud rate = T (time required to send 1 bit data) (s)

5.5

As mentioned above, the required time for serial communication may be selected as 16 µs

So from the equation 5.5:

16x10^-6 = 8*(1 / Baud rate)   for 8-bit data

Baud rate = 500 kHz

From the equation 5.4:

500000 = 4000000 / (4*(SPBRG+1))

SPBRG = 1

5.3 Reading Ignition Advance From External Eeprom

The most time consuming operation is reading ignition advance angle value from an external eeprom. This operation is held by using I^2C master mode operation. The master device generates all of the serial clock pulses and the start and stop conditions. The operation has two part as follows master transmitter mode and master receive mode. In master transmitter mode serial data is output through SDA pin (pin RC4) while SCL (pin RC3) outputs the serial clock. The first byte transmitted contains the slave address of the receiving device (7bit) and read/write (R/W) bit for this operation R/W bit will be logic 0; it means master device will write. After each byte is transmitted an acknowledge bit (ACK) is received. In master receive mode, the first byte transmitted contains the slave address of the transmitting device (7 bits) and the R/W bit, for this operation the R/W bit will be logic high “1”. Serial data is transmitted 8 bits at a time. After each byte is transmitted, an acknowledge bit (ACK) is received the assembly code to check ACK bit is command lines between 884 and 895 in Appendix A. The assembly code of the operations to read data from external eeprom is between command lines 828 and 937 in Appendix A. The external eeprom memory which is used in our system has 64 Kbit memories; so it is addressed with 2 bytes; they are called high byte and low byte. The data transfer rate of this communication is set with SSPADD register as below [1]

$Clock = F_{OSC} / (4*(SSPADD+1))$

5.6

The original communication speed was defined with a maximum 100 kbit per second (max frequency 100 KHz) so we will select clock as 100 KHz.

From the equation 5.6:

$100000 = 4000000 / (4*(SSPADD+1))$

$SSPADD = 9$

Equation 5.5 can be used to calculate required time to read or send 1-bit data as follows:

1/100000 = 10 µs required time to send 1-bit data.

The operational view of reading 8-bit data from external eeprom with 2 byte address is shown in Figure 5.2.

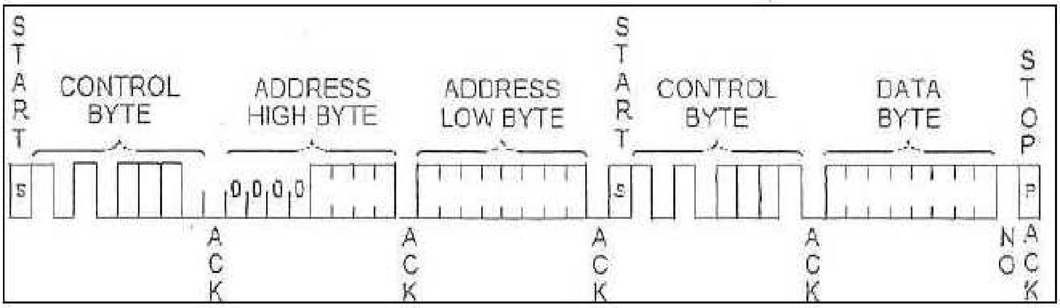


Figure 5.2: Operational view of reading 8-bits data in I^2C master mode

The operations to read ignition advance angle value in our system will be as follows:

- Send 8-bit control byte
- Wait for ACK signal
- Send high byte of address which will be read
- Wait for ACK signal
- Send low byte of address which will be read

- Wait for ACK signal
- Send 8-bit control byte
- Wait for ACK signal
- Read 8-bit data

As stated above, to read 8-bit data the system send or receives 8 bit data for five times and wait for ACK signal for four times. So required time to read 8-bit data will be:

$5*8*10\ \mu s$ + 4 wait for ACK signal

$400\ \mu s$ + 4 wait for ACK signal

The operations and their time consumption were given above, but there are also mathematical calculations and delays during the operation. And the time consumed during those operations related to the engine speed so this time will be determined experimentally. The important point here is the time consumed during those operations shall not exceed time interval between two ignitions. This time interval can be calculated as follows:

Time interval between two ignitions = (1000*60)/(8*Engine Speed) **5.7**

5.4 Calculating Advance Delay

In our system, advance angle values are kept in external eeprom. The control circuits read analog value and convert it into digital form. After the conversion, they scale it into 5-bits or 8-bits form to form external eeprom addresses. In our system, the cooling water temperature was taken as zero and advance angle addresses were calculated. So, engine speed is the only criterion to read advance angle. After conversion of engine speed into digital form, the related control circuit divides it to 4 to scale it into 8-bits form. It is calculated as in equation 5.8:

Eeprom address = Engine speed (volts) / [$4*4.8876x10^{-3}$ (volts)] **5.8**

Advance angles are determined after calibration of the engine, so at this time we do not have data to write to the eeprom addresses. So, the advance angle values were selected the same with eeprom addresses because we are just testing ignition system for the time being. Advance delay which is read from external eeprom can be calculated as in equation 5.9.

Advance delay = [Engine speed (volts) / [4*4.8876x10^{-3} (volts)]]*11 μs **5.9**

5.5 Determination of Ignition Modes

As stated before, the ignition process starts with the flowing of the current through the primary coil of the ignition coil. When the current is broken, the spark is generated. But to have suitable spark quality, the ignition coils should be saturated, so there is a minimum duration which the current should keep flowing. This duration was observed around 5 ms for our ignition system. With the increasing engine speed, the starting point of the ignition process should be advanced; this is called as dwell angle. The main control circuit which manages the all operations is capable of arranging the dwell angle with its code. There are 4 main modes which are mode_0, mode_1, mode_2 and mode_3. Also, there are 3 transition modes between the main modes; they are premode_1, premode_2 and premode_3. The ignition modes are determined with the codes between 68 and 736 in Appendix A.

We have 2 points which we can use to arrange dwell angle they are cylinder position signals and ignition points. We can start the ignition process when the cylinder position signal is received (mode_0) which is valid for low engine speeds. We can start the ignition process at the ignition point or cylinder position signals of the previous cylinders. In mode_1, the ignition process is started at the ignition point of the previous cylinder, in mode_2 the process is started at the cylinder position signal of the previous cylinder and in mode_3 the process is started at the ignition process of two cylinders before. And the premodes are used for the transition between two ignition modes. The ignition mode intervals can be calculated as below.

Sweep Time (ms) = [Crank Angle (degree)] x 60000 / [360 x Engine Speed (rpm)]
5.10

The cylinder position signals give the position of the point which is around 22.5˚ before the cylinder, and the angle between the actual cylinder position and the ignition point of the previous cylinder can be assumed as 45˚. The equation 5.10 can be used to determine the starting point of the ignition process. The most important parameter is that minimum sweep time between the starting point of the ignition process and the spark generation is 5 ms, and we can use the points at 22.5˚, 45˚, 67.5˚, 90˚ etc.

Sweep Time (ms) = [Crank Angle (degree)] x 60000 / [360 x Engine Speed (rpm)] **5.10**

We can arrange the equation 5.10 as follows.

Engine Speed (rpm) = [Crank Angle (degree)] x 60000 / [360 x Sweep Time (ms)]

Let`s calculate the maximum engine speed for 22.5˚ as a sample calculation:

Engine Speed = (22.5 x 60000) / (360 x 5)

Engine Speed (max) = 750 rpm this is the upper limit of the mode_0

For the sweep time 5 ms and crank angles 22.5, 45, 67.5 and 90˚, the engine speeds calculated as follows.

Table 5.1 Maximum engine speeds of the ignition modes

Ignition Mode	Crank Angle	Max. Engine Speed (rpm)
Mode_0	22.5˚	750
Mode_1	45˚	1500
Mode_2	67.5˚	2250
Mode_3	90˚	3000

To stay in the safe region, the engine speed limits for the ignition modes are selected as 650, 1350, 2050 and 3000. And the limits for the transition are selected as 700, 1400 and 2100. The usage of the speed limits is given in source code of the main control circuit with the lines 68 and 115 in Appendix A. And the decimal number which are used to determine the ignition mode (lines 74, 80, 86, 92, 98, 104 and 110) are the rounded digital values of the lower limits of the ignition modes, and they are calculated as follows.

Engine Speed (digital) = Engine Speed (rpm) x 4.8 / (3000 x Resolution) **5.11**

As it is stated in previous chapters, the frequency to voltage converter circuit is designed to have 4.8 volts output for engine speed and “Resolution” is the resolution of the ADC module which is calculated with the equation 5.3

CHAPTER 6

SOURCE CODES OF THE CONTROL CIRCUITS AND IGNITER CIRCUITS

As it was given in chapter 3, there are two control circuits and eight igniter circuits in our experimental set-up; and those circuits are microcontroller based circuits. In this chapter, the codes which were written and loaded to microcontrollers on the circuits will be stated and explained. The source codes of microcontrollers were written in assembly language and complied with MPLAB IDE v7.00 by Microchip. The assembly language is more complex language than C or Basic based microcontroller programming languages.

6.1 Source Code of the Main Control Circuit

In this part of the chapter, the source code of the main control circuit which is given in Appendix A will be explained. The duty of the main control circuit is to manage the operations, receive the rpm value from the secondary circuit, read the cooling water temperature and scale it into 5-bit form, combine the rpm value with the cooling water temperature to form the address of the external eeprom, read the advance value from the external eeprom and arrange the ignition points. The main control circuit is PIC16F877A based and it is working with 4 MHz crystal. As stated before, PIC16F877A has 40 pins; and these pins have jobs more than one. For example, a pin can be configured as analog input, digital input or digital output. So, first thing which should be done during programming is to configure the pins of microcontroller. The main body of the source code is labeled as main, the command lines 10 and 11 calls the subroutines which configure the microcontroller to do the jobs which are stated above. The command line 10 calls the subroutine which initializes the I2C communication, serial communication, input-output pins and analog channels. The duty of the subroutine “initialize” is as follows. As it is given in chapter 4, the main control circuit uses its PORTD to receive cylinder position signals from the secondary control circuit and send ready signal to the secondary control circuit. The 0th pin of PORTD is used to receive cylinder position signals, so it should be configured as input; and the 1st pin of PORTD is used to send ready signal, so it should be configured as output. The command lines between 744 and 748 in initialize subroutine are used to configure PORTD. After sending ready signal, the main circuit starts to wait for serial rpm value with synchronize serial communication. In the experimental set-up, main control circuit works as slave and the secondary control circuit work as master. The serial communication settings are arranged with the command lines which are given below:

---- ---- ---- ---- ----

```
bsf     TXSTA, SYNC              ;765 the SYNC bit of register TXSTA
                                 ;    should be set to 1
                                 ;    to select synchronous serial
                                 ;    communication
banksel RCSTA                    ;766 go to bank0
bsf     RCSTA, SPEN              ;767 opens the serial port
banksel TXSTA                    ;768 go to bank1
bcf     TXSTA, CSRC              ;769 selects the slave mode
bsf     PIE1, RCIE               ;770 activates the data receive
                                 ;    interrupt
banksel RCSTA                    ;771 go to bank0
bcf     RCSTA, RX9               ;772 data format is 8-bit
return                           ;773 quit from the subroutine
```

---- ---- ---- ----

There are some registers to configure serial communication mode and settings. One of them is TXSTA. This register is used to select synchronous or asynchronous and master or slave serial communication. The command line 765 is used to select synchronous serial communication and command line 769 is used to select slave mode serial communication. Another register is RCSTA, this is used to select 8-bit or 9-bit data transfer and open or close serial port. The command line 767 is used to open the serial port and the line 772 is used to select 8-bit data transfer. After receiving serial rpm data, the main control circuit reads analog cooling water temperature and converts it into digital form. So the analog to digital conversion parameters should be arranged. The command lines which are given below are used to configure ADC.

---- ---- ---- ----

```
                                    ; ADCON0 is a register which configures ADC
                                    ; the bits ADCON0,6  and ADCON0,7 are
                                    ; used to select ADC clock frequency
                                    ; and the bit ADCON0,0 is used to
                                    ; activate ADC module
                                    ;
                                    ; for clock=Fosc/8 ADCON0,6=1  ADCON0,7=0
                                    ; to activate the module ADCON0,0 shall be 1
                                    ; the sum of ADCON0,0 ADCON0,6
                                    ; equals to d'65'=0x41
movlw   0x41                        ;760 W=0x41
movwf   ADCON0                      ;761 ADCON0=0x41 it means clock
                                    ;    frequency is Fosc/8 and ADC
                                    ;    module is activated
movlw   0x80                        ;762 W=0x80
bsf     STATUS, RP0                 ;763 go to bank 1
movwf   ADCON1                      ;764 ADCON1=0x80
                                    ;    the 7th bit of ADCON1 register

                                     ;    shall be set
                                     ;    to "1" to arrange ADRESH
                                     ;    (high byte of ADC)
                                     ;    and ADRESL (low byte of ADC)
                                     ;    to get a 10-bit ADC result in form of
                                     ;    000000xx(ADRESH)xxxxxxxx(ADRESL)
                                     ;    x=0 or 1
                                     ;    so ADCON1=d'128'=0x80
```

---- ---- ---- ----

The related registers to configure ADC settings are ADCON0 and ADCON1. The value 0x41 is appointed to ADCON0 to set the ADC clock frequency Fosc/8 [1] with command line 760 and 761. PIC16F877A has 10-bit ADC module, the format of the 10-bit data can be arranged by ADFM (bit-7) of ADCON1. In the source code, the ADCON1 is arranged to have 000000xx (high byte of 10-bit data) and xxxxxxxx (low byte of 10-bit data) with the command lines 762 and 764.

The main control circuit reads advance angle value from an external eeprom with I2C protocol as it is given in part 5.3. From the result of equation 5.6 to have 100 kHz data transfer speed SSPADD register shall be 9. And to use I2C master mode and SDA and SCL pins for data transfer SSPCON register shall be equal to b'00101000'. All these requirements are arranged the codes in subroutine “I2C_init” which is the subroutine of “initialize” as below:

---- ---- ---- ----

```
I2C_init

        banksel SSPSTAT                 ;828
        clrf    SSPSTAT                 ;829
```

```
bsf      SSPSTAT, SMP              ;830 SSPSTAT, SMP is used to select
                                   ;    standard cycle frequency

movlw    B'00001001'               ;831 W=9
                                   ;    clock=Fosc/(4x(SSPADD+1)) Fosc=4MHz
                                   ;   so for 100kHz clock SSPADD=9
                                   ;
movwf    SSPADD                    ;832 SSPADD=9
clrf     SSPCON2                   ;833
movlw    B'10011000'               ;834 SDA and SCL are configured as input

movwf    TRISC                     ;835
movlw    B'00101000'               ;836
bcf      STATUS, RP0               ;837
movwf    SSPCON                    ;838 master I2C mode is selected
clrf     PORTC                     ;839
return                             ;840
```

---- ---- ---- ----

After initializing the ports and communication settings, the first duty of the main control circuit is send ready signal to the secondary control circuit by making high 1st pin of the PORTD with command line 12 in source codes, this is the starting point of the main loop which is called “loop”. Then it calls the “snkSlaveRead“subroutine. This subroutine is used to read serial rpm data which is coming from secondary control circuit by master-slave serial communication. The command lines of the subroutine are:

---- ---- ---- ----

```
snkSlaveRead

        banksel RCSTA               ;814
        bsf     RCSTA, SPEN         ;815 opens the serial port again
                                    ;    we should open the port
                                    ;    again for every reading

        banksel TXSTA               ;816
        bcf     TXSTA, CSRC         ;817 selects slave mode(after
                                    ;    receiving data port
                                    ;    configures itself to master mode)

        banksel RCSTA               ;818
        bsf     RCSTA, CREN         ;819 starts to waiting for
                                    ;    receiving data
```

```
btfss   PIR1, RCIF              ;820 bit RCIF of PIR1 is set
                                ;    when the data received so
                                ;
                                ;
                                ;
goto    $-1                     ;821 wait for the end
                                ;   of data transfer

movf    RCREG, W                ;822 if data transfer is
                                ;    completed, W=RCREG
                                ;    RCREG is a register which
                                ;    stores the received data
bcf     PIR1, RCIF              ;823 clear the flag of received
                                ;    data for the next data transfer

btfsc   RCSTA, CREN             ;824 if there is an error during
                                ;    the data transfer
                                ;    bit CREN of RCSTA is reset,
                                ;so check whether there is an error
                                ;    or not if there is an erro set
                                ;    kontrol_register,0 (line 826)
return                          ;825
---- ---- ---- ----
```

The command line 815 is used to open the serial communication port and command line 817 is used to configure slave communication mode. If there is an error during the serial communication, CREN bit of the RCSTA register will be zero so it should be set as high (1) before the communication, command line 819 is used for this purpose. The RCIF bit of the register PIR1 will be high (1) when the serial communication is completed. With the command line 820, the end of serial communication is waited. The line 822 gets the received data to temporary variable (W); and the command line 824 checks whether there is a communication error or not. If there is an error, the program sets the 0^{th} bit of konrol_register (it is a register defined by the user). Then the user can check the kontrol_register and avoid receiving wrong data. With the "return" command program returns line 18 and appoint the value of "W" to tempH this is the first 8-bit of advance angle address.

The next step is to read cooling water temperature with analog to digital conversion module. For this purpose there are two variables defined ADC_Oku_kanalno (line 22) and ADC_Oku_sonucbyte (line 24). ADC_Oku_kanalno is the number of analog channel. As stated before, the PIC16F877A has 10-bit ADC module, so the result of the conversion is two 8-bit data. They are the ADRESL and ADRESH; the low 8-bit of the conversion is ADRESL and high 8-bit of the conversion is ADRESH. The source code was written to read ADRESL firstly and read ADRESH secondly. To read ADRESL, the value 0x00 is loaded to ADC_Oku_sonucbyte(line 24) and the subroutine “ADC_Oku” is called. The subroutine “ADC_Oku” is between 783 and 801. The analog channel is chosen with the bit 5, 4 and 3 of the register ADCON0, so ADC_Oku_kanalno value should be required 3-bit format, this is done with the command lines 784,785 and 786. To initialize ADC module 0x41 values was loaded to ADCON0 with command line 761, so this value should be added to 3-bit channel number; this is done with command line 787.

---- ---- ---- ----

```
        bcf     STATUS,C                ;783 STATUS,C is affected by command rlf
                                        ;    so it should be disabled
                                        ;   before the operation

        rlf     ADC_Oku_kanalno, F      ;784 register ADCON0 is used
                                        ;    to configure ADC module
        rlf     ADC_Oku_kanalno, F      ;785 bit 3, bit 4 and bit 5 of
                                        ;    ADCON0 is used to select
        rlf     ADC_Oku_kanalno, W      ;786 ADC channel
                                        ;    xx000xxx channel 1
                                        ;    xx001xxx channel 2
                                        ;    xx010xxx channel 3
                                        ;         .
                                        ;         .
                                        ;    xx111xxx channel 7
                                        ;    so the value ADC_Oku_kanalno
                                        ;    should be shifted to
                                        ;    the left for 3 times
                                        ;
```

The analog channel is chosen with the bit 5, 4 and 3 of the register ADCON0, so ADC_Oku_kanalno value should be required 3-bit format, this is done with the command lines 784,785 and 786. To initialize ADC module 0x41 values was loaded to ADCON0 with command line 761, so this value should be added to 3-bit channel number; this is done with command line 787.

```
        iorlw   b'01000001'             ;787  to open ADC module ADCON0,0
                                        ;     and for the clock frequency
                                        ;     0x41 should be added
                                        ;     (lines 760 and 761)
                                        ;
        Banksel ADCON0                  ;788 iorlw   b'01000001'adds
                                        ;    0x41 to ADC_Oku_kanalno
        movwf   ADCON0                  ;789
        bsf     ADCON0, 2               ;790 starts the conversion

ADC_j1

        btfsc   ADCON0, 2               ;791 if ADCON0,2 is zero it means
                                        ;    it is the end of conversion
```

```
        movf     ADC_Oku_sonucbyte, F        ;     waits for the conversion
                                             ;793
        btfss    STATUS, Z                   ;794 if ADC_Oku_sonucbyte is
                                             ;     zero, it means read the
                                             ;     low byte of conversion
                                             ;     go to line 796

        goto     ADC_j2                      ;795 if it is not zero go to
                                             ;     ADC_j2 and read high byte

        bsf      STATUS, RP0                 ;796 go to bank1
        movf     ADRESL, W                   ;797 W=ADRESL
        return                               ;798 quit from the loop

ADC_j2

        bcf      STATUS, RP0                 ;799 go to bank0
        movf     ADRESH, W                   ;800 W=ADRESH
        return                               ;801 quit from the loop
```

---- ---- ---- ----

The conversion starts with the command line 790, bsf ADCON0; 2. If the ADC_Oku_kanalno is 0x00, program goes to “ADC_j1” and takes the low 8-bit of the conversion and loads it into sicaklikL (command line 28); if the ADC_Oku_kanalno is 0x01, program goes to “ADC_j2” and takes the high 8-bit of the conversion and loads it into sicaklikH (command line 40). As stated in previous chapters, the cooling water temperature will be scaled into 5-bit format. The command lines between 43 and 58 which is subroutine “dongu2” scale it into 5-bit format.

---- ---- ---- ----

```
dongu2

        movlw   d'33'                   ;43
        subwf   sicaklikL,1             ;44 sicaklikL=sicaklikL-33
        btfss   STATUS,C                ;45 if the new value of sicaklik is negative

                                        ;   (checks the overflow of 7th bit)
                                        ;   "C" bit of STATUS is set to zero when
                                        ;   the result of mathematical operation
        goto    $+3                     ;46 go to line 49
        incf    bolum,1                 ;47 bolum=bolum+1
        goto    dongu2                  ;48 go to line 43
        incf    bolum,1                 ;49 bolum=bolum+1
        bsf     STATUS,0                ;50 set "C" bit of STATUS to 1
                                        ;   for the next operation

        movlw   d'1'                    ;51
        subwf   sicaklikH,1             ;52 sicaklikH=sicaklikH-1

        btfss   STATUS,C                ;53 if there is an overflow go to line 56
        goto    $+2                     ;54 go to line 56
        goto    $+3                     ;55 go to line 58
        decf    bolum,1                 ;56 bolum=bolum-1
        goto    $+2                     ;57 go to line 59
        goto    dongu2                  ;58 go to the starting point of the "dongu2"
```

---- ---- ---- ----

Now the program is ready to form 13-bit address of the external eeprom and read advance value. In this study, the cooling water temperature was read for future works but was not used as an input in this study, so the high byte of the external eeprom is taken as zero with the line 62. The codes which are given below are used to form 13-bit eeprom address and call the subroutine which reads the advance value.

---- ---- ---- ----

```
        movf    tempH,0                 ;59 W=tempH, this line loads
                                        ;   the value of tempH to the
        movwf   sayacH                  ;60 sayacH=W it means sayacH=tempH

        clrf    I2C_Device              ;61 I2C_Device=0
        clrf    I2C_AdrH                ;62 I2C_AdrH=0 because we
                                        ;   did not use the cooling
                                        ;   water temperature for this study
                                        ;   but it may be used in
                                        ;   the future (it may be
                                        ;   the output of any sensor
                                        ;   with analog output)

        movf    sayacH,0                ;63 W=sayacH
        movwf   I2C_AdrL                ;64 I2C_AdrL=sayacH

        call    I2C_ReadEE              ;65 calls the subroutine
                                        ;   "I2C_ReadEE" which


                                        ;   reads 8-bit data from
                                        ;   the external eeprom

    bcf     PORTD,1                     ;66 makes the 1st bit of
                                        ;   PORTD logic low
                                        ;   elapsed time between
                                        ;   line 12 and line 66
                                        ;   gives the required time
                                        ;   to read serial rpm
                                        ;   data, read analog value
                                        ;   and convert it into
                                        ;   digital, scale 10-bit
                                        ;   ADC result into 5-bit
                                        ;   and read the advance value
                                        ;   from the external eeprom
```

---- ---- ---- ----

With the command lines 59 and 60, the serial rpm value which is in 8-bit format is loaded to “sayacH” then it is loaded to low value part of the eeprom address with the command lines 63 and 64. For the time being there is no cooling water so the high value part of the eeprom address is taken as zero with the command line 62. Now we are ready to read advance angle value with the command line 65, “call I2C_ReadEE”.

As it is stated in part 5.3 with figure 5.2, first of all we should start the I2C serial communication this is done with subroutine “I2CStart” (command line 841). In this subroutine, the start bit (SEN) of the register SSPCON2 is enabled by the command line 844). Then the program waits for the being disabled of SEN bit of the register SSPCON2 in subroutine “I2CStart_j1” to continue. Then it checks whether the initiated start condition was completed by the MSSP module, by checking SSPIF bit of the register PIR1 with command line 850. SSPIF bit will be high if the start condition is completed. If it is enabled, the program erase that flag with bcf PIR1,SSPIF command for the other operations. To learn the duties of the registers and their bits, it will be helpful to look at the datasheet of PIC16F877A. The codes required to start I2C communication are as below:

```
---- ---- ----- ----
I2CStart

        banksel PIR1                        ;841
        bcf     PIR1, SSPIF                 ;842 PIR1,SSPIF is set at the end of
                                            ;    the I2C communication
                                            ;    so it should be cleared before
                                            ;     the communication

        bsf     STATUS, RP0                 ;843
        bsf     SSPCON2, SEN                ;844  bit SEN of SSPCON2 is used to
                                            ;     start the I2C communication
                                            ;     line 844 starts the communication

I2CStart_j1

        btfsc   SSPCON2, SEN                ;845 waits for the starting operation
        goto    I2CStart_j1                 ;846 if it is not started yet
                                            ;    go to "I2CStart_j1"
        banksel PIR1                        ;847

I2CStart_j2

        btfss   PIR1, SSPIF                 ;848 checks whether the data
                                            ;    transfer is completed or not
        goto    I2CStart_j2                 ;849 waits for the data transfer

        bcf     PIR1, SSPIF                 ;850 if data is transferred clear the bit
        return
---- ---- ----- ----
```

Now we can send the control byte to the external epprom, the control byte is combination of hardware address of the eeprom (1010, MSB) and logic states of A0, A1 and A2 pins of the eeprom and R/W bit (LSB), R/W bit is used to select reading from eeprom or writing to the eeprom. R/W is 0 for wirting operation and 1 for reading operation. A0, A1 and A2 pins are used to address the eeproms and give us chance to use 8 eeproms at the same time (2^3=8, it means possibility of 8 different addresses). All the pins in our application are connected to the GND. So, the 4 less significant bits of the control byte is 0000. With the command lines 912, 913 and 914 the source code forms the control byte, by this method you can connect another eeprom to the circuit and use it without changing the source code. With the command line 915, the control byte is loaded to “I2CSend_data”.

---- ---- ---- ----

```
I2C_ReadEE

        call    I2CStart                        ;911 starts the communication
        rlf     I2C_Device, W                   ;912 data format of control byte
                                                ;    is 1010(A2)(A1)(A0)(R/W)
                                                ;    so to have this form we
                                                ;    shall shift the I2C_Device
                                                ;    to the left. Actually we can
                                                ;    write the control byte directly
                                                ;    because there is only one
                                                ;   external eeprom. This code form is
                                                ;    used for future works
                                                ;
        andlw   0xFE                            ;913
        iorlw   0xA0                            ;914 R/W is 0
        movwf   I2CSend_Data                    ;915 I2CSend_Data=control byte
        call    I2CSend                         ;916 calls the subroutine which sends
                                                ;    data to the external eeprom
```

---- ---- ---- -----

Then the program goes to the subroutine "I2CSend", this is the subroutine which sends the data to the external eeprom with the code given below. There is an another register called as "SSPBUF", this is the buffer of the master synchronous serial port; so to send the data I2CSend_Data is loaded into that register with the command line 863.

---- ---- ---- ----

```
I2CSend
        banksel PIR1                            ;861
        bcf     PIR1, SSPIF                     ;862 should be reset before
                                                ;    the data transfer
        movf    I2CSend_Data, W                 ;863 W=I2CSend_Data
        movwf   SSPBUF                          ;864 SSPBUF=I2CSend_Data
                                                ;    SSPBUF is buffer register,
                                                ; it stores the received or sent data
        return                                  ;865 quit from the routine
```

---- ---- ---- ----

The other subroutine in the routine "I2C_ReadEE" is "I2CAck", as it is seen in figure 5.2, after data transfer external eeprom send a received signal. (Ack means acknowledged). The most important line of that routine is "btfsc SSPCON2, ACKSTAT" because ACKSTAT bit of the SSPCON2 becomes low (0) when the data is received by the eeprom. The duty of I2CAck subroutine is to check whether the data sent to the eeprom is received or not.

After the control byte, the high byte part of the eeprom address is sent to eeprom, for each data transfer the I2CACK subroutine is called to check whether the data is sent or received. The codes below are used to send the high byte of the address and checkACK.

---- ---- ---- ----

```
movf    I2C_AdrH, W         ;918 W=high byte of eeprom address
                            ;    which the advance data will be read
movwf   I2CSend_Data        ;919 I2CSend_Data=high byte of address
call    I2CSend             ;920 calls the subroutine which sends
                            ;    data to the external eeprom
call    I2CAck              ;921 after sending high byte of
                            ;    address we should check ACK
```

---- ---- ---- ----

Then the low byte part of the eeprom address is sent to the eeprom and ACK is checked again.

---- ---- ---- ----

```
movf    I2C_AdrL, W         ;922 W=low byte of eeprom address
movwf   I2CSend_Data        ;923 I2CSend_Data=low byte of address
call    I2CSend             ;924 calls the subroutine which
                            ;    sends data to the external eeprom
call    I2CAck              ;925 after sending low byte of address
                            ;    we should check ACK
```

---- ---- ---- ----

The next step needs to be paid attention, the address value is sent to the eeprom and the data at that address will be read, to read a value from the external eeprom, new control byte with R/W=1 should be sent, so the eeprom should be restart again. To restart the eeprom the subroutine "I2CReStart" will be called, to restart the eeprom RSEN bit of SSPCON2 register will be set with the command "bsf SSPCON2, RSEN"(command line 857). Then control byte should be sent to the eeprom, but R/W bit shall be 1, it means reading operation will be held. The codes which are used to restart are given below.

---- ---- ---- ----

```
I2CReStart

        nop                         ;851
        nop                         ;852
        nop                         ;853
        nop                         ;854
        nop                         ;855
        banksel SSPCON2             ;856
        bsf     SSPCON2, RSEN       ;857 SSPCON2, RSEN is used to
                                    ;    restart the I2C mode

I2CReStart_j1

        btfsc   SSPCON2, RSEN       ;858 SSPCON2, RSEN is reset at
                                    ;    the end of resatrt operation
```

```
        goto    I2CReStart_j1           ;859 this lines are used to wait
                                        ;    for the end of restart
        return                          ;860
```

Finally the I2CRead subroutine will be executed. The value of the SSPBUF register is the value of the data which we want to read. “I2CRead” subroutine has also some registers and bits which are enabled or disabled after data transfer, these registers can be easily found in the datasheet of PIC16F877A [1].

---- ---- ---- ----

```
I2CRead
        banksel SSPCON2                 ;866
        bsf     SSPCON2, RCEN           ;867 this line activates the
                                        ;     receiving mode

I2CRead_j1

        btfsc   SSPCON2, RCEN           ;868 wait for the end of
                                        ;   activation of receiving mode
        goto    I2CRead_j1              ;869
        banksel PIR1                    ;870

I2CRead_j2

        btfss   PIR1, SSPIF             ;    is data received?
        goto    I2CRead_j2              ;871 if no, wait for the data transfer

        bcf     PIR1, SSPIF             ;872 after data transfer, reset
                                        ;    the data transfer flag
        movf    SSPBUF, W               ;873 read the received data

        return                          ;874 quit from the routine
```

The last step of reading advance angle data from an external eeprom is calling I2CNak subroutine. This routine is used to check whether reading operation completed or not, there are some registers which set or reset at the end of reading operation these registers can be easily found in the datasheet of the PIC16F877A[1]. The codes which are given below are used to check “NO ACK”.

```
---- ---- ---- ----

I2CNak
        banksel SSPCON2                 ;896
        bsf     SSPCON2, ACKDT          ;897 set bit ACKDT of SSPCON2
                                        ;
I2CNak_j1

        btfsc   SSPCON2, ACKSTAT        ;898 waits for the acknowledgement of
                                        ;    data by the slave device

        goto    I2CNak_j1               ;899
        bsf     SSPCON2, ACKEN          ;900 sets the receiving mode of
                                        ;    master device and
                                        ;    sends ACKDT bit to slave device
        bcf     STATUS, RP0             ;901
        bcf     PIR1, SSPIF             ;902 reset the bit SSPIF of PIR1

I2CNak_j2

        banksel SSPCON2                 ;903
        btfsc   SSPCON2, ACKEN          ;904 after sending of ACKDT,
                                        ;    ACKEN is reset
        goto    I2CNak_j2               ;905 so these lines checks
                                        ;    whether ACKDT is sent or not
        banksel PIR1                    ;906

I2CNak_j3

        btfss   PIR1, SSPIF             ;907 is the data transferred?
        goto    I2CNak_j3               ;908 waits for the data transfer

        bcf     PIR1, SSPIF             ;909 reset PIR1, SSPIF for
                                        ;    the next operations
        return                          ;910 quit from the routine

---- ---- ---- ----
```

When the advance angle value is read from the external eeprom, the main control circuit makes 1st bit of PORTD low by the command line 66. The read advance angle value is loaded to variable “avans” with command 67. Now the circuit is ready to receive cylinder position signals from the secondary control circuit and add advance value to the cylinder position and ignite the spark plugs. As stated in previous parts, to ignite the spark plugs we should saturate the ignition coils it means we let the current flow through the primary coil of ignition coils for a while, this duration is around 5 ms for our application. But, if the engine speed increases the time between two cylinder positions decreases, so we do not have required time to saturate the ignition coils and get poor spark quality. To avoid getting poor spark quality with the increasing engine speed, the code block which is between command lines 69 and 115 was written. With this code block, the start point of the current flow through the primary coil of ignition coils is advanced. With the commands between 68 and 72, the rpm value is loaded to a variable “mode_sayac” and according to this variable starting point of the current flow is determined.

For example, if the rpm value (mode_sayac) is between 1 and 54, it means the engine speed is between 0 and 650 rpm, the subroutine mode_0 (command lines between 116 and 196) is called, with this subroutine main circuit receives first cylinder position signal from the secondary control circuit with PORTD,0 and starts the current flow through the primary coil of first ignition coil and then breaks the current at the ignition point and spark occurs. And it repeats this sequence for the other seven ignition coils. Then it goes to the starting point of the main loop (“loop”). For this case, the engine speed is low and the time between two ignition points is much enough to saturate the ignition coils. The “loop 7” which is given below is used to check whether the engine speed is between 0 and 650 rpm

```
---- ---- ---- ----
loop7

        movlw   d'1'                    ;110 W=1
        subwf   mode_sayac,W             ;111 mode_sayac=mode_sayac-1

        btfss   STATUS,C                 ;112 whether the result of line 111 is
                                         ;    negative or not

        goto    loop                     ;113 if it is negative go to
                                         ;    starting of the "loop"
        call    mode_0                   ;114 if it is not negative, calls
                                         ;    the ignition mode "mode_0"

        goto    loop                     ;115 when the ignition sequence is
                                         ;    complete,
                                         ;    go to the starting of the "loop"

---- ---- ---- ----
```

For the case mode_1 (command lines between 279 and 368), there is not enough time between two ignition points, so the starting point of the current flow through the primary winding of ignition coils are advanced. The commands given below are from case mode_1, when the main control circuit ignites the 8^{th} ignition coil; it starts to saturate the 1^{st} coil according to these codes. But, there is an important point; while the first execution of mode_1 first ignition coil would not be started to saturate before, so the first park of the ignition coil 1 would have poor quality. To prevent this situation, the control code has “premode_x” routines. For example, the premode_1 subroutine is the same with the mode_0 routine except command line 277. With this command line it starts to saturate the 1^{st} ignition coil at the end of the ignition sequence and will be ready for the mode_1. There is a disadvantage of these premode_x routines, if the engine rotates with the speed within the premode_x routines for a long time the 1^{st} ignition coil and igniter circuit starts to heat, so the speed limits of premode_x were kept tight. The codes given below are the part of premode_1. With the line 277, the 1^{st} ignition coil is started to be saturated at the ignition point of the 8^{th} ignition coil.

---- ---- ---- ----

```
banksel PORTB                        ;272
bsf     PORTB,0                      ;273
movwf   delay_ms_data                ;274
call    delay_ms                     ;275
bcf     PORTB,0                      ;276
bsf     PORTB,7                      ;277 the 1st igition coils is
                                     ;    started to be saturated at this
                                     ;    point for the the mode_1
return                               ;278
```

---- ---- ---- ----

The other modes and premodes have the same philosophy with mode_0, premode_1 and mode_1. With the increasing engine speed, they advances the starting point of the current flow through the primary windings of ignition coils, and eliminate the decreasing spark quality with the increasing engine speed. The mode of the ignition ignition is determined with the loops “loop2”, “loop3”, “loop4”, “loop5”, “loop6”, “loop7” and lines between73-79.

After completing the ignition of all sparks, the program goes to the starting point of the “loop” (line 12) to repeat the steps which are told above.

6.2 Source Code of the Secondary Control Circuit

As stated before, the two control circuits communicate with each other by synchronous master-slave communication. Main control circuit works as slave circuit and secondary control circuit works as master circuit in our application. The source code of the main control circuit is given in Appendix A and explained in previous part. In this part, the source code of the secondary control circuit which is given in appendix B will be explained.

The main duty of the secondary control circuit is to read engine speed and send it to the main control circuit, and detect cylinder positions and send them to the main control circuit. As it is in the previous source code, the code starts with an initialization subroutine. In that subroutine, Input/output pins of the PORTD and PORTB is configured. With the command line 83, all the pins of PORTB configured as output, because the secondary control circuit shows number of pulses in binary form with the leds connected to PORTB, also 7^{th} pin of PORTB is used to send cylinder position signals to the main control circuit. 0^{th}, 1^{st} and 2^{nd} pins of PORTD shall be configured as input because 0^{th} pin detects the ready signal of the main control circuit, 1^{st} pin detects output of the reference point sensor and 2^{nd} pin detects output of cylinder position sensor. Those pins are configured as input with the command lines 86 and 87. The codes given below are used to configure the ports.

```
---- ---- ---- ----

initial
        bsf   STATUS,RP0              ;81 go to bank1
        clrf  TRISC                   ;82 all pins of PORTC are output
        clrf  TRISB                   ;83 all pins of PORTB are output
        movlw D'255'                  ;84 W=255
        movwf TRISA                   ;85 TRISA=255 it means all pins of PORTA are
                                      ;   input
        movlw d'7'                    ;86 W=7
        movwf TRISD                   ;87 TRISD=7 it means 0th, 1st and 2nd pins of
                                      ;    PORTD
                                      ;   are input, the other pins are output

        bcf   STATUS, RP0             ;88 go to bank0
        clrf  PORTB                   ;89 initial value of PORTB is zero
        clrf  rpmL                    ;90 initial value of rpmL is zero
        clrf  rpmH                    ;91 initial value of rpmH is zero
        clrf  sayac2                  ;92 initial value of sayac2 is zero
        clrf  sayac3                  ;93 initial value of sayac3 is zero

---- ---- ---- ----
```

The command lines between 95 and 98 are used to configure ADC module, this part is the same with the part which is given in part 6.1. The secondary circuit is master circuit, so serial communication rate will be set by the secondary control circuit. From the result of equation 5.4 SPBRG = 1 for 500 kHz communication rate. The command lines between 100 and 105 are written to set the baud rate to 500 kHz.

---- ---- ---- ----

```
      movlw 0x01                       ;100 W=0x01
                                       ;101
                                       ;

      banksel TXREG                    ;102 go to bank0
      clrf    TXREG                    ;103 TXREG=0

      banksel SPBRG                    ;104 go to bank1

                                       ;   the register SPBRG is used to select
                                       ;   serial communication baudrate
                                       ;   the formula to calculate the baudrate
                                       ;   is baudrate=Fosc/(4x(SPBRG+1))
                                       ;   we have selected the baudrate as 500000,
                                       ;   so 500000=4000000/(4x(SPBRG+1))
                                       ;   SPBRG=1

      movwf   SPBRG                    ;105 SPBRG=1
```

---- ---- ---- ----

The other settings of the serial communication are configured with the lines given below.

---- ---- ---- ----

```
      banksel TXSTA                    ;106
      bsf     TXSTA, SYNC              ;107 the SYNC bit of register
                                       ;    TXSTA should be set to 1
                                       ;    to select synchronous serial
                                       ;    communication

      bsf     TXSTA, CSRC              ;108 selects the master mode

      bsf     PIE1, TXIE               ;109 data sending interrupt is activated

      bcf     TXSTA, TX9               ;110 8-bit data format is selected

      bsf     TXSTA, TXEN              ;111 data sending is activated
      banksel RCSTA                    ;112
      bcf     RCSTA, SREN              ;113 no data receiving
      bsf     RCSTA, SPEN              ;114 opens the serial port

      return                           ;115
```

---- ---- ---- ----

Also, bsf TXSTA, CSRC (command line 108) is different from the main control circuit, this code is used to enable CSRC bit to set master mode.

Now the code has completed configuration and initialization parts, and it is ready for the operation. Main loop of the source code is called as “tekrar”, first of all it detects the ready signal of the main control circuit with the command line 2, when it receives ready signal it reads the engine speed with the command lines between 4 and 20. Then it scale the 2 two 8-bit data into 8-bit and send it to the main control circuit with the subroutine "dongu2", and sends it to the main control circuit with the subroutine "snkMasterWrite".

---- ---- ---- ----

```
snkMasterWrite
        banksel TXREG                ;152 go to bank0
        movwf   TXREG                ;153 with line 39, value of "bolum"
                                     ;    was loaded to W
                                     ;    TXREG=bolum (the data which
                                     ;    will be sent is loaded to TXREG)
        banksel PIR1                 ;154 go to bank 0
                                     ;
                                     ;    the bit TXIF of PIR1 is set when data
                                     ;    transfer is completed
                                     ;
        btfss   PIR1, TXIF           ;155 checks whether the transfer
                                     ;    is completed or not

        goto    $-1                  ;156 if not, wait for the data transfer
        bcf     PIR1, TXIF           ;157 if data is transferred, reset
                                     ;    the PIR1, TXIF
                                     ;    for the next communication
        return
```

---- ---- ---- ----

After sending rpm data to the main control circuit, it starts to detect the output of reference point sensor with the command line 42, at the falling edge of the pulse it sends first cylinder position signal to the main control circuit with PORTB,7. The PORTB,7 stays at logic high state for 20 us, then it goes to logic low again.

---- ---- ---- ----

```
        Banksel PORTB                ;41 go to bank0

        btfss PORTD,1                ;42 checks the first cylinder position
        goto  $-1                    ;43 waits for the cylinder position signal
        btfsc PORTD,1                ;44 checks the falling edge of the
                                     ;   first cylinder position signal
        goto  $-1                    ;45 waits for the falling edge
        bsf   PORTB,7                ;46 if the falling edge is detected,
                                     ;   send first cylinder position signal
                                     ;   to the main control circuit
        call  delay_20us             ;47 20 us delay
        bcf   PORTB,7                ;48 makes low the PORTB,7
```

---- ---- ---- ----

Then the program goes to another loop which is called as "dongu3", in this loop it counts the ten pulses to detect the positions of the other cylinders as follows. It counts 10 pulses because the gear wheel in our experimental set-up has 80 teeth, so 10 teeth mean the new cylinder position. Then it makes 7th pin of PORTB high for 20 us to send new position signal to the main control circuit. The program repeats this routine for 7 times and completes its duty. Then it goes to the main loop “tekrar”.

---- ---- ---- ----

```
dongu3

        bcf   STATUS,Z              ;49 clears the STATUS,Z
        nop                         ;50 no operation
        nop                         ;51 no operation
        btfss PORTD,2               ;52 is there a pulse?
        goto  $-1                   ;53 if no go to line 52
        btfsc PORTD,2               ;54 if yes wait for the falling edge
        goto  $-1                   ;55
        banksel PORTB               ;56
        incf  sayac2,F              ;57 sayac2=sayac2+1;
        movf  sayac2,0              ;58 W=sayac2
        movwf PORTB                 ;59 PORTB=sayac2, this is used to see
                                    ;    the pulses with the leds of PORTB
        movlw d'10'                 ;60 W=10
        subwf sayac2,W              ;61 W=sayac2-10
        btfss STATUS,Z              ;62 if sayac2=10 go to line 64
                                    ;   the gear wheel which is used to
                                    ;   measure the crank shaft angle
                                    ;   (detecting the cylinder positions)
                                    ;   has 80 teeth, so 10 teeth (pulses)
                                    ;   means 45 degree, new cylinder position

goto   dongu3                ;63 sayac2 is not equal to 10, go to
                             ;   the starting point of the dongu3
clrf   PORTB                 ;64 clears PORTB
bsf    PORTB,7               ;65 sends the cylinder position signal
                             ;   to the main control circuit
call   delay_20us            ;66 20 us delay

bcf    PORTB,7               ;67 makes PORTB,7 low
clrf   sayac2                ;68 sayac2=0, for the next cylinder
                             ;   position detection
banksel PORTB                ;69 go to bank0
incf   sayac3,F              ;70 sayac3=sayac3+1 sayac3 is
                             ;  the number of detected
                             ;   cylinders (except first cylinder)
movlw d'7'                   ;71 W=7
subwf sayac3,W               ;72 W=sayac3-7
btfss STATUS,Z               ;73 if sayac3=7 (if all cylinde are
                             ;   detected which means one full revolution)
                             ;   go to line 75
goto   dongu3                ;74 if not go to the starting point of the
                             ;   dongu3
banksel PORTB                ;75 go to bank0
bsf    PORTB,7               ;76 send cylinder position signal
                             ;   to the main control circuit

call   delay_20us            ;77 20 us delay
bcf    PORTB,7               ;78 makes PORTB,7 low
clrf   sayac3                ;79 sayac3=0
goto   tekrar                ;80
```

---- ---- ---- -----

6.3 Source Code of the Igniter Circuits

As it is stated before, igniter circuits are simple microcontroller based circuits, they waits for the ignition timing signal from the main control circuit, when they detect the rising edge of the ignition timing signal they start to let the current flow through the primary winding of ignition coils, then they start to detect the falling edge of the ignition timing signal. When they detects the falling edge of the ignition timing signal they break the current which flows through the ignition coil and initiate the spark generation. They have simple source code as below. As it can be understood, it is using the pin 5 of PORTB as input and pin 0 as output; the command lines 1, 2 and 3 are used to configure pin 5 of PORTB as input and the other pins of PORTB as output. The analog pins of the circuit are also configured as digital with the command lines 7 and 8, these pins may be used as input. The subroutine "RB5_TEST" is dedicated to detect the rising edge of the ignition timing signal which is connected to the pin 5 of PORTB, when it detects the rising edge; it makes the pin 0 of PORTB high with the command line 11 and goes to subroutine "RB5_TEST_low", this routine is dedicated to detect falling edge of the ignition timing signal. When it detects the falling edge it makes pin 0 of PORTB low and goes to "RB5_TEST".

---- ---- ---- -----

```
        movlw       b'00100000'     ;1
        BANKSEL     TRISB           ;2
        movwf       TRISB           ;3
        MOVLW       H'FF'           ;4
        MOVWF       TRISA           ;5
        BANKSEL     PORTB           ;6
        MOVLW       h'07'           ;7
        MOVWF       CMCON           ;8

RB5_TEST

        BTFSS       PORTB,5         ;9
        GOTO        RB5_TEST        ;10
        BSF         PORTB,0         ;11

RB5_TEST_low

        BTFSC       PORTB,5         ;12
        GOTO        RB5_TEST_low    ;13
        BCF         PORTB,0         ;14
        GOTO        RB5_TEST        :15
END                                 ;16
```

CHAPTER 7

EXPERIMENTAL RESULTS

In this study, a microcontroller based ignition system was designed and constructed for a special type of engine which is a new design. There are some design criteria which shall be achieved. In this chapter, those design criteria and how they were achieved will be stated. The design criteria can be stated as follows: Data transfer speed of the control circuits, correct advance angle, noise free ignition signals and spark quality. The data shown on figures 7.2, 7,3, 7.4 and 7.5 are collected with the DS1000 series Rigol digital oscilloscope.

7.1 Data Transfer Speed

The maximum speed of engine for which our ignition system is designed, is 3000 rpm. So, our system shall be fast enough to follow engine at 3000 rpm. Figure 7.1 shows ignition points of the engine and angle between two ignitions.

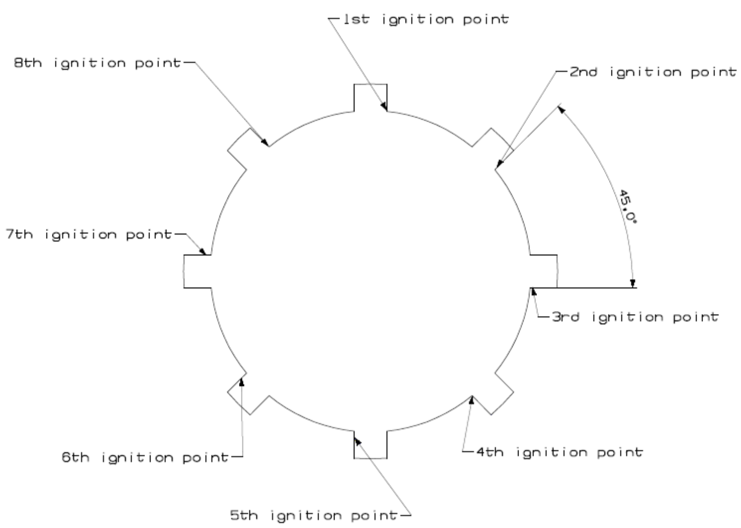


Figure 7.1: Ignition points of the engine

In our system, advance angle determination takes place between 8^{th} ignition and 1^{st} ignition as seen in Figure 7.1. There is 45° between two ignition points; during the determination two analog to digital conversions, mathematical operations and advance angle reading from external eeprom take place. These operations shall be completed before the 1^{st} ignition point. From the equation 5.7 in chapter 5, the maximum time interval in which our system shall complete all operations to determine advance angle value, can be found. According to the equation:

Maximum Time interval = (1000*60) / (8*3000)

= 2.5 ms

Our main control circuit makes one of its pins high to tell it is ready for data transfer and makes low when it completes all operations to find advance angle value. The time which the pin stays at logic high gives the time consumed for all operations. Figure 7.2 shows consumed time during those operations. It is around 1.5 milliseconds; it is acceptable because it means our system can work at 5000 rpm.

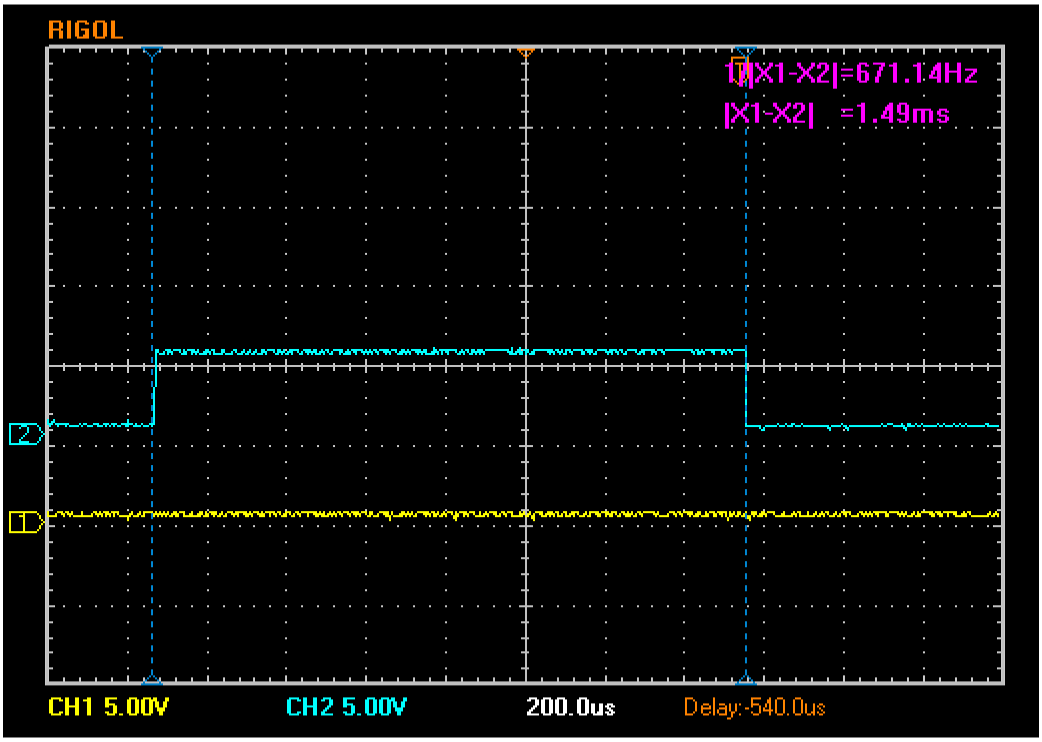


Figure 7.2: Time consumed during advance angle value determination

7.2 Advance Angle

Another requirement which shall be met is correct advance angle. Our system was tested for different engine speeds. Firstly, it is tested for engine speed which outputs 1 volt. The result of the test is given in Figure 7.3. The value X1-X2 in the figure gives the advance delay.

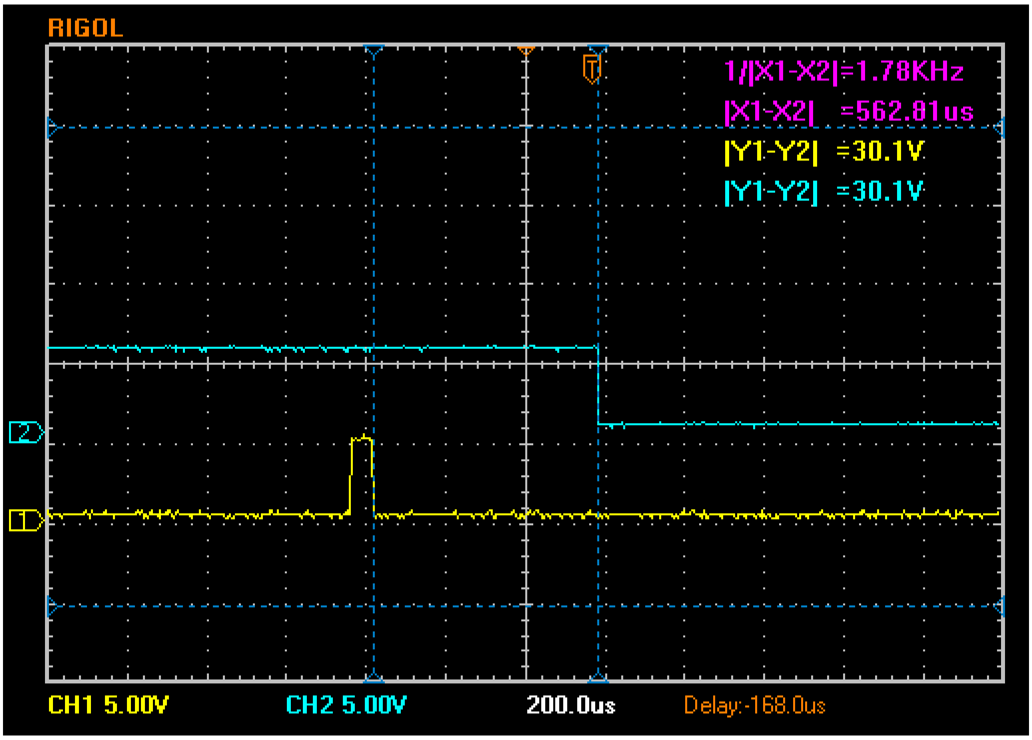


Figure 7.3: Advance delay for 1 Volt

According to equation 5.9 in chapter 5, the calculated advance delay will be as follow:

Advance delay = $[1 / (4*4.8876x10^{-3})]*11\ \mu s$

$= 562.65\ \mu s$

When we compared with the experimental result, it seems pretty good. But it is difficult to get exact value on the graph because the positions of the cursors adjusted manually. Secondly, it is tested for 2 volts; the related result is given in figure 7.4. According to equation 5.9 the advance delay would be as follow:

Advance delay = $[2 / (4*4.8876x10^{-3})]*11\ \mu s$

$= 1125.3\ \mu s$

The experimental result is 1.09 ms, but calculated one is around 1.13millisecond.

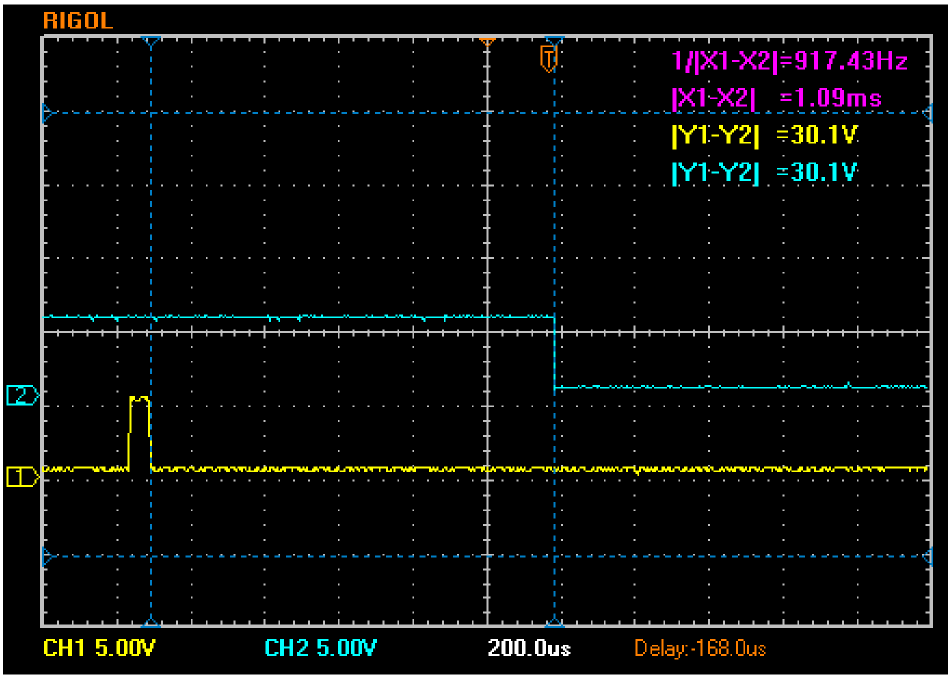


Figure 7.4: Advance delay for 2 Volts

Finally, the system is tested for 3 volts; the experimental result is given in Figure 7.5

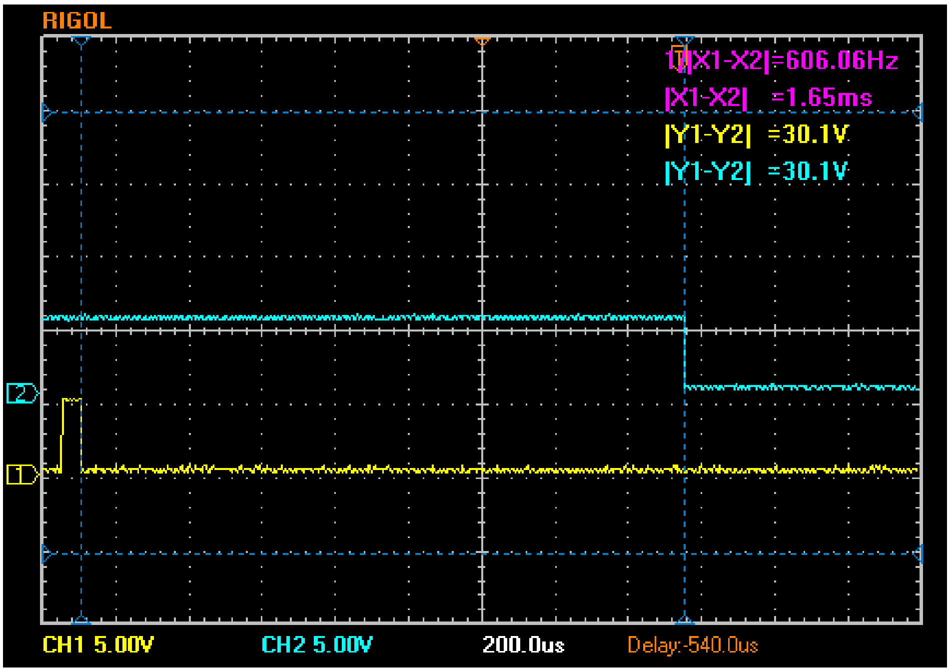


Figure 7.5: Advance delay for 3 Volts

The calculated advance delay is:

Advance delay = $[3 / (4*4.8876x10^{-3})]*11$ µs

= 1687.95 µs

The experimental results and calculated results were given above, there are small negligible differences. The reasons of these small differences can be stated as follows: With the 8-bit microcontrollers, floating point calculations cannot be done; this is one of the reasons. To adjust the positions of cursors on the graph to get exact numbers is so difficult. Engine speed outputs were measured 1, 2, and 3 volts but the voltmeter which was used to measure these values has a measuring tolerance. While calculating advance delays with equations 5.3 and 5.9 we used $Vref^+$ as 5 volts, but the voltage regulators which are assembled on our control circuits, have ±4 % output voltage tolerances; this may be stated as another reason. As stated above, there are small negligible differences between calculated and experimental results; the Table 7.1 gives tabulated results and the percentage of differences.

Table 7.1: Tabulated results and errors

Test Speed(volts)	Calculated Result(µs)	Experimental Result(µs)	Error (%)
1	562.65	562.81	0.03
2	1125.3	1090	3.1
3	1687.95	1650	2.2

7.3 Noise Free Ignition Signals

Control software was developed in Delphi 4.0; it is working with a data acquisition card. The digital inputs of the card are connected to ignition signal pins. With this control software we are able to scan ignition signals for a while and see whether there is a discontinuity or not. To check conditions of ignition signals such a scanning operation is held around maximum operating speed and figure 7.6 shows result of scanning. As seen in the figure, the result is acceptable there is no discontinuity in ignition signals and their positions according to each other are as expected.

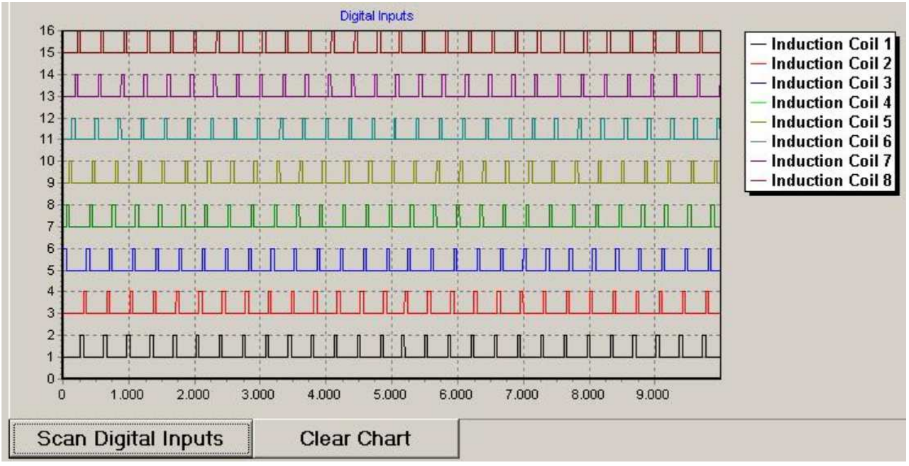


Figure 7.6: Ignition signals

7.4 Spark Quality

For the time being, there is no criterion for spark quality, so the spark quality was checked visually. Figure 7.7 shows a photo during spark generation, the spark seems reasonable.

Figure 7.7: Spark generated by our igniter circuit

CHAPTER 8

DISCUSSION AND CONCLUSION

In this study, electronic ignition system was designed and constructed for a special type of engine which was designed by Prof. A. Demir BAYKA. The engine has different working principle than the engines which are assembled on the cars in the market. There are many parts which were done during the study. First of all, two PIC16F877A based circuits were designed and related ports and pins were determined. Then, communication procedures between those two circuits were developed and working conditions were simulated with a signal generator and a power supply. With that simulation, bugs of the microcontroller codes were eliminated and the code was optimized. Then, the related hardware such as sensors, induction coils, spark plugs and igniter circuit were assembled and two PIC16F877A based circuits were tested with them. In this chapter, the results of ignition system tests, the difficulties with which were faced, advantages and disadvantages of the system and further recommendations related to the system will be stated.

The designed and constructed system is able to measure engine working conditions such as engine speed and the cooling water temperature, and it is able to adopt itself to those working conditions. It can detect cylinder position signals and determine the correct ignition points according to changing engine conditions. There are 8 igniter circuits and they are able to be triggered by the main control circuits with logic level signals. There are 2 control circuits and they are able to communicate with each other via serial communication and they are able to read 5 analog sensor outputs.

As it is stated in part 7.1, the necessary operations to find advance delay take place between ignition points 8 and 1; the angle between those two ignition points is 45º. For 3000 rpm, the engine travels 45º in 2.5 ms, so our control circuits shall complete all necessary communications and calculations in a time interval less than 2.5 ms. Figure 7.2 shows measured time interval in which all necessary operations take place to find advance delay. The result is around 1.5 ms; it is so good result because it means our system can work at around 5000 rpm. Also, this rpm value can be increased by optimizing communication and calculation rates, and changing 4MHz crystal with a high speed crystal.

The experimental results of advance delay were given in part 7.2; they are actually pretty good results, because the system can change the advance delay according to engine speed. There are also small difference between calculated results and experimental results; the reasons of those differences were given in chapter 5. Those differences are because of output tolerances of voltage regulators, measuring tolerances of voltmeter, lack of ability for floating point calculation and resolution of result graphs. The source code of control circuits were tested to check whether it is working correctly or not. For this purpose, the same advance value was written to all eeprom addresses and it was read and displayed in light emitting diodes which are connected to PORTB of main control circuits. The main control circuit was able to read and display the written value to eeprom addresses perfectly. So, the problems related to source codes which determine advance delay were not stated as a reason of differences between experimental and calculated results. In part 7.3, the ignition signals which are generated by the control circuits were given. As seen in Figure 7.6, there is no discontinuity in the signals. It means, the control circuit receives ignition timing signals and sends ignition signals correctly. In the next part, a figure shows generated spark was given. As seen in the figure, it is good enough to be seen in the day light. Actually, the spark quality is better in cylinder during combustion when it is compared with a generated spark in the atmosphere, because ionization in combustion chamber is higher because of higher temperature and pressure. It means the generated spark which is shown in Figure 7.7, is good enough and will be better in combustion chamber.

This is an experimental study, and when you working on an experimental study you face with a lot of difficulties. The most difficult thing faced during this study was magnetic field. In chapter 3, EMC is told; electromagnetic compatibility refers to the ability of equipment or a system to perform satisfactorily in its electromagnetic environment without introducing intolerable interference into anything in that environment. The ignition cable or induction coil manufacturers take into account electromagnetic compatibility, but the microcontrollers and frequency to voltage converters which were used on the circuits are very sensitive to electromagnetic field. The biggest source of electromagnetic interference is AC motor which was used to simulate engine speed in our experimental set-up. To overcome this difficulty, decoupling capacitors were used on frequency to voltage converter circuits to eliminate noise caused by AC motor. Also, the motor was put into metal cage which is called Faraday cage to block static or non-static electric fields. Another difficulty with which was faced was high voltage. To generate spark, the voltage is increased up to 20-30 kV; it is so high voltage because of this reason it can jump to anywhere by following the shortest way. The experimental set-up had been placed on a wooden table with metal chassis and all igniter circuits and control circuits were on the same table. The high voltage jumped to igniter circuits because the bottom surfaces of igniter circuits were not isolated and wooden was not a good isolating material. After that experience, all circuits were isolated with a good resistant material. The PIC microcontrollers which were used on the system have both digital and analog input pins. The analog pins are affected by electromagnetic field, so these pins should not be used as input pin. As it is stated above, the difficulties which were faced during the study may be stated as disadvantages of our system because the circuits which were used are not professionally soldered and isolated circuits. So, they are affected by electromagnetic field and high voltage easily. In modern automotive applications, ECU (Engine control unit) is used to control the processes during engine running to ensure the optimum running conditions. These units are microcontroller based circuits, too. However, they are designed to work in tough conditions, so they are not affected by electromagnetic field, vibration, temperature, etc. A commercial engine control unit might be modified to use in our application, but it would be very difficult to use because manufacturers make them too complicated to protect them against being copied. Advance angle map will be generated according to our special engine if we had used a commercial ECU, we would not have chance to change advance map of the ECU according to our special engine. To design and construct a PIC16F877A based circuit, and use it as control circuit is the easiest way because PIC16F877A is most popular microcontroller unit and you can find thousands of source codes on the internet. Also, PIC16F877A microcontroller is so cheap, easy to use and easily found in the market; these may be stated as advantage of our system.

As it is told in previous chapters, there are two PIC16F877A based circuits and they communicate via Master–Slave serial communication, this communication type is enough for this application, but if there were another circuit and if you needed to communicate with that circuits; traditional serial communication would not be enough. A modern car has around 70 control circuits, some of these circuits are independent systems, but most of them communicate with each others, so a special communication standard called as CAN is developed for automotive industry in 1980`s. This is a multi-master broadcast serial bus standard for connecting control circuits; and all circuits is able to send and receive messages. There are a few PIC microcontrollers which have CAN interface, but PIC16F877A does not have such an interface. This is another disadvantage of our system. The igniter circuits open and close primary voltage of induction coils with mosfets, IRF540N; these mosfets are driven by optocouplers, 4N35. The turn on and turn off times of 4N35 are around 10µs, actually turn off time is more important for us because ignition takes place by closing of mosfet. The turn off time of 4N35 may be accepted, but there are some optocouplers which have better closing times such as 6N139. Its turn off time is around 1µs. The optocouplers on the igniter circuits are used to drive mosfets, because IRF540N is not driven by logic signal, but there are some logic mosfets in the market such as IRL540 or IRLZ44, these mosfets can be driven by microcontrollers without a optocoupler. These options may be used in the future works of our ignition system

.

REFERENCES

[1] Microchip,(2003), PIC16F87XA Data Sheet, Microchip Technology Inc.

[2] Microchip, (2007), PIC16F627A/628A/648A Data Sheet, Microchip Technology Inc.

[3] Texas Instruments, (1998), 4N35, 4N36, 4N37 OPTOCOUPLERS, Texas Instruments Inc.

[4] International Rectifier, (2001), IRF540N HEXFET Power MOSFET, International Rectifier

[5] Vishay, (2011), IRLZ44, SiHLZ44 Power MOSFET, Vishay Siliconix

[6] Fairchild, (2005), Single-Channel: 6N138, 6N139 Dual-Channel: HCPL2730, HCPL2731
Low Input Current High Gain Split Darlington Optocouplers, FAIRCHILD SEMICONDUCTOR

[7] Webpage of Department of Physics and Astronomy, Georgia State Universty, " Faraday`s Law", Available at: http://hyperphysics.phy-astr.gsu.edu/hbase/electric/farlaw.html, (Accessed 17.04.2012)

[8] Webpage of RIBO, " Distributorless Ignition Systems ", Available at: http://www.riboparts.com/ada/ArticleEditor1/uploadfile/20110217212932897.jpg, (Accessed 10.04.2012)

[9] Patel, P., " Combustion Engines in Automobiles", Available at: http://www.unc.edu/~prinarp/ (Accessed 10.04.2012)

[10] Webpage of TESLA BLATNA, "Ignition Lead Sets", Available at: http://www.tesla-blatna.cz/en/products-ignition-lead-sets-parameters (Accessed 10.04.2012)

[11] Webpage of Motor Era, "Automobile History, Ignition System", Available at: http://www.motorera.com/history/hist05.htm (Accessed 10.04.2012)

[12] Webpage of CAN-KAR, " CAN-BUS", Available at: http://www.cankaroto.com/?gt=puf&pufid=214 (Accessed 10.04.2012)

[13] Webpage of MAKO, " Atesleme", Available at: http://www.mako.com.tr (Accessed 08.04.2012)

[14] Webpage of NGK, " Ignition Leads And Spark Plugs", Available at: http://www.ngk-elearning.de (Accessed 23.05.2012)

[15] US Patent 4265211, Michael R. Meloeny, Troy, Mich., "Distributorless Internal Combustion Engine Ignition System", issued 05.05.1981

[16] US Patent 4478201, Joseph R. Asik, Bloomfield Hills, Mich., "Enhanced Spark Energy Distributorless Ignition System", issued 10.23.1984

[17] US Patent 4690124, Kazuhiro Higashiyama, Ebina, Japan, "Spark Control System for an Engine" issued 08.01.1987

[18] US Patent 4742811, Yasushi Okada, Iwao Shimane, both of Wako, both of Japan, "Ignition Control System For Internal Combustion Engine" issued 05.10.1988

[19] US Patent 5042449, Alessandro Dassetto, Turin, Italy, "Method and Related System for Controlling the Ignition in Internal Combustion Engines, Particularly Direct-Ignition Engines with Individual Coils" issued 08.27.1991

[20] US Patent 5090394, Alfred Bruckelt, Steinheim; Günther Kaiser, Stuttgart; Immanuel Krauter, Erbstetten; Karl Ott, "Distributorless Ignition System" issued 02.25.1992

[21] Heywood, J., B., "Internal combustion Engine Fundamentals", McGraw-Hill, Inc., New York, USA (1988)

[22] Guleryuz, H., V., "Otomobil Elektroniği ve Devreleri", Birsen, Istanbul,Turkey (2003)

[23] Acar, C., Bulbul, S., Gumrah, F., Metin, C., Parlaktuna, M., "Petrol ve Doğal Gaz", Metu Press, Ankara, Turkey (2011)

[24] Tepper M., "Transistor Ignition Systems", John F. Rider Publisher, Inc., New York, USA (1965)

[25] Kaplan, C., Arslan, R., Surmen, A., "Otomotiv Elektriği", Alfa Aktüel, Bursa, Turkey (2009)

[26] Sahin, H., Dayanık, A., Altınbaşak, C., "Pic Programlama Teknikleri ve PIC16F877A" Altas, Istanbul, Turkey (2008)

[27] Erbil, B., "Design of A New and Original Axial-Cam Controlled Opposing-Piston Internal Combustion Engine, with Emphasis On the Efficiency", a master's Thesis for the degree of Master of Science in Mechanical Engineering, Middle East Technical University, Ankara (2004)

[28] Webpage of ASME, "Road and Off-Road Transportation", Available at: http://www.asme.org/about-asme/history/landmarks/topics-m-z/road-and-off-road-ransportation/-203-siegfried-marcus-car-(ca--1875) (Accessed 26.08.2012)

[29] Doric, J., Klinar, I., Doric, M., "Cosntant Volume Combustion Cycle For IC Engines", Serbia, (2011)

[30] National Semiconductor , (2008), LM2907/LM2917 Frequency To Voltage Converter, National Semiconductor Corporatio

APPENDIX A: SOURCE CODE OF THE MAIN CONTROL CIRCUIT

```
;*****************************************************************
;      Source Code of Main Control Circuit

;*******************************************************************
      list  p=16f877A
      #include <p16F877A.inc>
      __config H'3F31'


    delay_ms_data       equu 0x20          ;variable for delay
                                           ;subroutine
    sicaklikH           equ 0x22           ;higher value byte cooling
                                           ;water
                                           ;temperature
    tempH               equ 0x23           ;serial rpm data
    bolum               equ 0x24           ;5-bit form of
                                           ;SicaklikL+sicaklikH
    sayacH              equ 0x25           ;temporary variableto arange
                                           ;ignition mode
    kontrol_register    equ 0x26           ;variable to detect
                                           ;comunication error
    sicaklikL           equ 0x27           ;lower value byte of cooling
                                           ;water
                                           ;temperature
```

```
    avans               equ 0x28        ;advance angle value
    ADC_Oku_kanalno     equ 0x70        ;Analog channel number

    ADC_Oku_sonucbyte   equ 0x71        ;ADRESL-ADRESH selection
                                        ;variable

    mode_sayac          equ 0x72        ;variable to arrange
                                        ;ignition mode
    deneme              equ 0x73        ;temporary variable for port

                                        ;configuration
    I2CSend_Data        equ 0x74        ;Data sent with I2C
    I2C_Device          equ 0x75        ;hardware address of
                                        ;external  eeprom

    I2C_AdrH            equ 0x76        ;higher value byte of
                                        ;external
                                        ;eeprom address

    I2C_AdrL            equ 0x77        ;lower value byte of
                                        ;external
                                        ;eeprom address

    I2C_Data            equ 0x78        ;advance angle value read
                                        ;from the eeprom



        ORG     0x000
        clrf    PCLATH
        goto    main
        ORG 4

; interrupt subroutine is fired when the
; Timer0 is up

interrupt
        btfss   INTCON, 5               ;1 checks whether the Timer0

                                        ;  interrupt
                                        ;  is activated or not?

        goto    int_j1                  ;2 if not? goto int_j1
        btfss   INTCON, 2               ;3 checks whether the Timer0

                                        ;  interrupt is fired or not
        goto    int_j1                  ;4 bit 2 of INTCON register
                                        ;  is set when
                                        ;  the timer fires if not?
                                        ;  go to int_j1
        movlw   D'6'                    ;5 initial value of Timer0
                                        ;  for 2 ms timer period
        movwf   TMR0                    ;6
        bcf     INTCON, 2               ;7 clear the flag of Timer0
        bsf     kontrol_register,1      ;8 kontrol_register is
                                        ;  defined to check
                                        ;  whether 2ms period was
                                        ;  exceeded or not
                                        ;  this register may be used

                                        ;  durig the
                                        ;  serial communication
                                        ;  between two
                                        ;  control circuits.

int_j1
        retfie                          ;9 exit from the subroutine
```

```
main
        call    initialize              ;10 calls the subroutine
                                        ;   "initialize"
        call    ilk_islemler            ;11 calls the subroutine
                                        ;   "ilk_islemler"


loop
        bsf PORTD,1                     ;12 makes the 1st pin of
                                        ;   PORTD high, this is
                                        ;   ready signal sent to
                                        ;   the secondary circuit
        ;bsf    INTCON, D'5'            ;13 activates the Timer0
                                        ;   overflow interrup
        ;bsf    INTCON, D'7'            ;14 activates all interrupts

        nop                             ;15 no operation
        nop                             ;16 no operation
        call    snkSlaveRead            ;17 calls the subroutine
                                        ;   "snkSlaveRead",
                                        ;   this subroutine reads
                                        ;   synchronous
                                        ;   serial data from the
                                        ;   secondary circuit
                                        ;   and loads it to "W"
        movwf   tempH                   ;18 loads the serial data
                                        ;   read by
                                        ;   "snkSlaveRead" to the
                                        ;   variable "tempH"
        nop                             ;19 no operation
        nop                             ;20 no operation

        movlw   0x00                    ;21 analog channel 0 is
                                        ;   selected
        movwf   ADC_Oku_kanalno         ;22

        movlw   0x00                    ;23 the value 0x00 is loaded
                                        ;   to
                                        ;   "ADC_Oku_kanalno"
        movwf   ADC_Oku_sonucbyte       ;24 read the low byte
                                        ;   (ADRESL) of
                                        ;   analog digital
                                        ;   conversion
                                        ;   PIC16F877A has 10-bit
                                        ;   ADC module
                                        ;   so the result of ADC
                                        ;   is 2 bytes (they are
                                        ;   called high
                                        ;   byte and low byte)
                                        ;   PIC16F877A is a 8-bit
                                        ;   microcontroller
                                        ;   and has 8-bit registers
                                        ;   so we should
                                        ;   call "ADC_Oku" twice to
                                        ;   read 10-bit data

        call    ADC_Oku                 ;25 calls the subroutine
                                        ;   "ADC_Oku",
                                        ;   this subroutine reads
                                        ;   the analog value
                                        ;   and converts it into
                                        ;   digital

        Banksel PORTB                   ;26 go to bank0
;       movwf   PORTB                   ;27 may be used to see the
                                        ;   result
                                        ;   of ADC with the leds
                                        ;   of PORTB
```

```
        movwf   sicaklikL                ;28 loads the value read by
                                         ;   "ADC_Oku"
                                         ;    to the "sicaklikL"

        nop                              ;29 no operation
        nop                              ;30 no operation
        nop                              ;31 no operation
        nop                              ;32 no operation

        movlw  0x00                      ;33
        movwf  ADC_Oku_kanalno           ;34 analog channel 0 is
                                         ;   selected

        movlw  0x01                      ;35
        movwf  ADC_Oku_sonucbyte         ;36 value 0x01 is loaded to
                                         ;   "ADC_Oku_sonucbyte"
                                         ;   it means "read the high
                                         ;   byte of ADC

        call   ADC_Oku                   ;37 calls the subroutine
                                         ;   "ADC_Oku"

        Banksel PORTB                    ;38 go to bank0
;       movwf  PORTB                     ;39 may be used to see the
                                         ;   result
                                         ;   of ADC with the leds
                                         ;   of PORTB
        movwf  sicaklikH                 ;40 loads the value read
                                         ;   by "ADC_Oku"
                                         ;   to the "sicaklikH"

        movlw  d'0'                      ;41
        movwf  bolum                     ;42 initial value of
                                         ;   "bolum" is zero


; this subroutine is used to scale the 10-bit digital
; value into 5-bit. This is 16-bit division operation
; (10-bit ADC result)/33

dongu2

        movlw  d'33'                     ;43
        subwf  sicaklikL,1               ;44 sicaklikL=sicaklikL-33
        btfss  STATUS,C                  ;45 if the new value of
                                         ;   sicaklik is negative
                                         ;   (checks the overflow
                                         ;   of 7th bit)
                                         ;   "C" bit of STATUS is
                                         ;   set to zero when
                                         ;   the result of
                                         ;   mathematical operation
        goto   $+3                       ;46 go to line 49
        incf   bolum,1                   ;47 bolum=bolum+1
        goto   dongu2                    ;48 go to line 43
        incf   bolum,1                   ;49 bolum=bolum+1
        bsf    STATUS,0                  ;50 set "C" bit of STATUS
                                         ;   to 1
                                         ;   for the next operation

        movlw  d'1'                      ;51
        subwf  sicaklikH,1               ;52 sicaklikH=sicaklikH-1

        btfss  STATUS,C                  ;53 if there is an overflow
                                         ;   go to line 56
        goto   $+2                       ;54 go to line 56
        goto   $+3                       ;55 go to line 58
        decf   bolum,1                   ;56 bolum=bolum-1
        goto   $+2                       ;57 go to line 59
```

```
        goto    dongu2                      ;58 go to the starting point
                                            ;   of the "dongu2"


        movf    tempH,0                     ;59 W=tempH, this line loads
                                            ;   the value of tempH to
        movwf   sayacH                      ;60 sayacH=W it means
                                            ;   sayacH=tempH

        clrf    I2C_Device                  ;61 I2C_Device=0
        clrf    I2C_AdrH                    ;62 I2C_AdrH=0 because we
                                            ;   did not use the cooling
                                            ;   water temperature for
                                            ;   this study
                                            ;   but it may be used in
                                            ;   the future (it may be
                                            ;   the output of any sensor
                                            ;   with analog output)

        movf    sayacH,0                    ;63 W=sayacH
        movwf   I2C_AdrL                    ;64 I2C_AdrL=sayacH

        call    I2C_ReadEE                  ;65 calls the subroutine
                                            ;   "I2C_ReadEE" which
                                            ;   reads 8-bit data from
                                            ;   the external eeprom

        bcf     PORTD,1                     ;66 makes the 1st bit of
                                            ;   PORTD logic low
                                            ;   elapsed time between
                                            ;   line 12 and line 66
                                            ;   gives the required time
                                            ;   to read serial rpm
                                            ;   data, read analog value
                                            ;   and convert it into
                                            ;   digital, scale 10-bit
                                            ;   ADC result into 5-bit
                                            ;   and read the advance
                                            ;   value
                                            ;   from the external eeprom

        movwf   avans                       ;67 loads the value which
                                            ;   is read by
                                            ;   subroutine "I2C_ReadEE"
                                            ;   into "avans"
        clrf    mode_sayac                  ;68 initial value of
                                            ;   mode_Sayac is zero
        movf    sayacH,0                    ;69 W=sayacH
        movwf   mode_sayac                  ;70 mode_Sayac=sayacH

        nop                                 ;71 no operation
        nop                                 ;72 no operation

; this block checks mode_Sayac is greater than
; 175 or not.This means whether the engine speed
; is between 2100 and 3000 rpm or not
; if the result of (mode_Sayac-175)
; is negative STATUS,C will be 0


        bcf     STATUS,C                    ;73 makes STATUS,C zero
                                            ;   to guarantee
                                            ;   it is not "1"
                                            ;   because we are checking
                                            ;   it is
                                            ;   1 or not with line 76
```

```
        movlw   d'175'                    ;74 W=175
        subwf   mode_sayac,W              ;75 mode_Sayac=
                                          ;   mode_Sayac-175

        btfss   STATUS,C                  ;76 whether the result
                                          ;   of line
                                          ;   75 is negative or not
        goto    loop2                     ;77 if it is negative go
                                          ;   to "loop2"
        call    mode_3                    ;78 if it is not negative,
                                          ;   calls the
                                          ;   ignition mode "mode_3"


        goto    loop                      ;79 when the ignition
                                          ;   sequence is complete,
                                          ;   go to the starting of
                                          ;   the "loop"


; "loop2" checks mode_Sayac is greater than
; 170 or not. This means whether the engine speed
; is between 2050 and 2100 rpm or not
; if the result of (mode_Sayac-170)
; is negative STATUS,C will be 0

loop2
        movlw   d'170'                    ;80 W=170
        subwf   mode_sayac,W              ;81 mode_sayac=
                                          ;   mode_sayac-170

        btfss   STATUS,C                  ;82 whether the result
                                          ;   of line 81
                                          ;   is negative or not

        goto    loop3                     ;83 if it is negative go to
                                          ;  "loop3"
        call    premode_3                 ;84 if it is not negative,
                                          ;   calls the
                                          ;   ignition mode
                                          ;   "premode_3"
        goto    loop                      ;85 when the ignition
                                          ;   sequence
                                          ;   is complete,
                                          ;   go to the starting of
                                          ;   "loop"


; "loop3" checks mode_Sayac is greater than
; 117 or not. This means whether the engine speed
; is between 1400 and 2050 rpm or not
; if the result of (mode_Sayac-117)
; is negative STATUS,C will be 0

loop3

        movlw   d'117'                    ;86 W=117
        subwf   mode_sayac,W              ;87 mode_sayac=
                                          ;   mode_sayac-117

        btfss   STATUS,C                  ;88 whether the result of
                                          ;   line 87
                                          ;   is negative or not

        goto    loop4                     ;89 if it is negative go
                                          ;   to "loop4"
        call    mode_2                    ;90 if it is not negative,
                                          ;   calls the
                                          ;   ignition mode "mode_2"
```

```
        goto    loop                        ;91 when the ignition
                                            ;   sequence
                                            ;   is complete,
                                            ;   go to the starting of
                                            ;   the "loop"


; "loop4" checks mode_Sayac is greater than
; 113 or not. This means whether the engine speed
; is between 1350 and 1400 rpm or not
; if the result of (mode_Sayac-113)
; is negative STATUS,C will be 0

loop4

        movlw   d'113'                      ;92 W=113
        subwf   mode_sayac,W                ;93 mode_sayac=
                                            ;   mode_sayac-113

        btfss   STATUS,C                    ;94 whether the result of
                                            ;   line 93
                                            ;   is negative or not

        goto    loop5                       ;95 if it is negative go
                                            ;   to "loop5"
        call    premode_2                   ;96 if it is not negative,
                                            ;   calls the
                                            ;   ignition mode
                                            ;   "premode_2"
        goto    loop                        ;97 when the ignition
                                            ;   sequence is complete,
                                            ;   go to the starting of
                                            ;   the "loop"

; "loop5" checks mode_Sayac is greater than
; 58 or not. This means whether the engine speed is
; between 700 and 1350 rpm or not
; if the result of (mode_Sayac-58)
; is negative STATUS,C will be 0

loop5

        movlw   d'58'                       ;98 W=58
        subwf   mode_sayac,W                ;99 mode_sayac=
                                            ;   mode_sayac-58

        btfss   STATUS,C                    ;100 whether the result
                                            ;    of line 99
                                            ;    is negative or not

        goto    loop6                       ;101 if it is negative go
                                            ;    to "loop6"
        call    mode_1                      ;102 if it is not negative,
                                            ;    calls
                                            ;    the ignition mode
                                            ;   "mode_1"
        goto    loop                        ;103 when the ignition
                                            ;    sequence is complete,
                                            ;    go to the starting
                                            ;    of the "loop"

; "loop6" checks mode_Sayac is greater than
; 54 or not. This means whether the engine speed
; is between 650 and 700 rpm or not
; if the result of (mode_Sayac-54)
; is negative STATUS,C will be 0

loop6
```

```
        movlw   d'54'                       ;104 W=54
        subwf   mode_sayac,W                ;105 mode_sayac=
                                            ;    mode_sayac-54

        btfss   STATUS,C                    ;106 whether the result of
                                            ;    line 105
                                            ;    is negative or not

        goto    loop7                       ;107 if it is negative go
                                            ;    to "loop7"
        call    premode_1                   ;108 if it is not negative,
                                            ;    calls
                                            ;    the ignition mode
                                            ;    "premode_1"
        goto    loop                        ;109 when the ignition
                                            ;    sequence is complete,
                                            ;    go to the starting
                                            ;    of the "loop"


; "loop7" checks mode_Sayac is greater than
; 1 or not. This means whether the engine speed
; is between 0 and 650 or not
; if the result of (mode_Sayac-1)
; is negative STATUS,C will be 0


loop7

        movlw   d'1'                        ;110 W=1
        subwf   mode_sayac,W                ;111 mode_sayac=mode_sayac-1

        btfss   STATUS,C                    ;112 whether the result of
                                            ;    line 111 is
                                            ;    negative or not

        goto    loop                        ;113 if it is negative go to

                                            ;    starting of the "loop"
        call    mode_0                      ;114 if it is not negative,
                                            ;    calls the ignition
                                            ;    mode "mode_0"

        goto    loop                        ;115 when the ignition
                                            ;    sequence is
                                            ;    complete,
                                            ;    go to the starting
                                            ;    of the "loop"



;ignition mode "mode_0 is the ignition mode for the
;lowest engine speed
;engine speed low enough to saturate the ignition
;coil after cylinder position signal comes
;cylinder position signal does not give the actual position
;of the cylinder, it gives the 22.5 degree before the cylinder
;it is the middle of two cylinders

mode_0

        btfss   PORTD,0                     ;116 did the secondary
                                            ;    circuit
                                            ;    send the 1st
                                            ;    cylinder position?
                                            ;    if yeS
                                            ;    go to the
                                            ;     line 118
```

```
goto   $-1                        ;117 if not go to line 116
                                  ;    and wait
                                  ;    for the signal
btfsc  PORTD,0                    ;118 ignition process will
                                  ;    starting
                                  ;    with the falling
                                  ;    edge of the cylinder
                                  ;    position signal
                                  ;    so wait for the
                                  ;    falling edge.
                                  ;    if PORTD,0 is low,
                                  ;    go to line 120,
goto   $-1                        ;119 if not wait for the
                                  ;    falling
                                  ;    edge go to line 118

movf   avans,0                    ;120 W=avans
banksel PORTB                     ;121 go to bank0
bsf    PORTB,7                    ;122 makes the 7th bit of
                                  ;    PORTB
                                  ;    high, this is
                                  ;    ignition signal and 1st
                                  ;    igniter circuit
                                  ;    lets the current flow
                                  ;    through
                                  ;    the primary
                                  ;    winding of the 1st
                                  ;    ignition coil

movwf  delay_ms_data              ;123 delay_ms_data=
                                  ;    avans,this
                                  ;    is the duration
                                  ;    which PORTB,7 stays at
                                  ;    logic high state
call   delay_ms                   ;124 calls "delay_ms"
                                  ;    subroutine,
bcf    PORTB,7                    ;125 makes PORTB,7
                                  ;    logic low, this
                                  ;    is the end of ignition
                                  ;    signal
                                  ;    igniter circuit breaks
                                  ;    the current
                                  ;    which is flowing
                                  ;    through
                                  ;    the primary coil of
                                  ;    the first
                                  ;    ignition coil and
                                  ;    spark occurs


btfss  PORTD,0                    ;126 did the secondary
                                  ;    circuit
                                  ;    send the 2nd cylinder
                                  ;    position? if yes, go
                                  ;    to the line 128
goto   $-1                        ;127 if not go to line 126
                                  ;    and
                                  ;    wait for the signal
btfsc  PORTD,0                    ;128 ignition process will
                                  ;    starting
                                  ;    with the falling
                                  ;    edge of the cylinder
                                  ;    position signal
                                  ;    so wait for the
                                  ;    falling edge.
                                  ;    if PORTD,0 is low,
                                  ;    go to line 130,
goto   $-1                        ;129 if not wait for the
                                  ;    falling edge
```

```
                                        ;     go to line 128
movf    avans,0                         ;130 W=avans
banksel PORTB                           ;131 go to bank0
bsf     PORTB,6                         ;132 makes the 6th bit
                                        ;     of PORTB high,
                                        ;      this is
                                        ;     ignition signal
                                        ;     and 2nd
                                        ;     igniter circuit
                                        ;     lets the current
                                        ;     flow
                                        ;     through the primary
                                        ;     winding of the 2nd
                                        ;     ignition coil

movwf   delay_ms_data                   ;133 delay_ms_data=avans,
                                        ;     this is the duration
                                        ;     which PORTB,6 stays at
                                        ;     logic high state
call    delay_ms                        ;134 calls the subroutine
                                        ;     "delay_ms"
bcf     PORTB,6                         ;135 makes PORTB,6
                                        ;    logic low,
                                        ;    this is the end of
                                        ;    ignition signal
                                        ;    igniter circuit
                                        ;    breaks the
                                        ;    current which is
                                        ;    flowing through
                                        ;    the primary coil
                                        ;    of the 2nd
                                        ;    ignition coil and
                                        ;    spark occurs


btfss   PORTD,0                         ;136 did the secondary
                                        ;     circuit send the 3rd
                                        ;     cylinder position?
                                        ;     if yes,
                                        ;     go to the line 138
goto    $-1                             ;137 if not go to line 136
                                        ;     and
                                        ;     wait for the signal
btfsc   PORTD,0                         ;138 ignition process will
                                        ;     starting with the
                                        ;     falling edge of the
                                        ;     cylinder position
                                        ;     signal
                                        ;     so wait for the
                                        ;     falling edge.
                                        ;     if PORTD,0 is low,
                                        ;     go to line 140,
                                        ;
goto    $-1                             ;139 if not wait for
                                        ;     the falling
                                        ;     edge go to line 138
movf    avans,0                         ;140 W=avans
banksel PORTB                           ;141 go to bank0
bsf     PORTB,5                         ;142 makes the 5th bit
                                        ;     of PORTB
                                        ;     high, this is
                                        ;     ignition signal
                                        ;     and 3rd
                                        ;     igniter circuit
                                        ;     lets the current
                                        ;     flow through the
                                        ;     primary winding
                                        ;     of the 3rd
                                        ;     ignition coil
```

```
movwf  delay_ms_data           ;143 delay_ms_data=avans
call   delay_ms                ;144 calls the subroutine
                               ;   "delay_ms"
bcf    PORTB,5                 ;145 makes PORTB,5 logic
                               ;    low, this is
                               ;    the end of ignition
                               ;    signal
                               ;    igniter circuit
                               ;    breaks the current
                               ;    which is flowing
                               ;    through
                               ;    the primary coil
                               ;    of the 3rd
                               ;    ignition coil and
                               ;    spark occurs


btfss  PORTD,0                 ;146 did the secondary
                               ;    circuit send the 4th
                               ;    cylinder position?
                               ;    if yes,
                               ;    go to the line 148
goto   $-1                     ;147 if not go to line
                               ;    146 and wait
                               ;    for the signal
btfsc  PORTD,0                 ;148 ignition process will
                               ;    starting with the
                               ;    falling
                               ;    edge of the cylinder
                               ;    position signal
                               ;    so wait for the
                               ;    falling edge. if
                               ;    PORTD,0 is low, go
                               ;    to line 150,
goto   $-1                     ;149 if not wait for
                               ;    the falling
                               ;    edge go to line 148
movf   avans,0                 ;150 W=avans
banksel PORTB                  ;151 go to bank0
bsf    PORTB,4                 ;152 makes the 4th bit
                               ;    of PORTB high,
                               ;    this is
                               ;    ignition signal and 4th
                               ;    igniter circuit
                               ;    lets the current flow
                               ;    through
                               ;    the primary
                               ;    winding of the 4th
                               ;    ignition coil
movwf  delay_ms_data           ;153 delay_ms_data=avans
call   delay_ms                ;154 calls the subroutine
                               ;    "delay_ms"
bcf    PORTB,4                 ;155 makes PORTB,4 logic low
                               ;    this is
                               ;    the end of ignition
                               ;    signal
                               ;    igniter circuit breaks
                               ;    the current which
                               ;    is flowing through
                               ;    the primary coil of
                               ;    the 4th
                               ;    ignition coil and
                               ;    spark occurs


btfss  PORTD,0                 ;156 did the secondary
                               ;    circuit
                               ;    send the 5th
                               ;    cylinder position?
```

```
                                        ;    if yes,
                                        ;    go to the line 158
goto   $-1                              ;157 if not go to line 156
                                        ;    and wait for the signal
btfsc  PORTD,0                          ;158 ignition process will
                                        ;    starting with the
                                        ;    falling
                                        ;    edge of the cylinder
                                        ;    position signal
                                        ;    so wait for the falling
                                        ;    edge.
                                        ;    if PORTD,0 is low,
                                        ;    go to line 160,
goto   $-1                              ;159 if not wait for the
                                        ;    falling
                                        ;    edge go to line 158
movf   avans,0                          ;160 W=avans
banksel PORTB                           ;161 go to bank0
bsf PORTB,3                             ;162 makes the 3rd bit of
                                        ;    PORTB high, this is
                                        ;    ignition signal and
                                        ;    5th igniter circuit
                                        ;    lets the current flow
                                        ;    through the primary
                                        ;    winding of the 5th
                                        ;    ignition coil
movwf  delay_ms_data                    ;163 delay_ms_data=avans
call   delay_ms                         ;164 calls the subroutine
                                        ;    "delay_ms"
bcf    PORTB,3                          ;165 makes PORTB,3
                                        ;    logic low,
                                        ;    this is the end of
                                        ;    ignition signal
                                        ;    igniter circuit breaks
                                        ;    the current which is
                                        ;    flowing through
                                        ;    the primary coil
                                        ;    of the 5th
                                        ;    ignition coil and
                                        ;    spark occurs

btfss  PORTD,0                          ;166 did the secondary
                                        ;    circuit
                                        ;    send the 6th
                                        ;    cylinder position? if
                                        ;    yes, go to the line 168
goto   $-1                              ;167 if not go to line
                                        ;    166 and
                                        ;    wait for the signal
btfsc  PORTD,0                          ;168 ignition process will
                                        ;    starting with the
                                        ;    falling edge of the
                                        ;    cylinder position
                                        ;    signal
                                        ;    so wait for the
                                        ;    falling edge.
                                        ; if PORTD,0 is low,
                                        ;    go to line 170,
goto   $-1                              ;169 if not wait for
                                        ;    the falling
                                        ;    edge go to line 168
movf   avans,0                          ;170 W=avans
banksel PORTB                           ;171 go to bank0
bsf PORTB,2                             ;172 makes the 2nd bit of
                                        ;    PORTB high, this is
                                        ;    ignition signal and 6th
                                        ;    igniter circuit
                                        ;    lets the current flow
                                        ;    through the primary
```

```
                                        ;    winding of the
                                        ;    6th ignition coil
movwf   delay_ms_data                   ;173 delay_ms_data=avans
call    delay_ms                        ;174 calls the subroutine
                                        ;    "delay_ms"
bcf     PORTB,2                         ;175 makes PORTB,2
                                        ;    logic low, this
                                        ;    is the end of
                                        ;    ignition signal
                                        ;    igniter circuit
                                        ;    breaks the
                                        ;    current which is
                                        ;    flowing through
                                        ;    the primary coil
                                        ;    of the 6th
                                        ;    ignition coil and
                                        ;    spark occurs


btfss   PORTD,0                         ;176 did the secondary
                                        ;    circuit
                                        ;    send the 7th
                                        ;    cylinder position?
                                        ;    if yes,
                                        ;    go to the line 178
goto    $-1                             ;177 if not go to line 176
                                        ;    and wait for the signal
btfsc   PORTD,0                         ;178 ignition process will
                                        ;    starting with
                                        ;    the falling
                                        ;    edge of the cylinder
                                        ;    position signal
                                        ;    so wait for the
                                        ;    falling edge.
                                        ;    if PORTD,0 is low,
                                        ;    go to line 180,
goto    $-1                             ;179 if not wait for
                                        ;    the falling
                                        ;    edge go to line 178
movf    avans,0                         ;180 W=avans
banksel PORTB                           ;181 go to bank0
bsf     PORTB,1                         ;182 makes the 1st bit of
                                        ;    PORTB high, this is
                                        ;    ignition signal and
                                        ;    7th igniter circuit
                                        ;    lets the current flow
                                        ;    through the primary
                                        ;    winding of the 7th
                                        ;    ignition coil
movwf   delay_ms_data                   ;183 delay_ms_data=avans

call    delay_ms                        ;184 calls the subroutine
                                        ;    "delay_ms"
bcf     PORTB,1                         ;185 makes PORTB,1
                                        ;    logic low, this
                                        ;    is the end of
                                        ;    ignition signal
                                        ;    igniter circuit
                                        ;    breaks the
                                        ;    current which is
                                        ;    flowing through
                                        ;    the primary coil
                                        ;    of the 7th
                                        ;    ignition coil and
                                        ;    spark occurs

btfss   PORTD,0                         ;186 did the secondary
                                        ;    circuit
                                        ;    send the 8th cylinder
```

```
                                 ;    position? if yes, go to

                                 ;    the line 188
        goto   $-1               ;187 if not go to line 186
                                 ;    and wait for the signal
        btfsc  PORTD,0           ;188 ignition process will
                                 ;    starting with the
                                 ;    falling
                                 ;    edge of the cylinder
                                 ;    position signal
                                 ;    so wait for the
                                 ;    falling edge.
                                 ;    if PORTD,0 is low,
                                 ;    go to line 190,
        goto   $-1               ;189 if not wait for
                                 ;    the falling
                                 ;    edge go to line 188
        movf   avans,0           ;190 W=avans
        banksel PORTB            ;191 go to bank0
        bsf    PORTB,0           ;192 makes the 0th bit of
                                 ;    PORTB high, this is
                                 ;    ignition signal and 8th
                                 ;    igniter circuit
                                 ;    lets the current flow
                                 ;    through the primary
                                 ;    winding of the 8th
                                 ;    ignition coil
        movwf  delay_ms_data     ;193 delay_ms_data=avans
        call   delay_ms          ;194 calls the subroutine
                                 ;    "delay_ms"
        bcf    PORTB,0           ;195 makes PORTB,0
                                 ;    logic low,
                                 ;    this is the end of
                                 ;    ignition signal
                                 ;    igniter circuit breaks

                                 ;    the current which is
                                 ;    flowing through
                                 ;    the primary coil of
                                 ;    the 8th
                                 ;    ignition coil and
                                 ;    spark occurs
        return                   ;196 quit from the loop,


;premode_1 ignition mode is a transient mode between
;mode_0 and mode_1. The aim of this mode is
;preparation for the mode_1
;for engine speeds between 650 and 700 rpm
;there is only one difference between mode_0
;and premode_1 that is line 277

premode_1

        btfss  PORTD,0           ;197 did the secondary
                                 ;    circuit send the 1st
                                 ;    cylinder position? if
                                 ;    yes, go to the line 199
        goto   $-1               ;198 if not go to line 197
                                 ;    and wait for the signal

        btfsc  PORTD,0           ;199 ignition process will
                                 ;    starting with
                                 ;    the falling
                                 ;    edge of the cylinder
                                 ;    position signal
                                 ;    so wait for the
                                 ;    falling edge.
```

```
                                        ;    if PORTD,0 is low,
                                        ;    go to line 201,
goto   $-1                              ;200 if not wait for
                                        ;    the falling
                                        ;    edge go to line 199
movf   avans,0                          ;201 W=avans
banksel PORTB                           ;202 go to bank0
bsf    PORTB,7                          ;203 makes the 7th bit of
                                        ;    PORTB high, this is
                                        ;    ignition signal and 1st
                                        ;    igniter circuit
                                        ;    makes the 7th bit of
                                        ;    PORTB high, this is
                                        ;    ignition signal and
                                        ;    1st igniter circuit
movwf  delay_ms_data                    ;204 delay_ms_data=avans
call   delay_ms                         ;205 calls the subroutine
                                        ;    "delay_ms"
bcf    PORTB,7                          ;206 makes PORTB,7 logic
                                        ;    low, this
                                        ;    is the end of
                                        ;    ignition signal
                                        ;    igniter circuit
                                        ;    breaks the
                                        ;    current which is
                                        ;    flowing through
                                        ;    the primary coil
                                        ;    of the 1st
                                        ;    ignition coil and
                                        ;    spark occurs


btfss  PORTD,0                          ;207 The lines between
                                        ;    207 and 216
goto   $-1                              ;208 are the same operations

                                        ;    for 2nd ignition coil
btfsc  PORTD,0                          ;209
goto   $-1                              ;210
movf   avans,0                          ;211
banksel PORTB                           ;212
bsf PORTB,6                             ;213
movwf  delay_ms_data                    ;214
call   delay_ms                         ;215
bcf    PORTB,6                          ;216


btfss  PORTD,0                          ;217 The lines between
                                        ;    217 and 226
goto   $-1                              ;218 are the same operations

                                        ;    for 3rd ignition coil
btfsc  PORTD,0                          ;219
goto   $-1                              ;220
movf   avans,0                          ;221
banksel PORTB                           ;222
bsf PORTB,5                             ;223
movwf  delay_ms_data                    ;224
call   delay_ms                         ;225
bcf    PORTB,5                          ;226


btfss  PORTD,0                          ;227 The lines between
                                        ;    227 and 236
goto   $-1                              ;228 are the same operations
                                        ;    for 4th ignition coil
btfsc  PORTD,0                          ;229
goto   $-1                              ;230
movf   avans,0                          ;231
```

```
        banksel PORTB                   ;232
        bsf     PORTB,4                 ;233
        movwf   delay_ms_data           ;234
        call    delay_ms                ;235
        bcf     PORTB,4                 ;236

        btfss   PORTD,0                 ;237 The lines between
                                        ;    237 and 246
        goto    $-1                     ;238 are the same operations
                                        ;    for 5th ignition coil
        btfsc   PORTD,0                 ;239
        goto    $-1                     ;240
        movf    avans,0                 ;241
        banksel PORTB                   ;242
        bsf     PORTB,3                 ;243
        movwf   delay_ms_data           ;244
        call    delay_ms                ;245
        bcf     PORTB,3                 ;246


        btfss   PORTD,0                 ;247 The lines between
                                        ;    247 and 256
        goto    $-1                     ;248 are the same operations

                                        ;    for 6th ignition coil
        btfsc   PORTD,0                 ;249
        goto    $-1                     ;250
        movf    avans,0                 ;251
        banksel PORTB                   ;252
        bsf     PORTB,2                 ;253
        movwf   delay_ms_data           ;254
        call    delay_ms                ;255
        bcf     PORTB,2                 ;256


        btfss   PORTD,0                 ;257 The lines between
                                        ;    257 and 256
        goto    $-1                     ;258 are the same operations
                                        ;    for 7th ignition coil
        btfsc   PORTD,0                 ;259
        goto    $-1                     ;260
        movf    avans,0                 ;261
        banksel PORTB                   ;262
        bsf     PORTB,1                 ;263
        movwf   delay_ms_data           ;264
        call    delay_ms                ;265
        bcf     PORTB,1                 ;266



        btfss   PORTD,0                 ;267 The lines between
                                        ;    267 and 278
        goto    $-1                     ;268 are the same operations
                                        ;    for 8th ignition coil
        btfsc   PORTD,0                 ;269
        goto    $-1                     ;270
        movf    avans,0                 ;271
        banksel PORTB                   ;272
        bsf     PORTB,0                 ;273
        movwf   delay_ms_data           ;274
        call    delay_ms                ;275
        bcf     PORTB,0                 ;276
        bsf     PORTB,7                 ;277 the 1st igition
                                        ;    coils is
                                        ;    started to be
                                        ;    saturated at this
                                        ;    point for the the
mode_1
        return                          ;278
```

```
;this mode is for higher speeds than mode_0
;this is the ignition mode for engine speeds
;between 700 and 1350 rpm. For these engine speeds
;there is not enough time to saturate the ignition coils
;between two cylinder position signals. So the ignition coils
;should be started to be satureted before the cylinder position
;signal
;

mode_1

        btfss  PORTD,0                  ;279 did the secondary
                                        ;    circuit
                                        ;    send the 1st
                                        ;    cylinder position?
                                        ;    if yes,
                                        ;    go to the line 281
        goto   $-1                      ;280 if not go to line
                                        ;    279 and
                                        ;    wait for the signal
        btfsc  PORTD,0                  ;281 ignition process will
                                        ;    starting with the
                                        ;    falling
                                        ;    edge of the cylinder
                                        ;    position signal
                                        ;    so wait for the
                                        ;    falling edge.
                                        ;    if PORTD,0 is low,
                                        ;    go to line 283,
        goto   $-1                      ;282 if not wait for
                                        ;    the falling
                                        ;    edge go to line 281
        movf   avans,0                  ;283 W=avans
        banksel PORTB                   ;284 go to bank0
        bsf    PORTB,7                  ;285 makes the 7th bit
                                        ;    of PORTB high,
                                        ;    to guarantee
                                        ;    the start of
                                        ;    saturation of 1st
                                        ;    igniter circuit
        movwf  delay_ms_data            ;286 delay_ms_data=avans
        call   delay_ms                 ;287 calls the subroutine
                                        ;    "delay_ms"
        bcf    PORTB,7                  ;288 makes PORTB,7 logic
                                        ;    low, this
                                        ;    is the end of
                                        ;    ignition signal
                                        ;    igniter circuit
                                        ;    breaks the
                                        ;    current which is
                                        ;    flowing through
                                        ;    the primary coil of
                                        ;    the 1st
                                        ;    ignition coil and
                                        ;    spark occurs
        bsf    PORTB,6                  ;289 makes PORTB,6
                                        ;    logic high,this
                                        ;    is the starting
                                        ;    point of ignition
                                        ;    signal
                                        ;    for 2nd ignition coil


        btfss  PORTD,0                  ;290 The lines between
                                        ;    290 and 300
        goto   $-1                      ;291 are the same operations
```

```
                                       ;     for 2nd and 3rd
btfsc  PORTD,0                         ;292 ignition coils
goto   $-1                             ;293
movf   avans,0                         ;294
banksel PORTB                          ;295
bsf    PORTB,6                         ;296
movwf  delay_ms_data                   ;297
call   delay_ms                        ;298
bcf    PORTB,6                         ;299
bsf    PORTB,5                         ;300


btfss  PORTD,0                         ;301 The lines between
                                       ;     301 and 312
goto   $-1                             ;302 are the same operations
                                       ;     for 3rd and 4th
btfsc  PORTD,0                         ;303 ignition coils
goto   $-1                             ;304
movf   avans,0                         ;305
banksel PORTB                          ;306
bsf    PORTB,5                         ;307
movwf  delay_ms_data                   ;308
call   delay_ms                        ;309
bcf    PORTB,5                         ;310
bsf    PORTB,4                         ;312


btfss  PORTD,0                         ;313 The lines between
                                       ;     313 and 323
goto   $-1                             ;314 are the same operations

                                       ;     for 4th and 5th
btfsc  PORTD,0                         ;315 ignition coils
goto   $-1                             ;316
movf   avans,0                         ;317
banksel PORTB                          ;318
bsf PORTB,4                            ;319
movwf  delay_ms_data                   ;320
call   delay_ms                        ;321
bcf    PORTB,4                         ;322
bsf    PORTB,3                         ;323


btfss  PORTD,0                         ;324 The lines between
                                       ;     324 and 334
goto   $-1                             ;325 are the same operations

                                       ;     for 5th and 6th
btfsc  PORTD,0                         ;326 ignition coils
goto   $-1                             ;327
movf   avans,0                         ;328
banksel PORTB                          ;329
bsf    PORTB,3                         ;330
movwf  delay_ms_data                   ;331
call   delay_ms                        ;332
bcf    PORTB,3                         ;333
bsf    PORTB,2                         ;334


btfss  PORTD,0                         ;335 The lines between
                                       ;     335 and 345
goto   $-1                             ;336 are the same operations
                                       ;     for 6th and 7th
btfsc  PORTD,0                         ;337 ignition coils
goto   $-1                             ;338
movf   avans,0                         ;339
banksel PORTB                          ;340
bsf    PORTB,2                         ;341
movwf  delay_ms_data                   ;342
```

```
        call   delay_ms                 ;343
        bcf    PORTB,2                  ;344
        bsf    PORTB,1                  ;345


        btfss  PORTD,0                  ;346 The lines between
                                        ;    346 and 356
        goto   $-1                      ;347 are the same operations
                                        ;    for 7th and 8th
        btfsc  PORTD,0                  ;348 ignition coils
        goto   $-1                      ;349
        movf   avans,0                  ;350
        banksel PORTB                   ;351
        bsf    PORTB,1                  ;352
        movwf  delay_ms_data            ;353
        call   delay_ms                 ;354
        bcf    PORTB,1                  ;355
        bsf    PORTB,0                  ;356


        btfss  PORTD,0                  ;357 The lines between
                                        ;    346 and 356
        goto   $-1                      ;358 are the same operations
                                        ;    for 8th and 1st
        btfsc  PORTD,0                  ;359 ignition coils
        goto   $-1                      ;360
        movf   avans,0                  ;361
        banksel PORTB                   ;362
        bsf    PORTB,0                  ;363
        movwf  delay_ms_data            ;364
        call   delay_ms                 ;365
        bcf    PORTB,0                  ;366
        bsf    PORTB,7                  ;367
        return                          ;368 quit from the loop


;premode_2 ignition mode is a transient mode between
;mode_1 and mode_2.
;In ignition mode_2 the starting point of the saturation
;will be advanced more
;The aim of this mode is
;preparation for the mode_2
;for engine speeds between 1350 and 1400 rpm
;the only difference between mode_1 and premode_2 is
;line 453

premode_2

        btfss  PORTD,0                  ;369
        goto   $-1                      ;370
        btfsc  PORTD,0                  ;371
        goto   $-1                      ;372
        movf   avans,0                  ;373
        banksel PORTB                   ;374
        bsf    PORTB,7                  ;375 The first ignition
                                        ;    coil was
                                        ;    started to be saturated
                                        ;    (line 367)
                                        ;    with this line we`ve
                                        ;    guaranteed
                                        ;    the its starting
                                        ;    of being saturated
        movwf  delay_ms_data            ;376
        call   delay_ms                 ;377
        bcf    PORTB,7                  ;378
        bsf    PORTB,6                  ;379
        btfss  PORTD,0                  ;380
        goto   $-1                      ;381
        btfsc  PORTD,0                  ;382
```

```
goto    $-1                         ;383
movf    avans,0                     ;384
banksel PORTB                       ;385
bsf     PORTB,6                     ;386
movwf   delay_ms_data               ;387
call    delay_ms                    ;388
bcf     PORTB,6                     ;389
bsf     PORTB,5                     ;390
btfss   PORTD,0                     ;391
goto    $-1                         ;392
btfsc   PORTD,0                     ;393
goto    $-1                         ;394
movf    avans,0                     ;395
banksel PORTB                       ;396
bsf     PORTB,5                     ;397
movwf   delay_ms_data               ;398
call    delay_ms                    ;399
bcf     PORTB,5                     ;400
bsf     PORTB,4                     ;401
btfss   PORTD,0                     ;402
goto    $-1                         ;403
btfsc   PORTD,0                     ;404
goto    $-1                         ;405
movf    avans,0                     ;406
banksel PORTB                       ;407
bsf     PORTB,4                     ;408
movwf   delay_ms_data               ;409
call    delay_ms                    ;410
bcf     PORTB,4                     ;411
bsf     PORTB,3                     ;412
btfss   PORTD,0                     ;413
goto    $-1                         ;414
btfsc   PORTD,0                     ;415
goto    $-1                         ;416
movf    avans,0                     ;417
banksel PORTB                       ;418
bsf     PORTB,3                     ;419
movwf   delay_ms_data               ;420
call    delay_ms                    ;421
bcf     PORTB,3                     ;422
bsf     PORTB,2                     ;423
btfss   PORTD,0                     ;424
goto    $-1                         ;425
btfsc   PORTD,0                     ;426
goto    $-1                         ;427
movf    avans,0                     ;428
banksel PORTB                       ;429
bsf     PORTB,2                     ;430
movwf   delay_ms_data               ;431
call    delay_ms                    ;432
bcf     PORTB,2                     ;433
bsf     PORTB,1                     ;434
btfss   PORTD,0                     ;435
goto    $-1                         ;436
btfsc   PORTD,0                     ;437
goto    $-1                         ;438
movf    avans,0                     ;439
banksel PORTB                       ;440
bsf     PORTB,1                     ;441
movwf   delay_ms_data               ;442
call    delay_ms                    ;443
bcf     PORTB,1                     ;444
bsf     PORTB,0                     ;445

btfss   PORTD,0                     ;446
goto    $-1                         ;447
btfsc   PORTD,0                     ;448
goto    $-1                         ;449
movf    avans,0                     ;450
```

```
        banksel PORTB                   ;451
        bsf     PORTB,0                 ;452
        bsf     PORTB,7                 ;453
        movwf   delay_ms_data           ;454
        call    delay_ms                ;455
        bcf     PORTB,0                 ;456
;       bsf     PORTB,6                 ;457
        return                          ;458

; this is ignition mode for engine speeds
; between 1400 and 2050 rpm
; In this mode, the starting point of the ignition coils
; is at the cylindir position signal of the previous cylindir


mode_2

        btfss   PORTD,0                 ;459 did the secondary
                                        ;    circuit
                                        ;    send the 1st
                                        ;    cylinder position?
                                        ;    if yes,
                                        ;    go to the line 461
        goto    $-1                     ;460 if not go to line 459
                                        ;    and wait for the signal
        btfsc   PORTD,0                 ;461 ignition process will
                                        ;    starting with
                                        ;    the falling
                                        ;    edge of the cylinder
                                        ;    position signal
                                        ;    so wait for
                                        ;    the falling
                                        ;    edge. if PORTD,0
                                        ;    is low, go to
                                        ;    line 463,
        goto    $-1                     ;462 if not wait for
                                        ;    the falling
                                        ;    edge go to line 461

        movf    avans,0                 ;463 W=avans
        banksel PORTB                   ;464 go to bank0
        bsf     PORTB,7                 ;465 makes the 7th bit of
                                        ;    PORTB high,to guarantee

                                        ;    the start of saturation

                                        ;    of 1st igniter circuit
                                        ;    (it was set high
                                        ;    with line 453)

        bsf     PORTB,6                 ;466 starts to saturate
                                        ;    the 2nd ignition coil
                                        ;    for the next spark
                                        ;    generation
        movwf   delay_ms_data           ;467 delay_ms_data=avans
        call    delay_ms                ;468 waits for a while,
                                        ;    duration
                                        ;    is advance value
        bcf     PORTB,7                 ;469 makes PORTB,7 logic
                                        ;    low, this
                                        ;    is the end of ignition
                                        ;    signal
                                        ;    igniter circuit
                                        ;    breaks the
                                        ;    current which is
                                        ;    flowing through

                                        ;    the primary coil
                                        ;    of the 1st
```

```
                                  ;    ignition coil and
                                  ;    spark occurs

btfss  PORTD,0                    ;470 The lines between
                                  ;    470 and 480
goto   $-1                        ;471 are the same operations
                                  ;    for 2nd and 3rd
btfsc  PORTD,0                    ;472 ignition coils
goto   $-1                        ;473
movf   avans,0                    ;474
banksel PORTB                     ;475

bsf    PORTB,6                    ;476
bsf    PORTB,5                    ;477
movwf  delay_ms_data              ;478
call   delay_ms                   ;479
bcf    PORTB,6                    ;480


btfss  PORTD,0                    ;481 The lines between
                                  ;    481 and 491
goto   $-1                        ;482 are the same operations
                                  ;    for 3rd and 4th
btfsc  PORTD,0                    ;483 ignition coils
goto   $-1                        ;484
movf   avans,0                    ;485
banksel PORTB                     ;486
bsf    PORTB,5                    ;487
bsf    PORTB,4                    ;488
movwf  delay_ms_data              ;489
call   delay_ms                   ;490
bcf    PORTB,5                    ;491


btfss  PORTD,0                    ;492 The lines between
                                  ;    492 and 502
goto   $-1                        ;493 are the same operations
                                  ;    for 4th and 5th
btfsc  PORTD,0                    ;494 ignition coils
goto   $-1                        ;495
movf   avans,0                    ;496
banksel PORTB                     ;497
bsf    PORTB,4                    ;498
bsf    PORTB,3                    ;499
movwf  delay_ms_data              ;500
call   delay_ms                   ;501
bcf    PORTB,4                    ;502


btfss  PORTD,0                    ;503 The lines between
                                  ;    503 and 513
goto   $-1                        ;504 are the same operations
                                  ;    for 5th and 6th

btfsc  PORTD,0                    ;505 ignition coils
goto   $-1                        ;506
movf   avans,0                    ;507
banksel PORTB                     ;508
bsf    PORTB,3                    ;509
bsf    PORTB,2                    ;510
movwf  delay_ms_data              ;511
call   delay_ms                   ;512
bcf    PORTB,3                    ;513
```

```
        btfss  PORTD,0                  ;514 The lines between
                                        ;    514 and 524
        goto   $-1                      ;515 are the same operations
                                        ;    for 6th and 7th
        btfsc  PORTD,0                  ;516 ignition coils
        goto   $-1                      ;517
        movf   avans,0                  ;518
        banksel PORTB                   ;519
        bsf    PORTB,2                  ;520
        bsf    PORTB,1                  ;521
        movwf  delay_ms_data            ;522
        call   delay_ms                 ;523
        bcf    PORTB,2                  ;524


        btfss  PORTD,0                  ;525 The lines between
                                        ;    525 and 535
        goto   $-1                      ;526 are the same operations
                                        ;    for 7th and 8th
        btfsc  PORTD,0                  ;527 ignition coils
        goto   $-1                      ;528
        movf   avans,0                  ;529
        banksel PORTB                   ;530
        bsf    PORTB,1                  ;531
        bsf    PORTB,0                  ;532
        movwf  delay_ms_data            ;533
        call   delay_ms                 ;534
        bcf    PORTB,1                  ;535


        btfss  PORTD,0                  ;536 The lines between
                                        ;    536 and 546
        goto   $-1                      ;537 are the same operations
                                        ;    for 8th and 1st
        btfsc  PORTD,0                  ;538 ignition coils
        goto   $-1                      ;539
        movf   avans,0                  ;540
        banksel PORTB                   ;541
        bsf    PORTB,0                  ;542
        bsf    PORTB,7                  ;543
        movwf  delay_ms_data            ;544
        call   delay_ms                 ;545
        bcf    PORTB,0                  ;546

        return                          ;547

;premode_3 ignition mode is a transient mode between
;mode_2 and mode_3.
;In ignition mode_3 the starting point of the saturation
;will be advanced more
;The aim of this mode is
;preparation for the mode_3
;for engine speeds between 2050 and 2100 rpm
;the only difference between mode_2 and premode_3 is
;lines 624 and 635


premode_3

        btfss  PORTD,0                  ;548
        goto   $-1                      ;549
        btfsc  PORTD,0                  ;550
                                        ;
        goto   $-1                      ;551
        movf   avans,0                  ;552
```

```
banksel PORTB                          ;553
bsf     PORTB,7                        ;554


movwf   delay_ms_data                  ;555
call    delay_ms                       ;556
bcf     PORTB,7                        ;557



btfss   PORTD,0                        ;558
goto    $-1                            ;559
btfsc   PORTD,0                        ;560
goto    $-1                            ;561
movf    avans,0                        ;562
banksel PORTB                          ;563

bsf     PORTB,6                        ;564
bsf     PORTB,5                        ;565
movwf   delay_ms_data                  ;566
call    delay_ms                       ;567
bcf     PORTB,6                        ;568


btfss   PORTD,0                        ;569
goto    $-1                            ;570
btfsc   PORTD,0                        ;571
goto    $-1                            ;572
movf    avans,0                        ;573
banksel PORTB                          ;574
bsf     PORTB,5                        ;575
bsf     PORTB,4                        ;576
movwf   delay_ms_data                  ;577
call    delay_ms                       ;578
bcf     PORTB,5                        ;579


btfss   PORTD,0                        ;580
goto    $-1                            ;581
btfsc   PORTD,0                        ;582
goto    $-1                            ;583
movf    avans,0                        ;584
banksel PORTB                          ;585
bsf     PORTB,4                        ;586
bsf     PORTB,3                        ;587
movwf   delay_ms_data                  ;588
call    delay_ms                       ;589
bcf     PORTB,4                        ;590


btfss   PORTD,0                        ;591
goto    $-1                            ;592
btfsc   PORTD,0                        ;593
goto    $-1                            ;594
movf    avans,0                        ;595
banksel PORTB                          ;596
bsf     PORTB,3                        ;597
bsf     PORTB,2                        ;598
movwf   delay_ms_data                  ;599
call    delay_ms                       ;600
bcf     PORTB,3                        ;601
```

```
        btfss  PORTD,0                  ;602
        goto   $-1                      ;603
        btfsc  PORTD,0                  ;604
        goto   $-1                      ;605
        movf   avans,0                  ;606
        banksel PORTB                   ;607
        bsf    PORTB,2                  ;608
        bsf    PORTB,1                  ;609
        movwf  delay_ms_data            ;610
        call   delay_ms                 ;611
        bcf    PORTB,2                  ;612



        btfss  PORTD,0                  ;613
        goto   $-1                      ;614
        btfsc  PORTD,0                  ;615
        goto   $-1                      ;616
        movf   avans,0                  ;617
        banksel PORTB                   ;618
        bsf    PORTB,1                  ;619
        bsf    PORTB,0                  ;620
        movwf  delay_ms_data            ;621
        call   delay_ms                 ;622
        bcf    PORTB,1                  ;623
        bsf    PORTB,7                  ;624


        btfss  PORTD,0                  ;625
        goto   $-1                      ;626
        btfsc  PORTD,0                  ;627
        goto   $-1                      ;628
        movf   avans,0                  ;629
        banksel PORTB                   ;630
        bsf    PORTB,0                  ;631

        movwf  delay_ms_data            ;632
        call   delay_ms                 ;633
        bcf    PORTB,0                  ;634
        bsf    PORTB,6                  ;635
        return                          ;636


; this is the ignition mode for max engine speed
; in this ignition mode, the ignition coils will be started to
; saturated at the ignition point of cylinder which
;is 90 degree before

mode_3

        btfss  PORTD,0                  ;638 cylinder position
                                        ;    signal?
        goto   $-1                      ;639 if not go to line 638
        btfsc  PORTD,0                  ;640 if yes, wait for
                                        ;    the falling edge
        goto   $-1                      ;641 wait fot the
                                        ;    falling edge
        movf   avans,0                  ;642 W=avans
        banksel PORTB                   ;643 go to bank0
        bsf    PORTB,7                  ;644 makes high PORTB,7,
                                        ;    to guarantee the
                                        ;    starting of being
                                        ;    saturated of
                                        ;    ignition coil 1
        movwf  delay_ms_data            ;645 delay_ms_data=avans
        call   delay_ms                 ;646
        bcf    PORTB,7                  ;647 The 1st ignition coil
                                        ;    was started to
```

```
                                       ;    be saturated with
                                       ;    line 624
                                       ;    this is the ignition
                                       ;    point of first
                                       ;    ignition coil
        bsf     PORTB,5                ;648 3rd ignition coil
                                       ;    is started
                                       ;    to be saturated

        btfss   PORTD,0                ;649 The lines between
                                       ;    649 and 659
        goto    $-1                    ;650 are the same operations
                                       ;    for 2nd and 4th
        btfsc   PORTD,0                ;651 ignition coils
        goto    $-1                    ;652
        movf    avans,0                ;653
        banksel PORTB                  ;654
        bsf     PORTB,6                ;655
        movwf   delay_ms_data          ;656
        call    delay_ms               ;657
        bcf     PORTB,6                ;658
        bsf     PORTB,4                ;659


        btfss   PORTD,0                ;670 The lines between
                                       ;    670 and 680
        goto    $-1                    ;671 are the same operations
                                       ;    for 3rd and 5th
        btfsc   PORTD,0                ;672 ignition coils
        goto    $-1                    ;673
        movf    avans,0                ;674
        banksel PORTB                  ;675
        bsf     PORTB,5                ;676
        movwf   delay_ms_data          ;677
        call    delay_ms               ;678
        bcf     PORTB,5                ;679
        bsf     PORTB,3                ;680


        btfss   PORTD,0                ;681 The lines between
                                       ;    681 and 691
        goto    $-1                    ;682 are the same operations
                                       ;    for 4th and 6th
        btfsc   PORTD,0                ;683 ignition coils
        goto    $-1                    ;684
        movf    avans,0                ;685
        banksel PORTB                  ;686
        bsf     PORTB,4                ;687
        movwf   delay_ms_data          ;688
        call    delay_ms               ;689
        bcf     PORTB,4                ;690
        bsf     PORTB,2                ;691


        btfss   PORTD,0                ;692 The lines between
                                       ;    692 and 702
        goto    $-1                    ;693 are the same operations
                                       ;    for 5th and 7th

        btfsc   PORTD,0                ;694 ignition coils
        goto    $-1                    ;695
        movf    avans,0                ;696
        banksel PORTB                  ;697
        bsf     PORTB,3                ;698
        movwf   delay_ms_data          ;699
        call    delay_ms               ;700
        bcf     PORTB,3                ;701
        bsf     PORTB,1                ;702
```

```
        btfss   PORTD,0                 ;703 The lines between
                                        ;    703 and 713
        goto    $-1                     ;704 are the same operations
                                        ;    for 6th and 8th
        btfsc   PORTD,0                 ;705 ignition coils
        goto    $-1                     ;706
        movf    avans,0                 ;707
        banksel PORTB                   ;708
        bsf     PORTB,2                 ;709
        movwf   delay_ms_data           ;710
        call    delay_ms                ;711
        bcf     PORTB,2                 ;712
        bsf     PORTB,0                 ;713


        btfss   PORTD,0                 ;714 The lines between
                                        ;    714 and 724
        goto    $-1                     ;715 are the same operations
                                        ;    for 7th and 1st
        btfsc   PORTD,0                 ;716 ignition coils
        goto    $-1                     ;717
        movf    avans,0                 ;718
        banksel PORTB                   ;719
        bsf     PORTB,1                 ;720
        movwf   delay_ms_data           ;721
        call    delay_ms                ;722
        bcf     PORTB,1                 ;723
        bsf     PORTB,7                 ;724


        btfss   PORTD,0                 ;725 The lines between
                                        ;    725 and 736
        goto    $-1                     ;726 are the same operations
                                        ;    for 8th and 2st
        btfsc   PORTD,0                 ;727 ignition coils
        goto    $-1                     ;728
        movf    avans,0                 ;729
        banksel PORTB                   ;730
        bsf     PORTB,0                 ;731
        movwf   delay_ms_data           ;732
        call    delay_ms                ;733
        bcf     PORTB,0                 ;734
        bsf     PORTB,6                 ;735
        return                          ;736 quit from the loop



;this subroutine initializes the ADC, I2C and PORT configurations
;
;

initialize

        call    I2C_init                ;737 calls the subroutine
                                        ;    "I2C_init"
                                        ;    to initialize the I2C
                                        ;    communication

        movlw   b'11111111'             ;738 W=b'11111111'
        bsf     STATUS,RP0              ;739 go to bank1 to
                                        ;    reach to the
                                        ;    TRIS register

        movwf   TRISC                   ;740 TRISC=b'11111111'
                                        ;    (all pins of PORTC
                                        ;    are input)
        movwf   TRISA                   ;741 TRISA=b'11111111'
```

```
                                  ;    (all pins of PORTA
                                  ;    are input)
clrf    TRISB                     ;742 clear TRISB, it
                                  ;    means all
                                  ;    pins of PORTB are
                                  ;    output
banksel PORTB                     ;743 go to bank0
movlw    d'1'                     ;744
movwf   deneme                    ;745
movf    deneme,0                  ;746 W=1
bsf     STATUS,RP0                ;747 go to bank1 to
movwf   TRISD                     ;748 TRISD=1, it means
                                  ;    PORTD,0 is input
                                  ;    and the others
                                  ;    are output
banksel PORTB                     ;749 go to bank0
clrf    PORTB                     ;750 initial value of
                                  ;    PORTB is zero
clrf    PORTD                     ;751 initial value of
                                  ;    PORTD is zero
clrf    tempH                     ;752 tempH=0
clrf    sayacH                    ;753 sayacH=0
clrf    mode_sayac                ;754 mode_sayac=0
clrf    sicaklikL                 ;755 sicaklikL=0
clrf    sicaklikH                 ;756 sicaklikH=0
clrf    I2C_Data                  ;757 I2C_Data=0
clrf    I2C_AdrL                  ;758 initial value
                                  ;    of low byte
                                  ;    of eeprom address
                                  ;    is zero
clrf    I2C_AdrH                  ;759 initial value of
                                  ;    high byte
                                  ;    of eeprom address
                                  ;    is zero


                                  ; ADCON0 is a register
                                  ; which configures ADC
                                  ; the bits ADCON0,6
                                  ; and ADCON0,7 are
                                  ; used to select ADC
                                  ; clock frequency
                                  ; and the bit ADCON0,0
                                  ; is used to
                                  ; activate ADC module
                                  ;
                                  ; for clock=Fosc/8
                                  ; ADCON0,6=1  ADCON0,7=0
                                  ; to activate the module
                                  ; ADCON0,0 shall be 1
                                  ; the sum of ADCON0,0
                                  ; ADCON0,6
                                  ; equals to d'65'=0x41

movlw   0x41                      ;760 W=0x41
movwf   ADCON0                    ;761 ADCON0=0x41
                                  ;    it means clock
                                  ;    frequency is Fosc/8
                                  ;    and ADC
                                  ;    module is activated
movlw   0x80                      ;762 W=0x80
bsf     STATUS, RP0               ;763 go to bank 1
movwf   ADCON1                    ;764 ADCON1=0x80
                                  ;    the 7th bit of
                                  ;    ADCON1 register
                                  ;    shall be set
                                  ;    to "1" to arrange
                                  ;    ADRESH
                                  ;    (high byte of ADC)
```

```
                                        ;    and ADRESL (low
                                        ;    byte of ADC)
                                        ;    to get a 10-bit ADC
                                        ;    result in form of
                                        ;    000000xx(ADRESH)
                                        ;    xxxxxxxx(ADRESL)
                                        ;    x=0 or 1
                                        ;    so ADCON1=d'128'=0x80
                                        ;
        bsf     TXSTA, SYNC             ;765 the SYNC bit of
                                        ;    register TXSTA
                                        ;    should be set to 1
                                        ;    to select synchronous
                                        ;    serial
                                        ;    communication

        banksel RCSTA                   ;766 go to bank0
        bsf     RCSTA, SPEN             ;767 opens the serial
                                        ;    port
        banksel TXSTA                   ;768 go to bank1
        bcf     TXSTA, CSRC             ;769 selects the
                                        ;    slave mode
        bsf     PIE1, RCIE              ;770 activates the
                                        ;    data receive
                                        ;    interrupt
        banksel RCSTA                   ;771 go to bank0
        bcf     RCSTA, RX9              ;772 data format is 8-bit
        return                          ;773 quit from the
                                        ;    subroutine


;this subroutine initializes the Timer0
;
;


ilk_islemler
                                        ;OPTION_REG register
                                        ;is uset to
                                        ;configure Timer0 module
                                        ;0xD2 is selected
                                        ;to have timer0
                                        ;ratio 1/8 and
                                        ;clock source is internal
                                        ;command cycle
                                        ;
                                        ;
                                        ;
                                        ;
                                        ;
        movlw   0xD2                    ;774 W=0xD2

        banksel OPTION_REG              ;775 go to bank1

        movwf   OPTION_REG              ;776 OPTION_REG=0xD2

        bcf     STATUS, RP0             ;777 go to bank0
        movlw   D'6'                    ;778 initial value
                                        ;    of TMR0=6
                                        ;    to have 2 ms
                                        ;    timer period

        movwf   TMR0                    ;779 8us(256-TMR0)=2000 us



        ;bsf    INTCON, D'5'            ;780 enables Timer0
                                        ;    interrupt
        ;bsf    INTCON, D'7'            ;781 activates all enabled
```

```
                                    ;    interrupts

        return                      ;782



ADC_Oku

        bcf     STATUS,C            ;783 STATUS,C is affected by

                                    ;    command rlf
                                    ;    so it should be
                                    ;    disabled
                                    ;    before the operation
        rlf     ADC_Oku_kanalno, F  ;784 register ADCON0 is used

                                    ;    to configure ADC module

        rlf     ADC_Oku_kanalno, F  ;785 bit 3, bit 4
                                    ;    and bit 5 of
                                    ;    ADCON0 is used to
                                    ;    select
        rlf     ADC_Oku_kanalno, W  ;786 ADC channel
                                    ;    xx000xxx channel 1
                                    ;    xx001xxx channel 2
                                    ;    xx010xxx channel 3
                                    ;          .
                                    ;          .
                                    ;    xx111xxx channel 7
                                    ;    so the value
                                    ;    ADC_Oku_kanalno
                                    ;    should be shifted to
                                    ;    the left for 3 times
                                    ;
                                    ;
        iorlw   b'01000001'         ;787  to open ADC module
                                    ;     ADCON0,0
                                    ;     and for the clock
                                    ;     frequency
                                    ;     0x41 should be added
                                    ;     (lines 760 and 761)
                                    ;
        Banksel ADCON0              ;788 iorlw   b'01000001'adds
                                    ;    0x41 to ADC_Oku_kanalno

        movwf   ADCON0              ;789
        bsf     ADCON0, 2           ;790 starts the conversion

ADC_j1

        btfsc   ADCON0, 2           ;791 if ADCON0,2 is
                                    ;    zero it means
                                    ;    it is the end of
                                    ;    conversion
        goto    ADC_j1              ;792 if it is not completed,

                                    ;    waits for the
                                    ;    conversion
        movf    ADC_Oku_sonucbyte, F    ;793
        btfss   STATUS, Z           ;794 if ADC_Oku_sonucbyte is

                                    ;    zero, it means read the

                                    ;    low byte of conversion
                                    ;    go to line 796
```

```
        goto    ADC_j2                  ;795 if it is not zero go to
                                        ;    ADC_j2 and read
                                        ;    high byte

        bsf     STATUS, RP0             ;796 go to bank1
        movf    ADRESL, W               ;797 W=ADRESL
        return                          ;798 quit from the loop

ADC_j2

        bcf     STATUS, RP0             ;799 go to bank0
        movf    ADRESH, W               ;800 W=ADRESH
        return                          ;801 quit from the loop


;this routine is used to have a delay during the program
;the delay duration is value of delay_ms_data
;
delay_ms

delay_j0

        movlw   D'1'                    ;802
        movwf   delay_ms_data+1         ;803
        nop                             ;804
        nop                             ;805

delay_j1

        nop                             ;806
        decfsz  delay_ms_data+1, F      ;807
        goto    delay_j1                ;808

        nop                             ;809
        decfsz  delay_ms_data, F        ;810

        goto    delay_j0                ;811
        nop                             ;812
        return                          ;813


;this routine is used to read serial rpm data
;from the secondary circuit

snkSlaveRead

        banksel RCSTA                   ;814
        bsf     RCSTA, SPEN             ;815 opens the serial
                                        ;    port again
                                        ;    we should open the port

                                        ;    again for every reading

        banksel TXSTA                   ;816
        bcf     TXSTA, CSRC             ;817 selects slave
                                        ;    mode(after
                                        ;    receiving data port
                                        ;    configures itself
                                        ;    to master mode)

        banksel RCSTA                   ;818
        bsf     RCSTA, CREN             ;819 starts to waiting for
                                        ;    receiving data

        btfss   PIR1, RCIF              ;820 bit RCIF of PIR1 is set

                                        ;    when the data
```

```
                                        ;    received so
                                        ;
                                        ;
                                        ;
        goto    $-1                     ;821 wait for the end
                                        ;   of data transfer

        movf    RCREG, W                ;822 if data transfer is
                                        ;    completed, W=RCREG
                                        ;    RCREG is a register
                                        ;    which stores
                                        ;     the received data
        bcf     PIR1, RCIF              ;823 clear the flag
                                        ;    of received
                                        ;    data for the next
                                        ;    data transfer

        btfsc   RCSTA, CREN             ;824 if there is an
                                        ;    error during
                                        ;    the data transfer
                                        ;    bit CREN of RCSTA
                                        ;    is reset,
                                        ;    so check whether
                                        ;    there is an error
                                        ;    or not if there is
                                        ;    an erro set
                                        ;    kontrol_register,0
                                        ;    (line 826)
        return                          ;825

        bsf     kontrol_register,0      ;826
        return                          ;827

I2C_init

        banksel SSPSTAT                 ;828
        clrf    SSPSTAT                 ;829
        bsf     SSPSTAT, SMP            ;830 SSPSTAT, SMP is used
                                        ;    to select
                                        ;    standard cycle
                                        ;    frequency

        movlw   B'00001001'             ;831 W=9
                                        ;    clock=Fosc/
                                        ;    (4x(SSPADD+1))
                                        ;    Fosc=4MHz
                                        ;    so for 100kHz clock
                                        ;    SSPADD=9
                                        ;
        movwf   SSPADD                  ;832 SSPADD=9
        clrf    SSPCON2                 ;833
        movlw   B'10011000'             ;834 SDA and SCL are
                                        ;    configured as input

        movwf   TRISC                   ;835
        movlw   B'00101000'             ;836

        bcf     STATUS, RP0             ;837
        movwf   SSPCON                  ;838 master I2C mode is
                                        ;    selected
        clrf    PORTC                   ;839
        return                          ;840

; this subroutine sends start bit to the external eeprom

I2CStart

        banksel PIR1                    ;841
        bcf     PIR1, SSPIF             ;842 PIR1,SSPIF is set at
```

```
                                        ;    the end of
                                        ;    the I2C communication
                                        ;    so it should be
                                        ;    cleared before
                                        ;    the communication

        bsf     STATUS, RP0             ;843
        bsf     SSPCON2, SEN            ;844  bit SEN of SSPCON2
                                        ;     is used to
                                        ;     start the I2C
                                        ;     communication
                                        ;     line 844 starts
                                        ;     the communication

I2CStart_j1

        btfsc   SSPCON2, SEN            ;845 waits for the
                                        ;    starting operation
        goto    I2CStart_j1             ;846 if it is not
                                        ;    started yet
                                        ;    go to "I2CStart_j1"
        banksel PIR1                    ;847

I2CStart_j2

        btfss   PIR1, SSPIF             ;848 checks whether the data

                                        ;    transfer is
                                        ;    completed or not
        goto    I2CStart_j2             ;849 waits for the
                                        ;    data transfer

        bcf     PIR1, SSPIF             ;850 if data is transferred
                                        ;    clear the bit
        return


I2CReStart

        nop                             ;851
        nop                             ;852
        nop                             ;853
        nop                             ;854
        nop                             ;855
        banksel SSPCON2                 ;856
        bsf     SSPCON2, RSEN           ;857 SSPCON2, RSEN
                                        ;    is used to
                                        ;    restart the I2C mode

I2CReStart_j1

        btfsc   SSPCON2, RSEN           ;858 SSPCON2, RSEN
                                        ;    is reset at
                                        ;    the end of restart
                                        ;    operation
        goto    I2CReStart_j1           ;859 this lines are used
                                        ;    to wait
                                        ;    for the end of restart
        return                          ;860

I2CSend
        banksel PIR1                    ;861
        bcf     PIR1, SSPIF             ;862 should be reset before
                                        ;    the data transfer
        movf    I2CSend_Data, W         ;863 W=I2CSend_Data
        movwf   SSPBUF                  ;864 SSPBUF=I2CSend_Data
                                        ;    SSPBUF is
                                        ;    buffer register,
                                        ;    it stores the received
```

```
                                        ;     or sent data
        return                          ;865 quit from the routine

I2CRead
        banksel SSPCON2                 ;866
        bsf     SSPCON2, RCEN           ;867 this line activates the
                                        ;     receiving mode

I2CRead_j1

        btfsc   SSPCON2, RCEN           ;868 wait for the end of
                                        ;    activation of
                                        ;    receiving mode
        goto    I2CRead_j1              ;869
        banksel PIR1                    ;870

I2CRead_j2

        btfss   PIR1, SSPIF             ;    is data received?
        goto    I2CRead_j2              ;871 if no, wait for the
                                        ;    data transfer

        bcf     PIR1, SSPIF             ;872 after data transfer,
                                        ;    reset
                                        ;    the data transfer flag
        movf    SSPBUF, W               ;873 read the received data

        return                          ;874 quit from the routine

I2CStop
        banksel SSPCON2                 ;875
        bsf     SSPCON2, PEN            ;876 when the bit PEN of
                                        ;    SSPCON2 is set
                                        ;    it sends stop bit
I2CStop_j1

        btfsc   SSPCON2, PEN            ;877 waits for the end of
                                        ;    sending stop bit
        goto    I2CStop_j1              ;878
        banksel PIR1                    ;879

I2CStop_j2

        btfss   PIR1, SSPIF             ;880 checks whether
                                        ;    the stop-bit
                                        ;    transfer is completed

        goto    I2CStop_j2              ;881 if not go to the
                                        ;    "I2CStop_j2"

        bcf     PIR1, SSPIF             ;882 if yes, clear the
                                        ;    "PIR1, SSPIF"
        return                          ;883

I2CAck
        banksel SSPCON2                 ;884
        bcf     SSPCON2, ACKDT          ;885 bit ACKDT of
                                        ;    SSPCON2 is set when
                                        ;    the data is
                                        ;    acknowledged
                                        ;    (master receiving mode)
                                        ;    so before the
                                        ;    data transfer
                                        ;    it should be reset
                                        ;
        bsf     SSPCON2, ACKSTAT        ;886 bit ACKSTAT of SSPCON2
                                        ;    is reset
                                        ;    when the data is
                                        ;    acknowledged by
```

```
                                        ;    the slave
                                        ;    so it should be
                                        ;    set before
                                        ;    the communication

I2CAck_j1                               ;887
                                        ;888
        btfsc   SSPCON2, ACKSTAT        ;889 waits until the
                                        ;    received data is
                                        ;    acknowledged by the
                                        ;    slave device

        goto    I2CAck_j1               ;890
        banksel PIR1                    ;891

I2CAck_j2

        btfss   PIR1, SSPIF             ;892 checks whether
                                        ;    data sending is
                                        ;    completed or not
        goto    I2CAck_j2               ;893
        bcf     PIR1, SSPIF             ;894
        return                          ;895

I2CNak
        banksel SSPCON2                 ;896
        bsf     SSPCON2, ACKDT          ;897 set bit ACKDT of
                                        ;    SSPCON2
                                        ;
I2CNak_j1

        btfsc   SSPCON2, ACKSTAT        ;898 waits for the
                                        ;    acknowledgement of
                                        ;    data by the
                                        ;    slave device

        goto    I2CNak_j1               ;899
        bsf     SSPCON2, ACKEN          ;900 sets the receiving
                                        ;    mode of
                                        ;    master device and
                                        ;    sends ACKDT bit to
                                        ;    slave device
        bcf     STATUS, RP0             ;901
        bcf     PIR1, SSPIF             ;902 reset the bit SSPIF
                                        ;    of PIR1

I2CNak_j2

        banksel SSPCON2                 ;903
        btfsc   SSPCON2, ACKEN          ;904 after sending of ACKDT,
                                        ;    ACKEN is reset
        goto    I2CNak_j2               ;905 so these lines checks
                                        ;    whether ACKDT is
                                        ;    sent or not
        banksel PIR1                    ;906

I2CNak_j3

        btfss   PIR1, SSPIF             ;907 is the data
                                        ;    transferred?
        goto    I2CNak_j3               ;908 waits for the
                                        ;    data transfer

        bcf     PIR1, SSPIF             ;909 reset PIR1, SSPIF for
                                        ;    the next operations
        return                          ;910 quit from the routine

; this subroutine is used to read advance data
; from the external eeprom
```

```
; to read data from the external eeprom
; first of all we send control byte
; control byte is the combination of hardware address
; logic states of A0, A1 and A2 pins ( which are used to address
; the external device) and R/W  bit
; 1010(A2)(A1)(A0)(R/W) is the for of
; control byte
; A2, A1 and A0 are connected to GND in our application
; so for reading operations, the control byte is 10100001
; for writing operations, the control byte is 10100000
; after sending control byte, we should check ACK (acknowledged)
; then we willsend high address byte and check ACK
; after checking the ACK, we will send low address byte and
; check ACK. Now we are ready to read the data of sent address
; for reading operation we should restart the device,
;send reading control byte
; and check the ACK. After ACK is received, advance data will
received
; the operations will end with No ACK and we
;will stop the communication

I2C_ReadEE

        call    I2CStart                ;911 starts the
                                        ;    communication
        rlf     I2C_Device, W           ;912 data format of
                                        ;    control byte
                                        ;    is 1010
                                        ;   (A2)(A1)(A0)(R/W)
                                        ;    so to have this form we

                                        ;    shall shift the
                                        ;    I2C_Device
                                        ;    to the left.
                                        ;    Actually we can
                                        ;    write the control
                                        ;    byte directly
                                        ;    because there is
                                        ;    only one
                                        ;    external eeprom.
                                        ;    This code form is
                                        ;    used for future works
                                        ;

        andlw   0xFE                    ;913
        iorlw   0xA0                    ;914 R/W is 0

        movwf   I2CSend_Data            ;915 I2CSend_Data=control
                                        ;    byte
        call    I2CSend                 ;916 calls the subroutine
                                        ;    which sends
                                        ;    data to the
                                        ;    external eeprom
        call    I2CAck                  ;917 after sending control
                                        ;    byte we
                                        ;    should check ACK
        movf    I2C_AdrH, W             ;918 W=high byte of eeprom
                                        ;    address
                                        ;    which the advance
                                        ;    data will be read
        movwf   I2CSend_Data            ;919 I2CSend_Data=high
                                        ;    byte of address
        call    I2CSend                 ;920 calls the subroutine
                                        ;    which sends
                                        ;    data to the external
                                        ;    eeprom
        call    I2CAck                  ;921 after sending
                                        ;    high byte of
                                        ;    address we should
```

```
                                    ;    check ACK
        movf    I2C_AdrL, W         ;922 W=low byte of
                                    ;    eeprom address
        movwf   I2CSend_Data        ;923 I2CSend_Data=low
                                    ;    byte of address
        call    I2CSend             ;924 calls the subroutine
                                    ;    which
                                    ;    sends data to the
                                    ;    external eeprom
        call    I2CAck              ;925 after sending low
                                    ;    byte of address
                                    ;    we should check ACK
        call    I2CReStart          ;926 for reading
                                    ;    operation we
                                    ;    should restart
                                    ;    the device

        rlf     I2C_Device,     W   ;927 formation of
                                    ;    control byte for
                                    ;    reading operation

        andlw   0xFE                ;928
        iorlw   0xA1                ;929 R/W is 1

        movwf   I2CSend_Data        ;930 I2CSend_Data=control
                                    ;    byte

        call    I2CSend             ;931 sends the control byte
        call    I2CAck              ;932 checks whether
                                    ;    the control
                                    ;    byte acknowledged
                                    ;    or not
        call    I2CRead             ;933 reads the advance
                                    ;    data from the eeprom

        movwf   I2C_Data            ;934 I2C_Data=advance value
        call    I2CNak              ;935 checks the No ACK

        call    I2CStop             ;936 stops the I2C
                                    ;    communication
        return                      ;937

        END                         ;938
;*******************************************************************
```

APPENDIX B: SOURCE CODE OF THE SECOND CONTROL CIRCUIT

```
;******************************************************************
;      Source Code of Secondary Control Circuit
;********************************************************************
list       p=16f877A
      #include <p16F877A.inc>
      __config H'3F31'        ;PWRT on, diðerleri kapalý,
                              ;Osilatör XT ve 4 Mhz.
;--------------------------------------------------------------------
; Deðiþken tanýmlama
;--------------------------------------------------------------------

delay_ms_data        equ 0x20       ;delay routine variable
rpmL                 equ 0x25       ;low  byte  of rpm value
rpmH                 equ 0x23       ;high byte of rpm value
bolum                equ 0x24       ;8-bit form of rpmL+rpmH
ADC_Oku_kanalno      equ 0x70       ;ADC channel number

ADC_Oku_sonucbyte    equ 0x71       ;ADRESL or ADRESH selection
varibale
sayac2               equ 0x72       ;counter for gear wheel pulses
sayac3               equ 0x73       ;counter for cylinder number

      ORG    0x000

      goto  main
```

```
main
        call    initial                 ;1
tekrar


        btfss PORTD,0                   ;2 is the main
                                        ;  contror circuit
                                        ;  ready for data transfer?
        goto $-1                        ;3 wait for the ready
                                        ;  signal of
                                        ;  the main control circuit
        movlw   0x00                    ;4 W=0x00
        movwf   ADC_Oku_kanalno         ;5 ADC_Oku_kanalno=0x00
                                        ;  analog
                                        ;  channel 0 is selected
        movlw   0x00                    ;6 W=0x00
        movwf   ADC_Oku_sonucbyte       ;7 ADC_Oku_sonucbyte=0x00
                                        ;  read the low byte of ADC

        call    ADC_Oku                 ;8 calls the subroutine
                                        ;  "ADC_Oku"
        Banksel PORTB                   ;9 go to bank0
        movwf   rpmL                    ;10 rpmL=low byte of ADC
        nop                             ;11 no operation
        nop                             ;12 no operation
        nop                             ;13 no operation
        movlw   0x00                    ;14
        movwf   ADC_Oku_kanalno         ;15 analog channel 0 selected
        movlw   0x01                    ;16
        movwf   ADC_Oku_sonucbyte       ;17 reads the high
                                        ;   byte of ADC
        call    ADC_Oku                 ;18 calls the subroutine
                                        ;  "ADC_Oku" to read high
                                        ;   byte of rpm
        Banksel PORTB                   ;19 go to bank0
        movwf   rpmH                    ;20 rpmH= high byte of ADC
        movlw   d'0'                    ;21 W=0
        movwf   bolum                   ;22 bolum=0, initial value
                                        ;   of bolum is zero


dongu2

        movlw d'4'                      ;23 the operations which are
                                        ;   done with lines
                                        ;   between 23-38
        subwf rpmL ,1                   ;24 are the mathematical
                                        ;   operations (16-bit
                                        ;   division)
        btfss STATUS,C                  ;25 which is done to scale
                                        ;   10-bit
                                        ;   ADC result to 8-bit
        goto  $+3                       ;26
        incf  bolum,1                   ;27
        goto  dongu2                    ;28
        incf  bolum,1                   ;29
        bsf   STATUS,0                  ;30
        movlw d'1'                      ;31
        subwf rpmH,1                    ;32
        btfss STATUS,C                  ;33
        goto  $+2                       ;34
        goto  $+3                       ;35
        decf  bolum,1                   ;36
        goto  $+2                       ;37
        goto  dongu2                    ;38
        movf  bolum,0                   ;39 W=bolum, bolum is the
                                        ;   8-bit form of rpm value
        call  snkMasterWrite            ;40 calls the subroutine
                                        ;   which sends
```

```
                                        ;   the rpm data to the main
                                        ;   control circuit
        Banksel PORTB                   ;41 go to bank0


        btfss PORTD,1                   ;42 checks the first
                                        ;   cylinder position
        goto  $-1                       ;43 waits for the cylinder
                                        ;   position signal
        btfsc PORTD,1                   ;44 checks the falling
                                        ;   edge of the
                                        ;   first cylinder
                                        ;   position signal
        goto  $-1                       ;45 waits for the
                                        ;   falling edge
        bsf   PORTB,7                   ;46 if the falling edge
                                        ;   is detected,
                                        ;   send first cylinder
                                        ;   position signal
                                        ;   to the main control
                                       ;    circuit
        call  delay_20us                ;47 20 us delay
        bcf   PORTB,7                   ;48 makes low the PORTB,7

; this loop is detects the position of
; remaining 7 cylinders and sends cylinder
; position signals to the
; main control circuit

dongu3

        bcf   STATUS,Z                  ;49 clears the STATUS,Z
        nop                             ;50 no operation
        nop                             ;51 no operation
        btfss PORTD,2                   ;52 is there a pulse?
        goto  $-1                       ;53 if no go to line 52
        btfsc PORTD,2                   ;54 if yes wait for the
                                        ;   falling edge
        goto  $-1                       ;55
        banksel PORTB                   ;56
        incf  sayac2,F                  ;57 sayac2=sayac2+1;
        movf  sayac2,0                  ;58 W=sayac2
        movwf PORTB                     ;59 PORTB=sayac2, this
                                        ;   is used to see
                                        ;   the pulses with the
                                        ;   leds of PORTB
        movlw d'10'                     ;60 W=10
        subwf sayac2,W                  ;61 W=sayac2-10
        btfss STATUS,Z                  ;62 if sayac2=10 go to
                                        ;   line 64
                                        ;   the gear wheel
                                        ;   which is used to
                                        ;   measure the crank
                                        ;   shaft angle
                                        ;   (detecting the
                                        ;   cylinder positions)
                                        ;   has 80 teeth, so 10
                                        ;   teeth (pulses)
                                        ;   means 45 degree, new
                                        ;   cylinder position

        goto  dongu3                    ;63 sayac2 is not equal
                                        ;   to 10, go to
                                        ;   the starting point
                                        ;   of the dongu3
        clrf  PORTB                     ;64 clears PORTB
        bsf   PORTB,7                   ;65 sends the cylinder
                                        ;   position signal
                                        ;   to the main
```

```
                                        ;   control circuit
        call  delay_20us                ;66 20 us delay
        bcf   PORTB,7                   ;67 makes PORTB,7 low
        clrf  sayac2                    ;68 sayac2=0, for the
                                        ;   next cylinder
                                        ;   position detection
        banksel PORTB                   ;69 go to bank0
        incf  sayac3,F                  ;70 sayac3=sayac3+1
                                        ;   sayac3 is
                                        ;   the number of detected
                                        ;   cylinders (except
                                        ;   first cylinder)
        movlw d'7'                      ;71 W=7
        subwf sayac3,W                  ;72 W=sayac3-7
        btfss STATUS,Z                  ;73 if sayac3=7 (if all
                                        ;   cylinde are
                                        ;   detected which means one
                                        ;   full revolution)
                                        ;   go to line 75
        goto  dongu3                    ;74 if not go to the starting

                                        ;   point of the dongu3
        banksel PORTB                   ;75 go to bank0
        bsf   PORTB,7                   ;76 send cylinder
                                        ;   position signal
                                        ;   to the main control
                                        ;   circuit
                                        ;
                                        ;
                                        ;

        call  delay_20us                ;77 20 us delay
        bcf   PORTB,7                   ;78 makes PORTB,7 low
        clrf  sayac3                    ;79 sayac3=0
        goto  tekrar                    ;80


initial
        bsf   STATUS,RP0                ;81 go to bank1
        clrf  TRISC                     ;82 all pins of
                                        ;   PORTC are output
        clrf  TRISB                     ;83 all pins of
                                        ;   PORTB are output
        movlw D'255'                    ;84 W=255
        movwf TRISA                     ;85 TRISA=255 it means
                                        ;   all pins of PORTA
                                        ;   are input
        movlw d'7'                      ;86 W=7
        movwf TRISD                     ;87 TRISD=7 it means 0th,
                                        ;   1st and 2nd pins
                                        ;   of PORTD
                                        ;   are input, the other
                                        ;   pins are output

        bcf   STATUS, RP0               ;88 go to bank0
        clrf  PORTB                     ;89 initial value of
                                        ;   PORTB is zero
        clrf  rpmL                      ;90 initial value of
                                        ;   rpmL is zero
        clrf  rpmH                      ;91 initial value of
                                        ;   rpmH is zero
        clrf  sayac2                    ;92 initial value of
                                        ;   sayac2 is zero
        clrf  sayac3                    ;93 initial value of
                                        ;   sayac3 is zero


                                        ;   ADCON0 is a register
```

```
                                        ;   which configures ADC
                                        ;   the bits ADCON0,6
                                        ;   and ADCON0,7 are
                                        ;   used to select ADC
                                        ;   clock frequency
                                        ;   and the bit ADCON0,0
                                        ;   is used to
                                        ;   activate ADC module
                                        ;   for clock=Fosc/8
                                        ;   ADCON0,6=1
                                        ;   ADCON0,7=0
                                        ;   to activate the
                                        ;   module ADCON0,0
                                        ;   shall be 1
                                        ;   the sum of ADCON0,0
                                        ;   ADCON0,6
                                        ;   equals to d'65'=0x41

movlw 0x41                              ;95  W=0x41
movwf ADCON0                            ;96  ADCON0=0x41 ADCON0=0x41
                                        ;    it means
                                        ;    clock frequency is
                                        ;    Fosc/8 and ADC


                                        ;  the 7th bit of
                                        ;  ADCON1 register
                                        ;  shall be set
                                        ;  to "1" to arrange
                                        ;  ADRESH(high byte of ADC)
                                        ;  and ADRESL
                                        ;  (low byte of ADC)
                                        ;  to get a 10-bit ADC
                                        ;  result in form of
                                        ;  000000xx(ADRESH)
                                        ;  xxxxxxxx(ADRESL)
                                        ;  x=0 or 1
                                        ;  so ADCON1=d'128'=0x80

movlw 0x80                              ;97 W=0x80
bsf   STATUS, RP0                       ;98 go to bank1
movwf ADCON1                            ;99 ADCON1=0x80


movlw 0x01                              ;100 W=0x01
                                        ;101
                                        ;

banksel TXREG                           ;102 go to bank0
clrf    TXREG                           ;103 TXREG=0

banksel SPBRG                           ;104 go to bank1

                                        ;   the register SPBRG is
                                        ;   used to select
                                        ;   serial communication
                                        ;   baudrate
                                        ;   the formula to calculate
                                        ;   the baudrate
                                        ;   is baudrate=
                                        ;   Fosc/(4x(SPBRG+1))
                                        ;   we have selected the
                                        ;   baudrate as 500000,
                                        ;   so 500000=
                                        ;   4000000/(4x(SPBRG+1))
                                        ;   SPBRG=1

movwf   SPBRG                           ;105 SPBRG=1
banksel TXSTA                           ;106
```

```
        bsf     TXSTA, SYNC             ;107 the SYNC bit of register

                                        ;    TXSTA should be set to 1

                                        ;    to select
                                        ;    synchronous serial
                                        ;    communication

        bsf     TXSTA, CSRC             ;108 selects the master mode

        bsf     PIE1, TXIE              ;109 data sending
                                        ;    interrupt is activated

        bcf     TXSTA, TX9              ;110 8-bit data format
                                        ;    is selected

        bsf     TXSTA, TXEN             ;111 data sending is
                                        ;    activated
        banksel RCSTA                   ;112
        bcf     RCSTA, SREN             ;113 no data receiving
        bsf     RCSTA, SPEN             ;114 opens the serial port

        return                          ;115

delay_20us
        nop                             ;116
        nop                             ;117
        nop                             ;118
        nop                             ;119
        nop                             ;120
        nop                             ;121
        nop                             ;122
        nop                             ;123
        nop                             ;124
        nop                             ;125
        nop                             ;126
        nop                             ;127
        nop                             ;128
        nop                             ;129
        nop                             ;130
        nop                             ;131
        nop                             ;132
        nop                             ;133
        nop                             ;134
        nop                             ;135
        return                          ;136


;delay subroutine

delay_ms
delay_j0
        movlw   D'1'                    ;137
        movwf   delay_ms_data+1         ;138

        nop                             ;139
        nop                             ;140
delay_j1
        nop                             ;141
        nop                             ;142
        nop                             ;143
        nop                             ;144
        decfsz  delay_ms_data+1, F      ;145
        goto    delay_j1                ;146
        nop                             ;147
        decfsz  delay_ms_data, F        ;148
        goto    delay_j0                ;149
        nop                             ;150
        return                          ;151
```

```
; this subroutine is used to send data with
; synchronous serial communication

snkMasterWrite

        banksel TXREG                   ;152 go to bank0

        movwf   TXREG                   ;153 with line 39,
                                        ;    value of "bolum"
                                        ;    was loaded to W
                                        ;    TXREG=bolum
                                        ;    (the data which
                                        ;    will be sent is
                                        ;    loaded to TXREG)
        banksel PIR1                    ;154 go to bank 0
                                        ;
                                        ;    the bit TXIF of
                                        ;    PIR1 is set when data
                                        ;    transfer is completed
                                        ;
        btfss   PIR1, TXIF              ;155 checks whether
                                        ;    the transfer
                                        ;    is completed or not

        goto    $-1                     ;156 if not, wait for
                                        ;    the data transfer
        bcf     PIR1, TXIF              ;157 if data is transferred,
                                        ;    reset
                                        ;    the PIR1, TXIF
                                        ;    for the next
                                        ;    communication
        return

; this routine is used to
; read analog value and convert it into digital
; with "ADC_Oku_kanalno" any channel can be selected
; with "ADC_Oku_sonucbyte" high or low byte of ADC is selected

ADC_Oku

        bcf STATUS,C                    ;158 STATUS,C is
                                        ;    affected by
                                        ;    command rlf
                                        ;    so it should be
                                        ;    disabled
                                        ;    before the operation

        rlf     ADC_Oku_kanalno, F      ;159 register ADCON0
                                        ;    is used to
                                        ;    configure ADC module
        rlf     ADC_Oku_kanalno, F      ;160 bit 3, bit 4
                                        ;    and bit 5
                                        ;    of ADCON0 is
                                        ;    used to select
        rlf     ADC_Oku_kanalno, W      ;161 ADC channel
                                        ;    xx000xxx channel 1
                                        ;    xx001xxx channel 2
                                        ;    xx010xxx channel 3
                                        ;          .
                                        ;          .
                                        ;    xx111xxx channel 7
                                        ;    so the value
                                        ;    ADC_Oku_kanalno
                                        ;    should be shifted to
                                        ;    the left for 3
                                        ;    times to
                                        ;    get right form
                                        ;
```

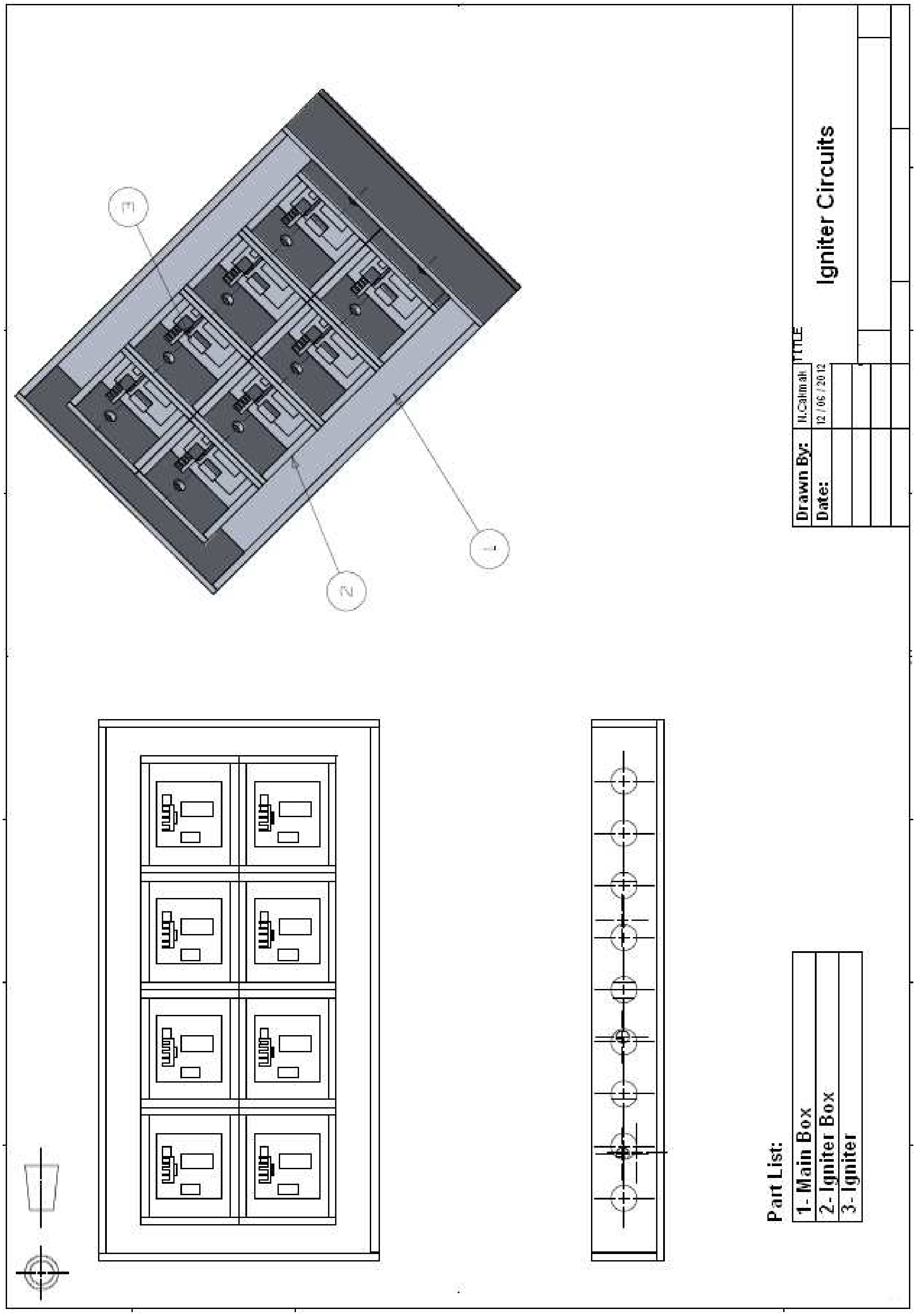
```
        iorlw   b'01000001'             ;162 to open ADC module
                                        ;    ADCON0,0
                                        ;    and for the clock
                                        ;    frequency
                                        ;    0x41 should be added
                                        ;    (lines 95 and 96)

        Banksel ADCON0                  ;163
        movwf   ADCON0                  ;164 ADCON0=0x41
        bsf     ADCON0, 2               ;165 starts the conversion
ADC_j1
        btfsc   ADCON0, 2               ;166 if ADCON0,2 is zero
                                        ;    it means
                                        ;    it is the end of
                                        ;    conversion
        goto    ADC_j1                  ;167 if it is not completed,
                                        ;    waits for the conversion
        movf    ADC_Oku_sonucbyte, F    ;168
        btfss   STATUS, Z               ;169 if ADC_Oku_sonucbyte
                                        ;    is zero,
                                        ;    it means read the
                                        ;    low byte of
                                        ;    conversion go
                                        ;    to line 171

        goto    ADC_j2                  ;170 if it is not
                                        ;    zero go to
                                        ;    ADC_j2 and read
                                        ;    high byte

        bsf     STATUS, RP0             ;171 go to bank1
        movf    ADRESL, W               ;172 W=ADRESL low
                                        ;    byte of ADC
                                        ;    is loaded to W
        return                          ;173
ADC_j2
        bcf     STATUS, RP0             ;174 go to bank0
        movf    ADRESH, W               ;175 W=ADRESH high byte of
                                        ;    ADC is loaded to W
        return                          ;176


        END                             ;177
;*******************************************************************
```

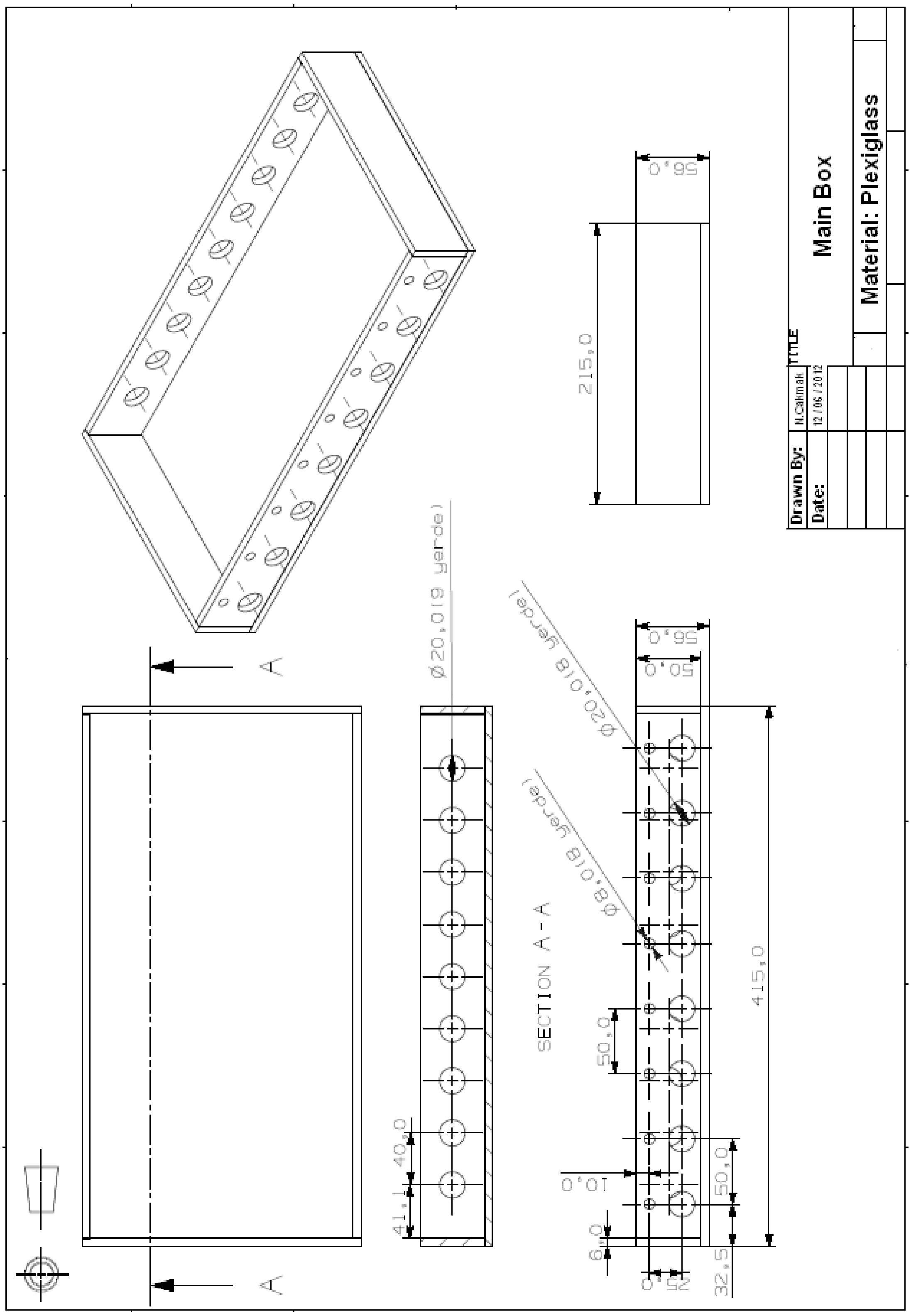
APPENDIX C: SOURCE CODE OF THE IGNITER CIRCUIT

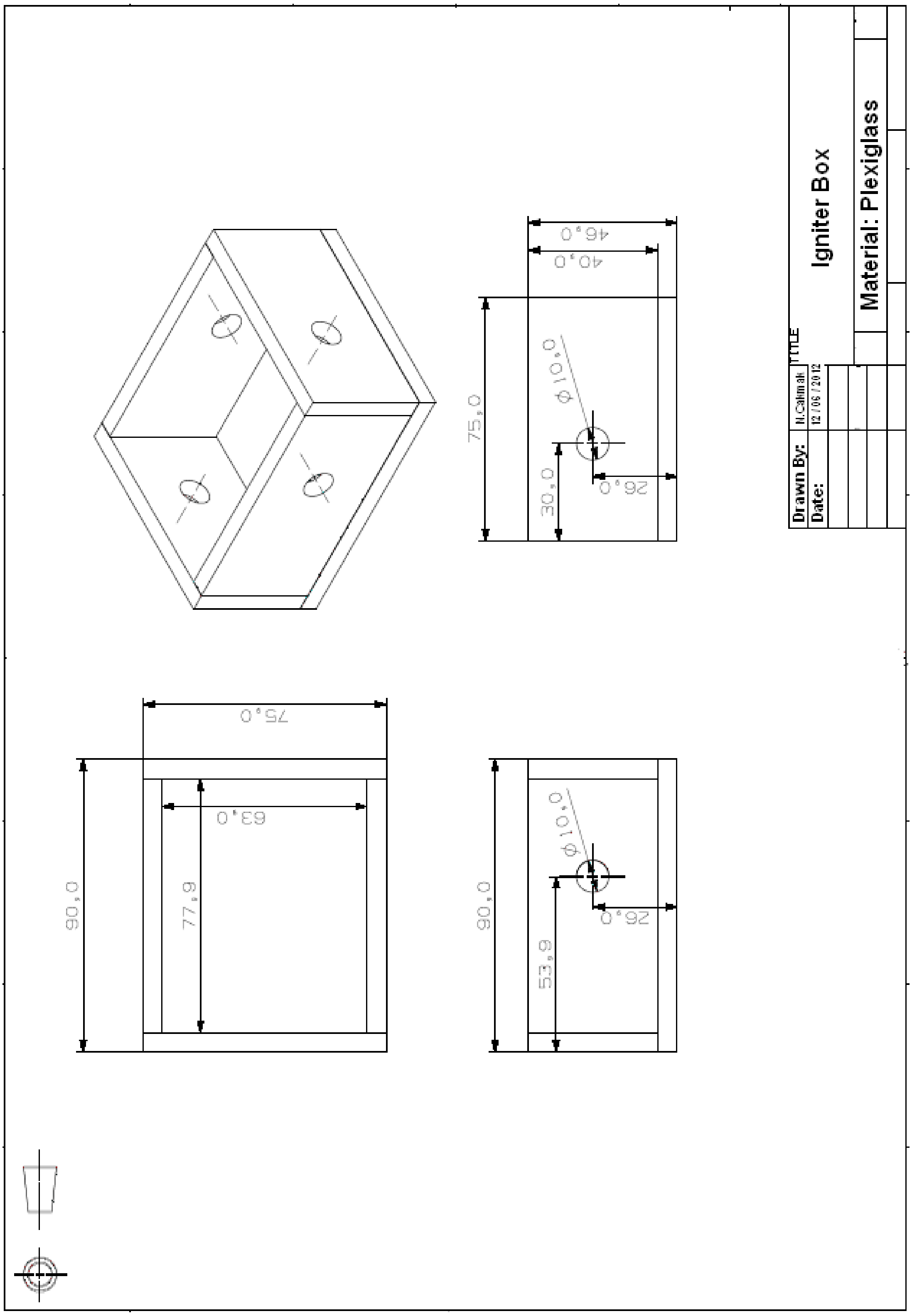
```
;*****************************************************************

;      Source Code of Igniter Circuits

;*******************************************************************
LIST  P=16F628A
      INCLUDE     "P16F628A.INC"
      __CONFIG _XT_OSC & _WDT_OFF & _PWRTE_ON & _MCLRE_ON &
_BODEN_OFF & _LVP_OFF & _DATA_CP_OFF & _CP_OFF



      ORG         h'00'

      movlw       b'00100000'        ;1
      BANKSEL     TRISB              ;2
      movwf       TRISB              ;3
      MOVLW       H'FF'              ;4
      MOVWF       TRISA              ;5
      BANKSEL     PORTB              ;6
      MOVLW       h'07'              ;7
      MOVWF       CMCON              ;8
RB5_TEST

        BTFSS     PORTB,5            ;9
        GOTO      RB5_TEST           ;10
        BSF       PORTB,0            ;11
```

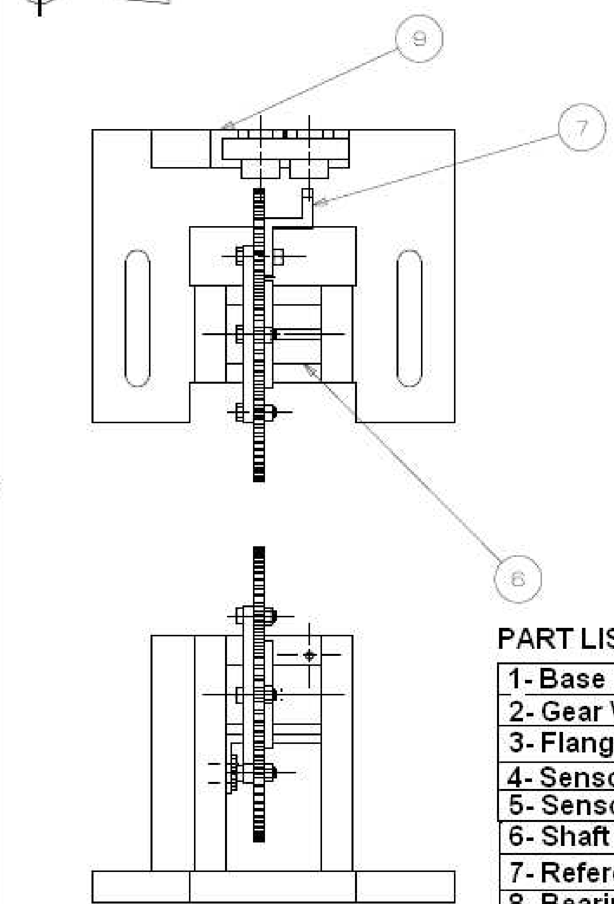
```
RB5_TEST_low

        BTFSC       PORTB,5         ;12
        GOTO        RB5_TEST_low    ;13
        BCF         PORTB,0         ;14
        GOTO        RB5_TEST        ;15


END                                 ;16
```

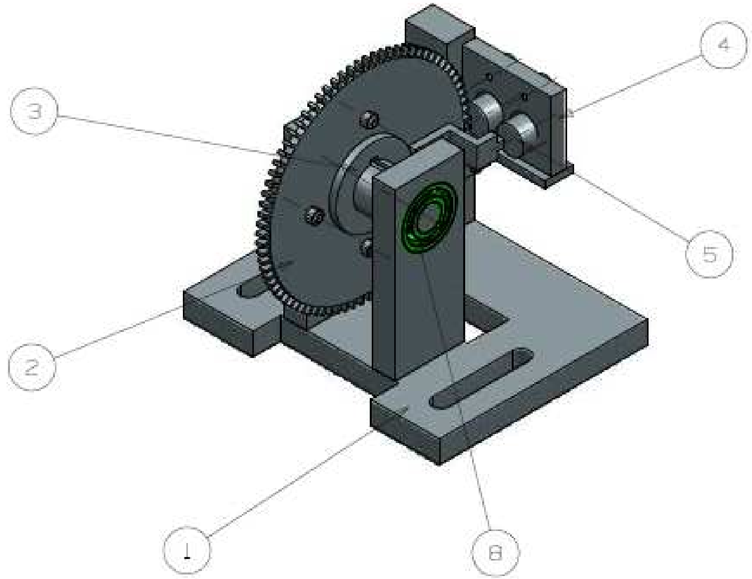
APPENDIX D: TECHNICAL DRAWINGS




Main Box
Material: Plexiglass
TITLE
Drawn By:
Date:
12/06/2012
SECTION A - A
A
A
Ø20,019 yerde
Ø20,018 yerde
Ø8,018 yerde
56,0
215,0
56,0
50,0
415,0
50,0
50,0
40,0
10,0
6,0
25,0
32,5


Drawn By: N.Cahmah
Date: 12 / 06 / 2012
TITLE
Igniter Box
Material: Plexiglass
46,0
40,0
75,0
φ10,0
30,0
26,0
75,0
63,0
90,0
77,9
90,0
φ10,0
26,0
53,9

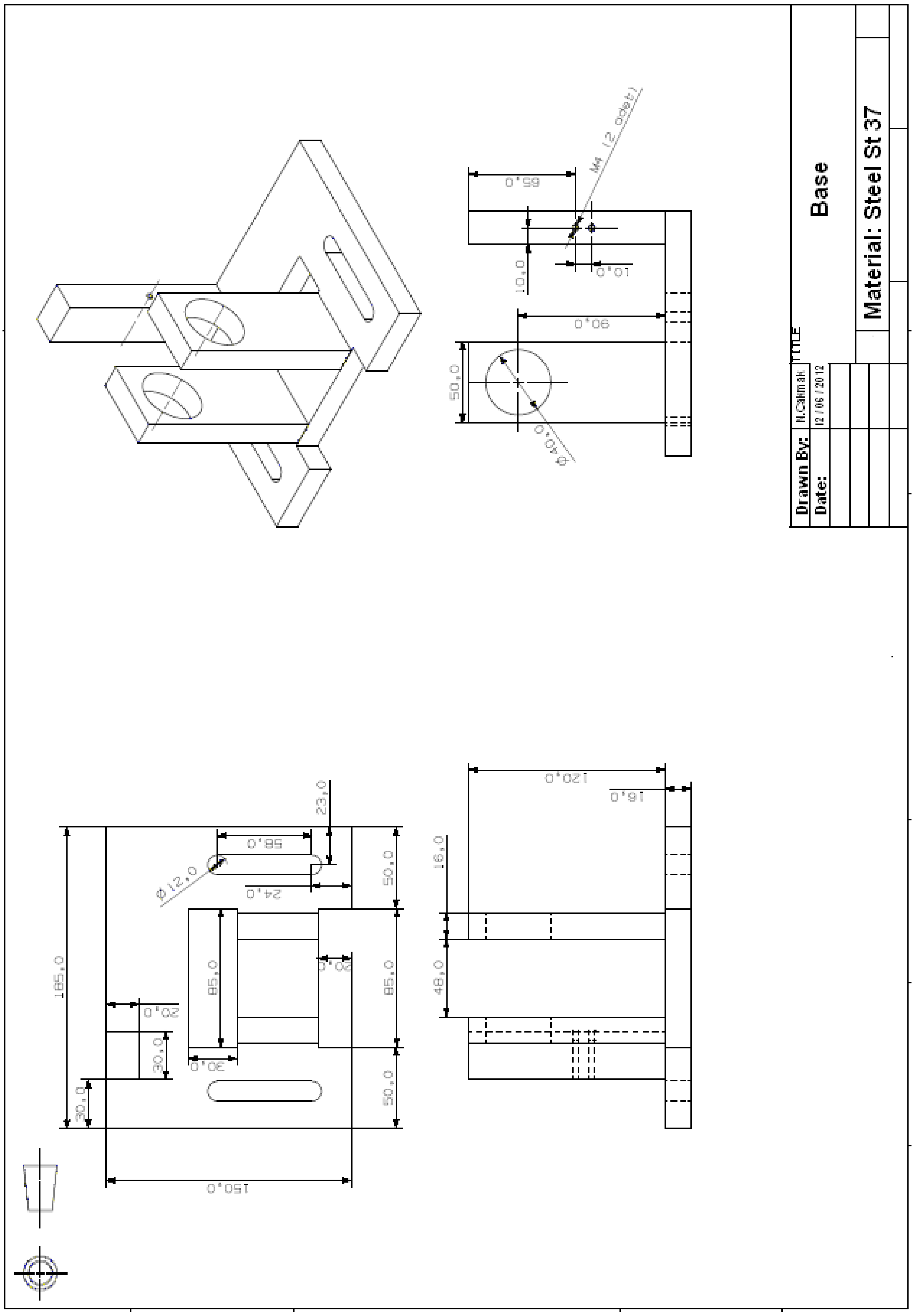


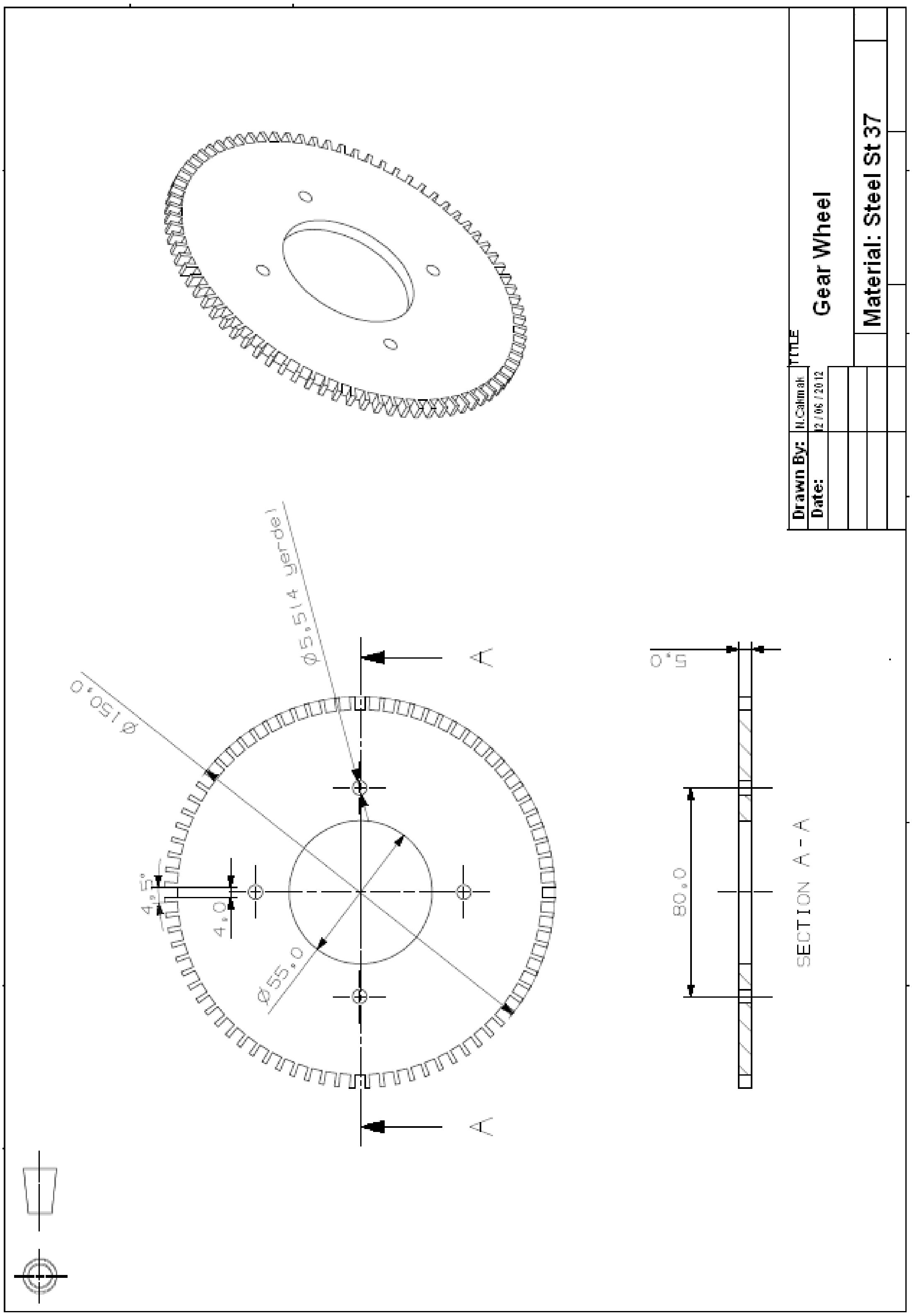


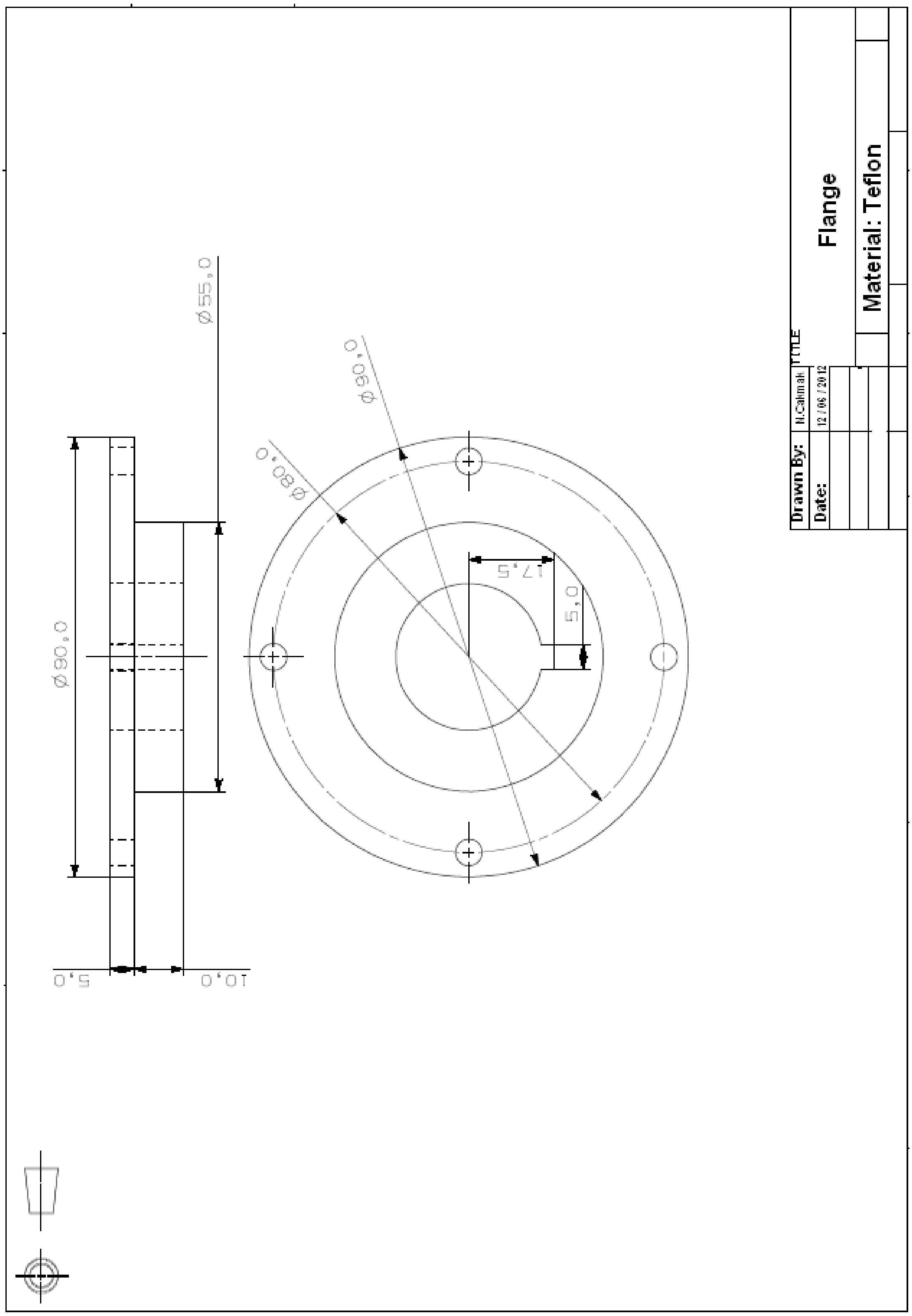
PART LIST:

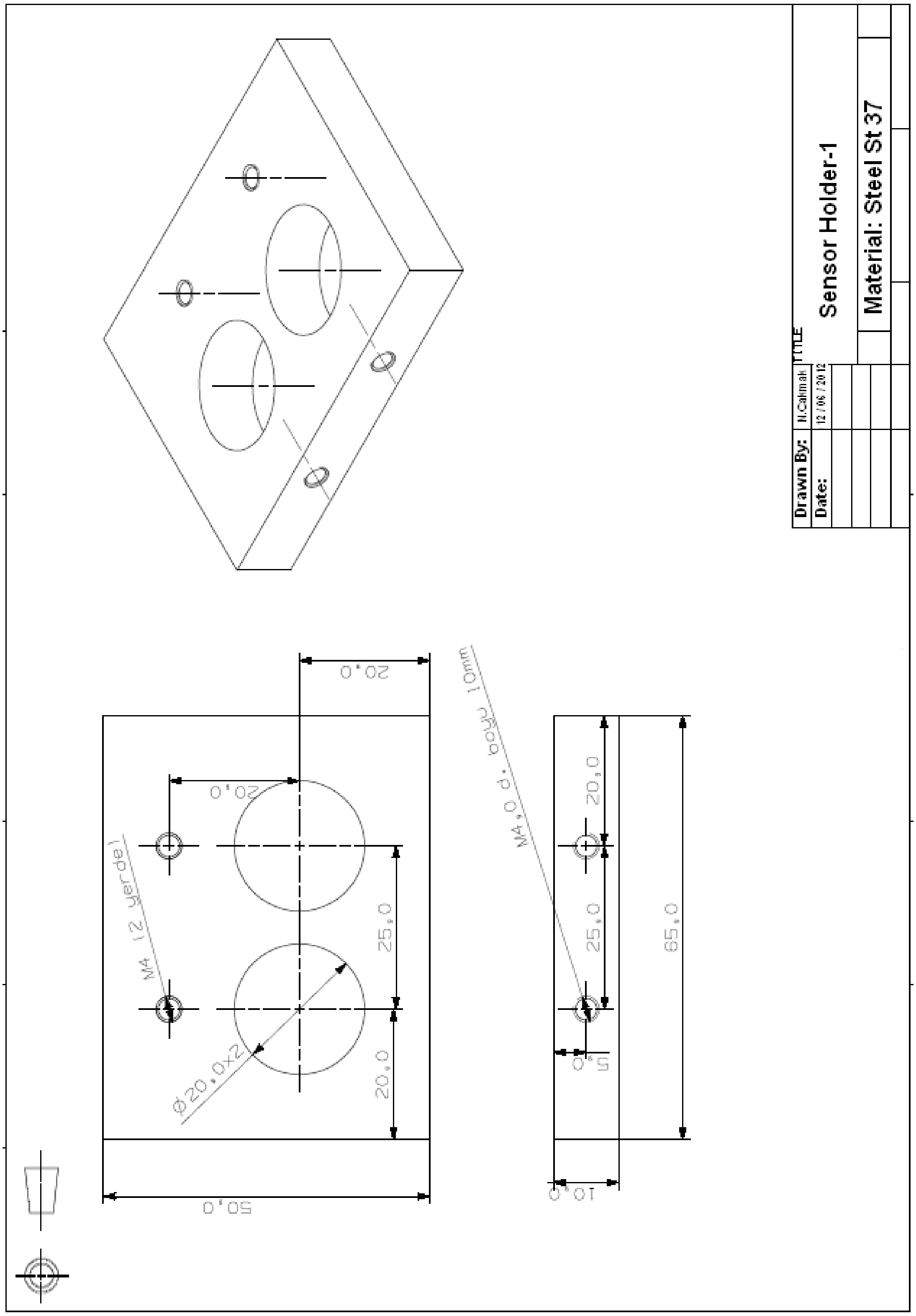
1- Base
2- Gear Wheel
3- Flange
4- Sensor Holder-1
5- Sensor
6- Shaft
7- Reference Point
8- Bearing
9- Sensor Holder-2

Drawn By	N.Cakmak	TITLE
Date:	12 / 06 / 2012	Gear Wheel And Sensors

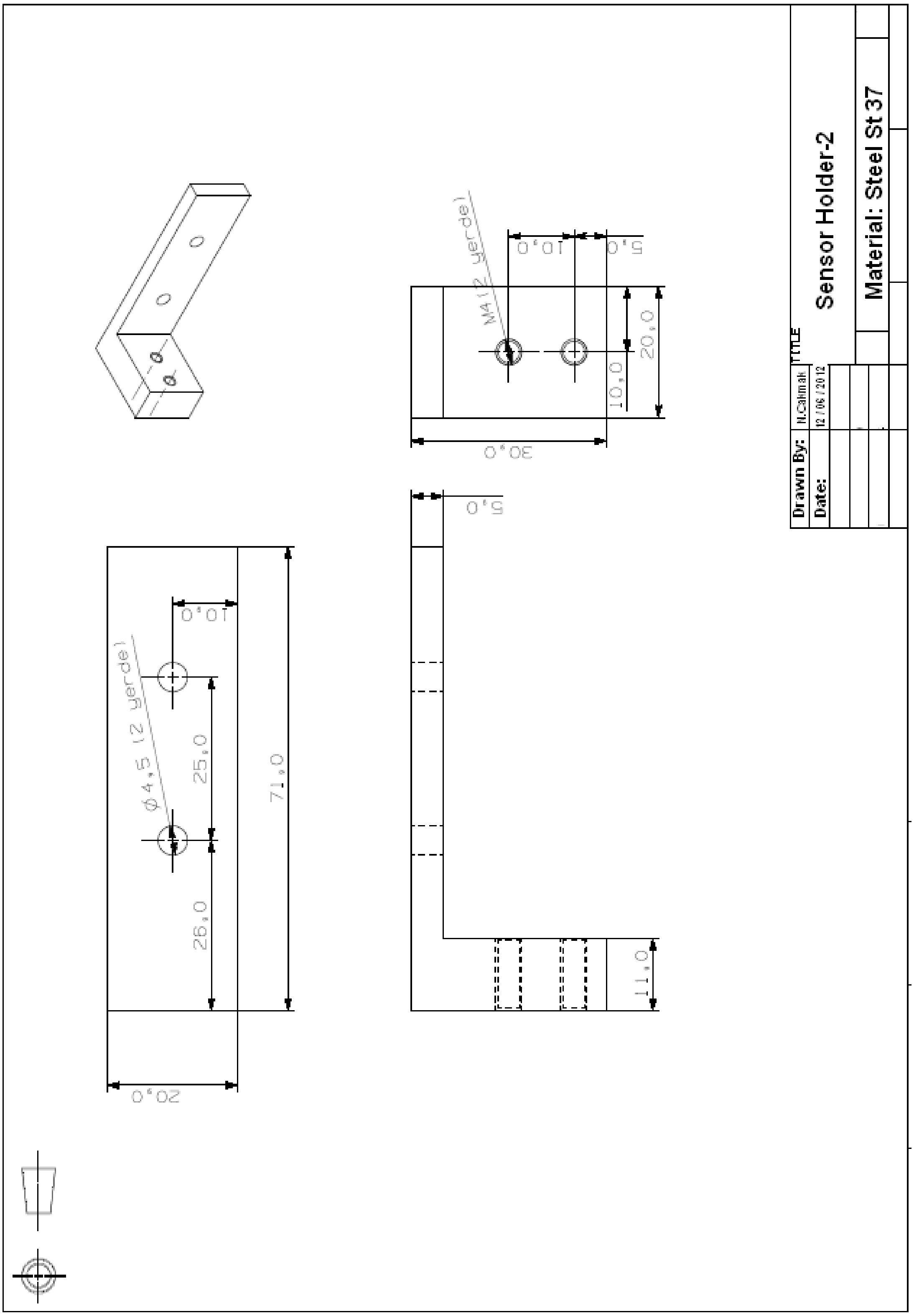

Base
Material: Steel St 37
TITLE
Drawn By: H.Cakmak
Date: 12 / 06 / 2012
65,0
M4 (2 adet)
10,0
10,0
90,0
50,0
Ø40,0
120,0
16,0
16,0
48,0
23,0
58,0
Ø12,0
24,0
50,0
85,0
85,0
50,0
20,0
20,0
30,0
30,0
30,0
185,0
150,0


Drawn By: N.Cakmak
Date: 12/06/2012
TITLE
Gear Wheel
Material: Steel St 37
Ø150,0
Ø5,514 yerde!
Ø55,0
4,5°
4,0
5,0
80,0
A
A
SECTION A - A

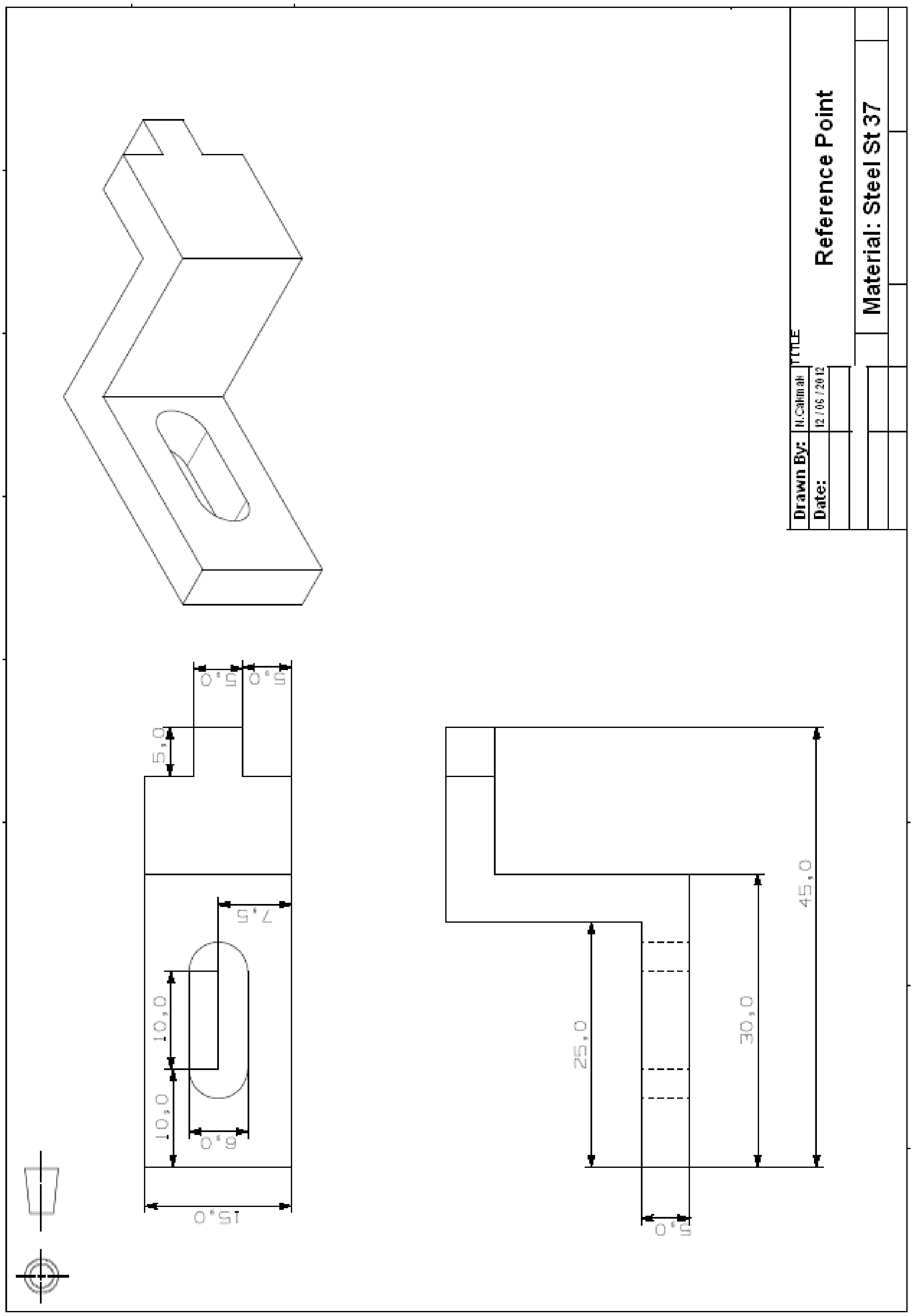

Flange
Material: Teflon
TITLE
Drawn By:
Date:
12 / 06 / 2012
Ø55,0
Ø90,0
Ø80,0
Ø90,0
17,5
5,0
5,0
10,0

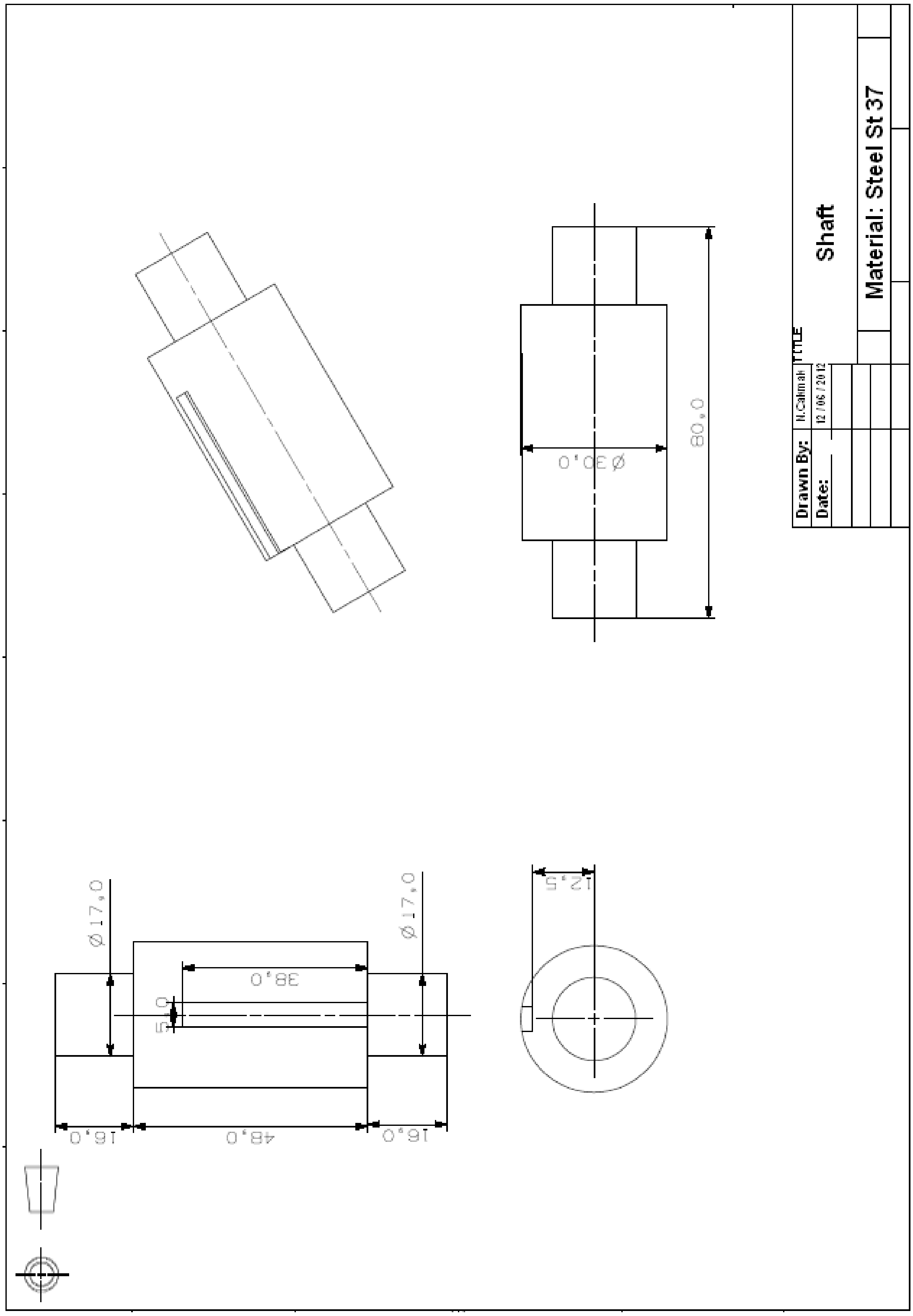


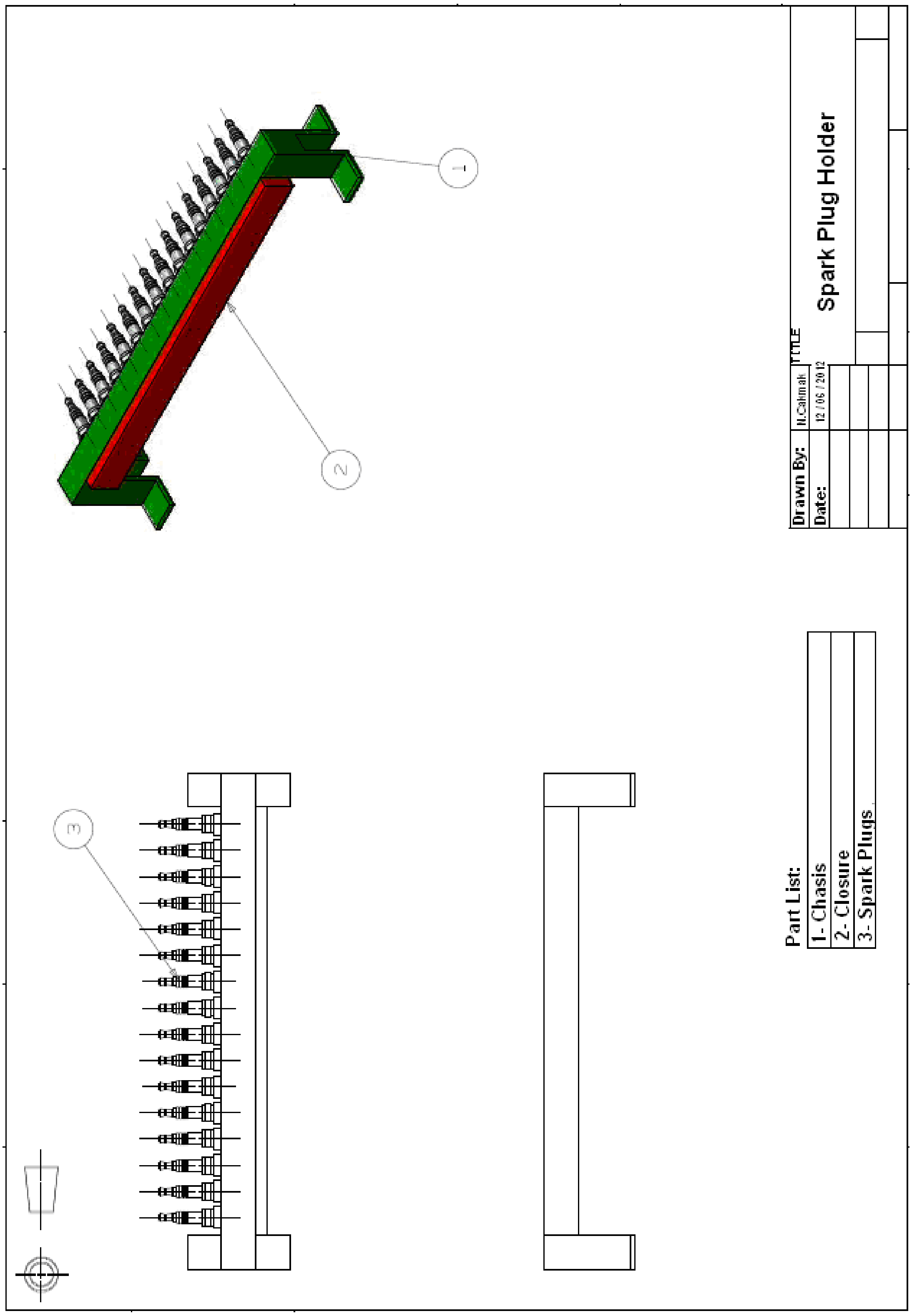
Drawn By:
N.Cakmak
Date:
12 / 06 / 2012
TITLE
Sensor Holder-1
Material: Steel St 37
20,0
20,0
M4 (2 yerde)
25,0
20,0
Ø20,0x2
50,0
M4,0 d. boyu 10mm
20,0
25,0
65,0
5,0
10,0

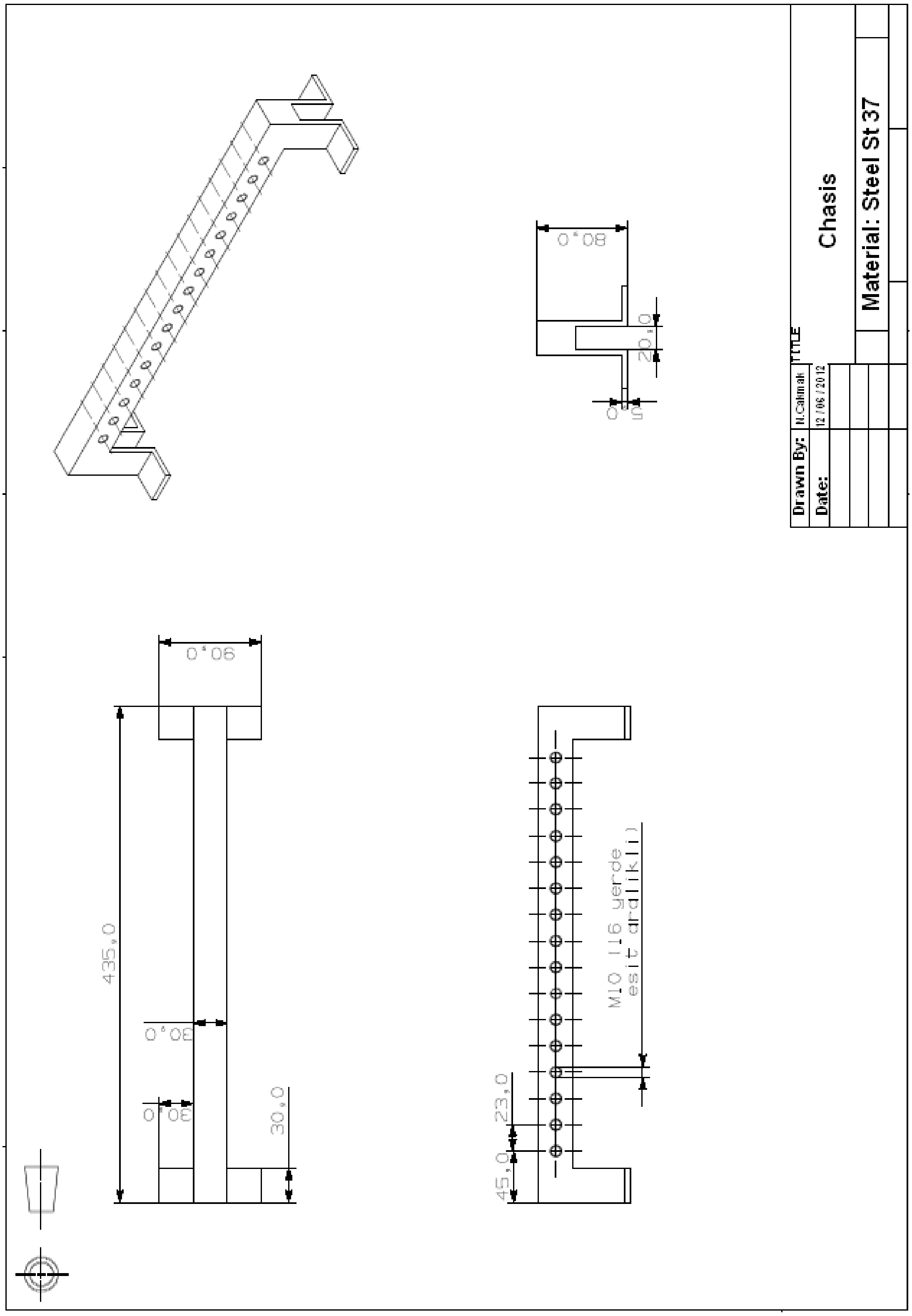


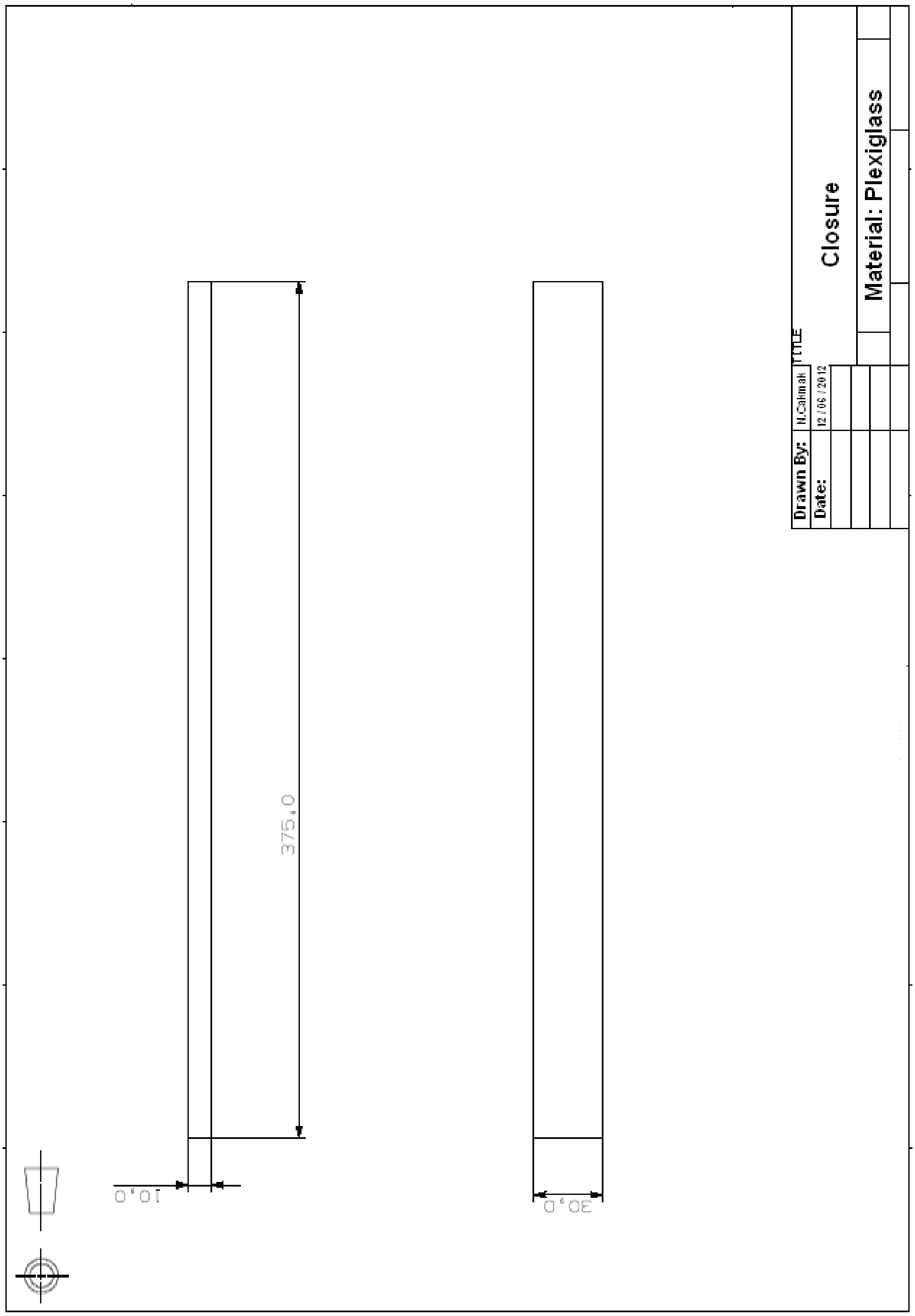
TITLE
Sensor Holder-2
Material: Steel St 37
Drawn By: N.Cakmak
Date: 12 / 06 / 2012
M4 (2 yerde)
10,0
5,0
20,0
10,0
30,0
5,0
11,0
Φ4,5 (2 yerde)
10,0
25,0
26,0
71,0
20,0

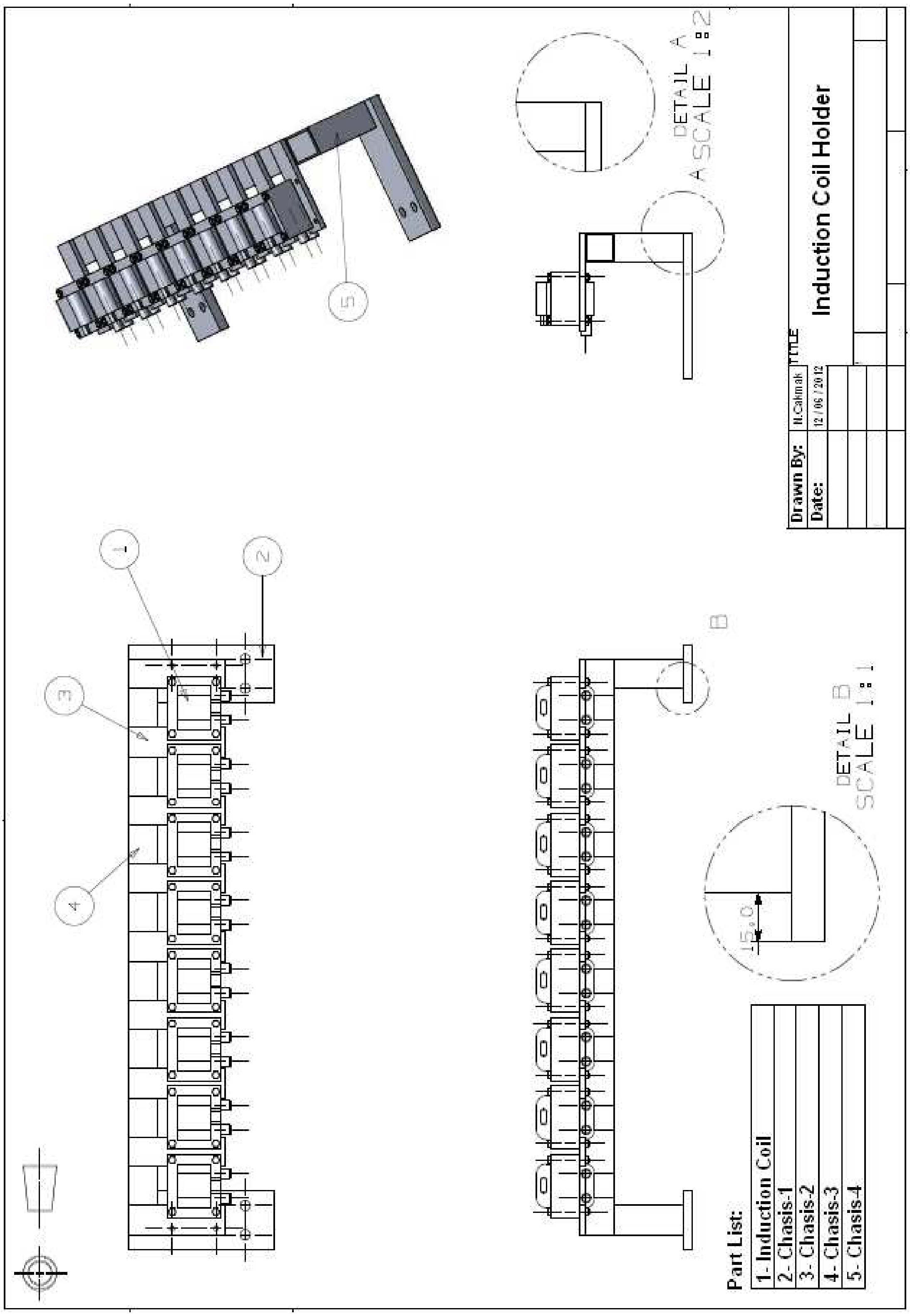

Reference Point
Material: Steel St 37
Drawn By:
N.Cakmak
Date:
12 / 06 / 2012
TITLE
5,0
5,0
5,0
7,5
10,0
10,0
8,0
15,0
45,0
30,0
25,0
5,0


Shaft
Material: Steel St 37
TITLE
Drawn By: N.Cakmak
Date: 12 / 06 / 2012
80,0
Ø30,0
Ø17,0
Ø17,0
38,0
5,0
16,0
48,0
16,0
12,5

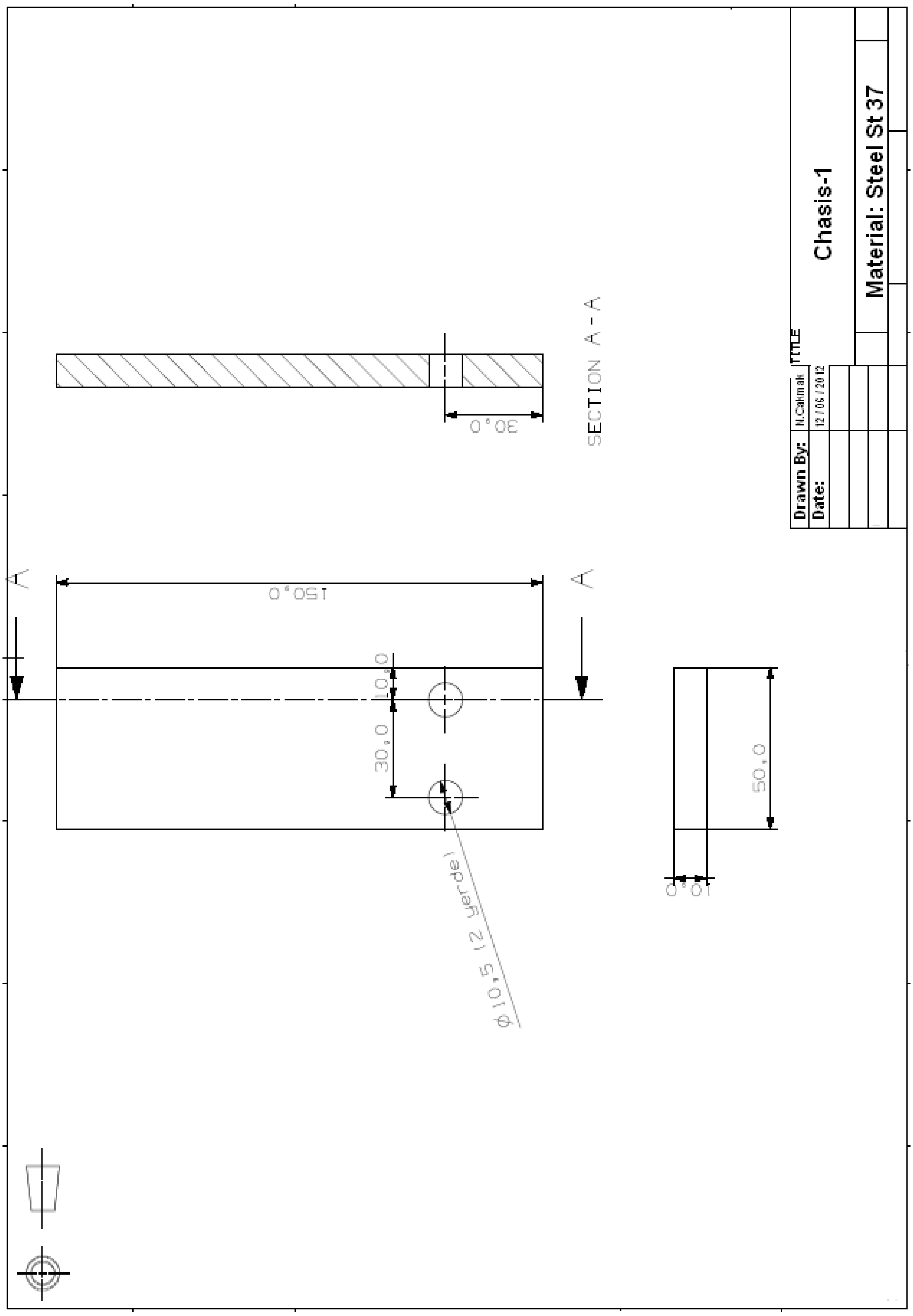

Spark Plug Holder
TITLE
Drawn By: H.Cahmak
Date: 12 / 06 / 2012
Part List:
1- Chasis
2- Closure
3- Spark Plugs
1
2
3

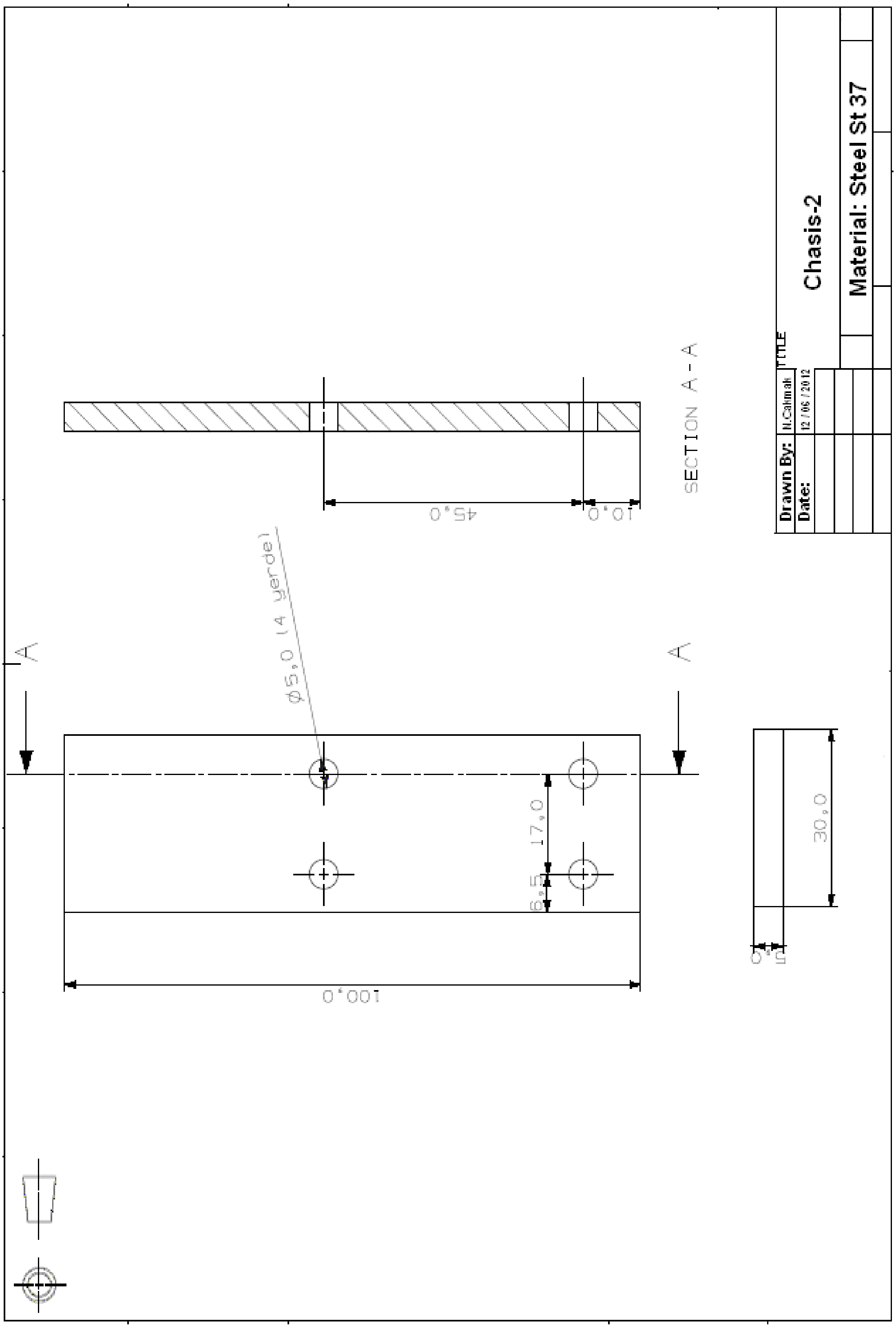

TITLE
Chasis
Material: Steel St 37
Drawn By: N.Cakmak
Date: 12 / 06 / 2012
80,0
20,0
5,0
90,0
435,0
30,0
30,0
30,0
23,0
45,0
M10 116 yerde
esit aralikli

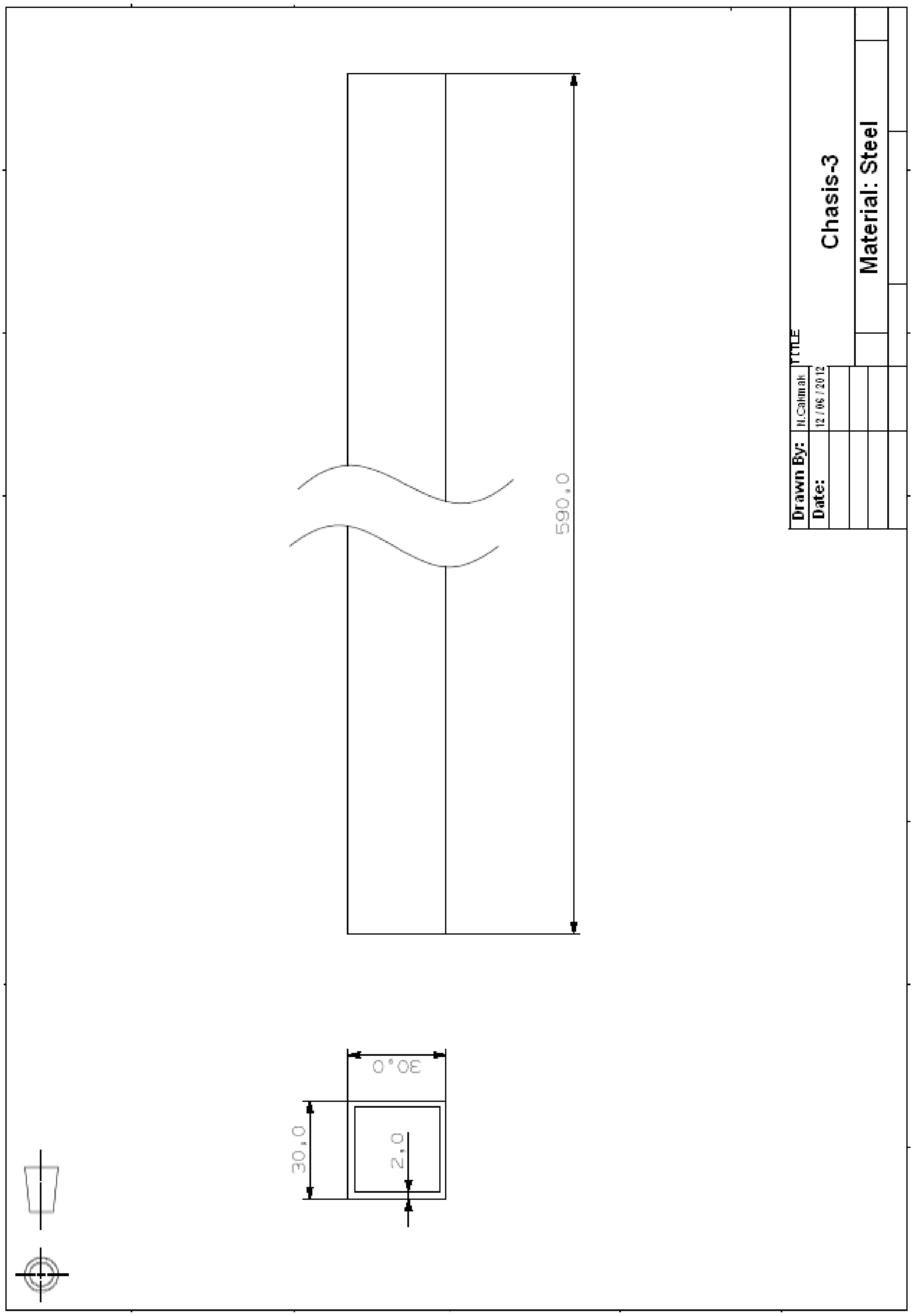

Closure
Material: Plexiglass
TITLE
Drawn By: N.Cakmak
Date: 12 / 06 / 2012
375,0
10,0
30,0

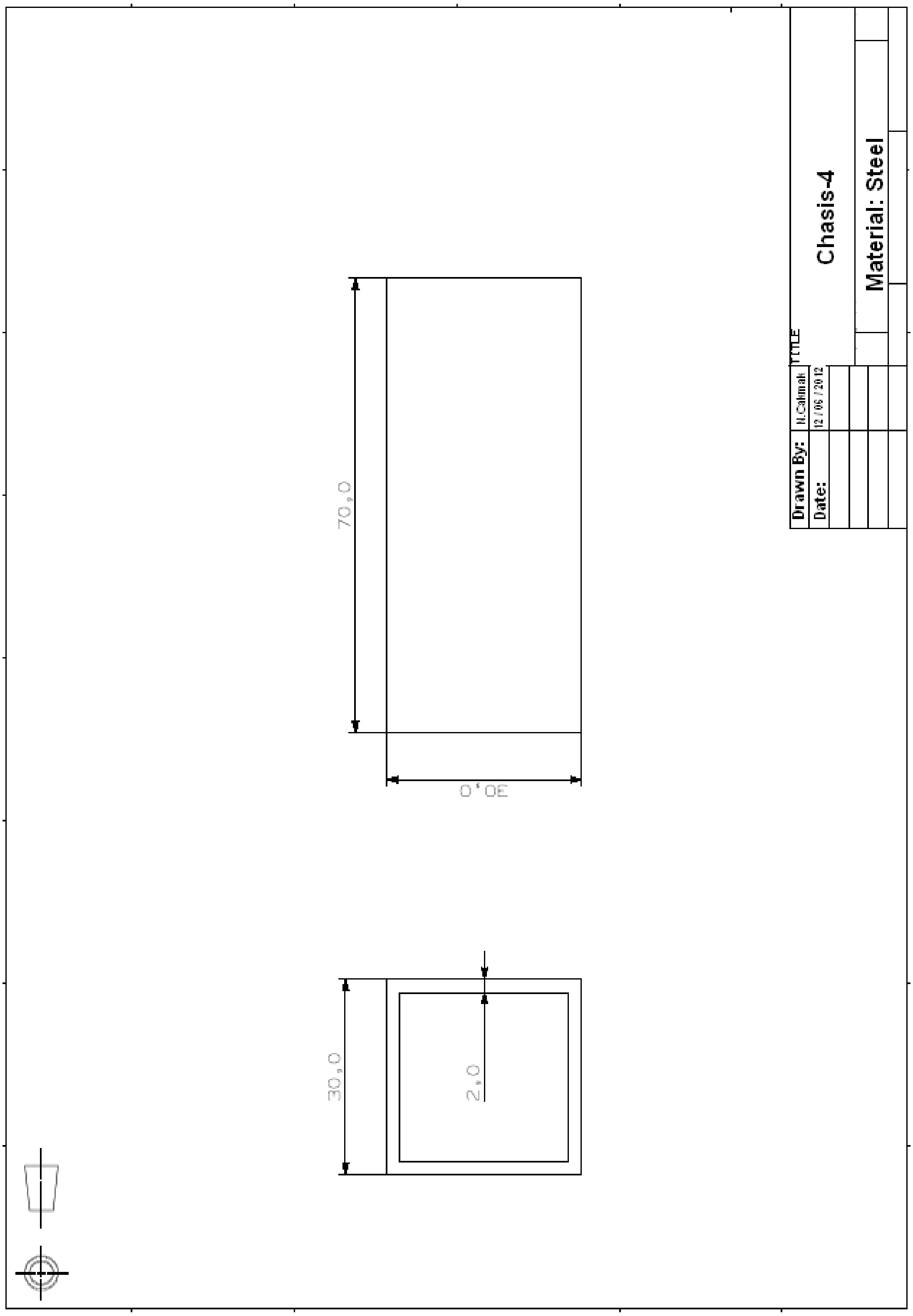


Induction Coil Holder
Drawn By: N.Cakmak
Date: 12 / 06 / 2012
TITLE
Part List:
1- Induction Coil
2- Chasis-1
3- Chasis-2
4- Chasis-3
5- Chasis-4
DETAIL A
SCALE 1:2
A
DETAIL B
SCALE 1:1
B
15.0
1
2
3
4
5


Drawn By:
N.Cahmah
Date:
12 / 06 / 2012
TITLE
Chasis-1
Material: Steel St 37
SECTION A - A
30,0
150,0
10,0
30,0
50,0
10,0
ϕ10,5 (2 yerde)
A
A


Chasis-2
Material: Steel St 37
TITLE
Drawn By: N.Cakmak
Date: 12 / 06 / 2012
SECTION A-A
45,0
10,0
Ø5,0 (4 yerde)
A
A
17,0
6,5
100,0
30,0
5,0


590,0
30,0
30,0
2,0
Drawn By: N.Cakmak
Date: 12 / 06 / 2012
TITLE
Chasis-3
Material: Steel


70,0
30,0
30,0
2,0
Drawn By:
N.Cakmak
Date:
12 / 06 / 2012
TITLE
Chasis-4
Material: Steel