# FLEXIBLE COMPUTER BASED CONTROL OF IGNITION AND INJECTION UNITS OF A GASOLINE ENGINE WITH SKIP CYCLE MECHANISM

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***Abstract:*** *In this study, timing of injection and ignition also duration of injection and dwell time of a single cylinder research engine were controlled with a computer based electronic unit. To determine the valid timing and duration, the compression top dead center of engine crankshaft was become equivalent to the trigger signal of incremental encoder and the control system was able to design for adapting the conversions at load and engine speed. By using the control system, the real time tests were carried out in a gasoline engine with skip cycle mechanism depending upon permitted certain parameters constant and others changed.*

**Keywords**: SKIP CYCLE MECHANISM, COMPUTER BASED CONTROL, IGNITION, INJECTION

## *1. Introduction*

Skip cycle strategy is one of the methods to reduce the fuel consumption and pumping losses at part load conditions in spark ignition engines. The aim of the method is to cut off the fuel and stop the air supply into the combustion chamber (S : Skip cycle mode) in some sequential four stroke cycles by controlling the intake and exhaust poppet valves also increase the fuel – air charge in normal cycles ( N : Normal cycle mode) [1]

Skip cycle system gives the opportunity to control the effective stroke volume of the engine and reduces the negative effects of conventional throttle valve control at part loads. This effect is similar to that of variable displacement method which disables some of the cylinders. But there is no possibility to practice the variable displacement method in a single cylinder engine. Besides, skip cycle system has the potential to control individual cylinders working conditions. This has an additional advantage to change engine operation from one mode to another during load control by smaller steps, thus smoothing this mode transition, which leads to prevent engine roughness caused by sudden fluctuations in engine moment [2]

Engine research and development always has been very expensive, time – consuming and complex work. Experimental studies on this field include lots of different constructions and measurements on an engine. The most important and necessary part of this work is the research engine. Because of its reducing testing costs, minimizing development times and having great flexibility, generally single cylinder engines are used as research engine.

There are many various studies focused on controlling of ignition and injection. In the study of Kutlar et al., the control of a single cylinder with four stroke gasoline engine was carried out by a standard inexpensive PC. According to the resolution of used encoder, the advances and time values also throttle position were adjusted arbitrarily to obtain an engine optimization. [3]

Robert T P et al controlled a two cylinder and four stroke motorcycle engine by a microprocessor based unit. The throttle valve position with respect to crankshaft angle, temperature of inlet air, injection advance and dwell angle could be altered on account of serial communicated interface programme. [4]

In a recent study; injection duration, injection angle, ignition angle and dwell angle were controlled considering the engine map, engine speed and load conditions of a four stroke motorcycle engine [5]

In this study, the ignition and injection units of a a single cylinder, four stroke gasoline engine were kept under control by a microcontroller, which operated the coil and injector drivers, through a flexible computer interface.

## *2. The Importance of ignition and injection on cycle skipping and engine performance*

Alongside of poppet valves control, cut off injection from over injector also ignition from spark plug have significant impacts on a full skipped cycle. If the injection proceeds during the skipped cycle, the fuel cumulates in front of intake port. While the engine runs on a normal cycle, the fuel is smeared to manifold walls and poppet valve also the directed into the combustion chamber. This causes a fuel consumption increase in skipped cycle due to the lack of air flow between manifold and cylinder. Cutting off ignition application is a precaution against the possibility of fresh charge leakage through the poppet valves in skipped cycle.

Injection duration of fuel also advances of injection and ignition are impressive on engine performance. To optimize the engine, all of these parameters have to be controlled. In a conventional spark ignition engine, the fuel and air mixed together in the intake system, inducted through the intake valve into the cylinder, where mixing with residual gases take place, and then compressed. Under normal operating conditions, combustion is initiated towards the end of the compression stroke at the spark plug by an electrical discharge. Combustion event must be properly located relative to the TDC to obtain maximum power or torque. Ignition advance is particularly effective on knock possibility and maximum engine moment.

In Figure1, graphs about the impacts of ignition advances were shown. Case (a) represents the optimum ignition timing. The area under the cylinder pressure – advance angle diagram shows the maximum value. In other words, cycle efficiency is maximum.

If the start of combustion process is progressively advanced before TDC, the compression stroke work transfer, which is from the piston to the cylinder gases, increases (Case b). Due to the bigger advance angle the temperature and pressure reach a level with the knock possibility and piston is exposed to sudden and high forces.

If the end of the combustion process is progressively delayed by retarding the spark timing, the peak cylinder pressure occurs later in the expansion stroke and is reduced in magnitude (Case c). These changes reduce the expansion stroke work transfer from the cylinder gases to the piston. The optimum timing which gives maximum brake torque, called maximum brake torque or MBT timing, occurs when magnitude of these two opposing trends just offset each other. Timing which is advanced or retarded from the optimum, gives lower torque.

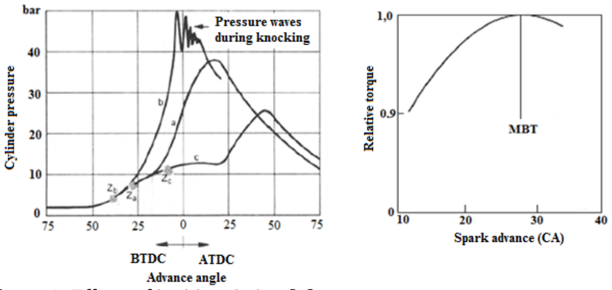


***Figure 1**. Effects of ignition timing [6]*

The other parameter, has to be controlled, is opened position duration of primer circuit called as dwell time. Dwell is the length of time the ignition coil takes to fully charge ready to make a spark. The dwell angle was the amount of rotation of the crankshaft that corresponded to the points being closed. This affects the charge time of the coil and hence spark length. Dwell was important then, because at higher rpm's the dwell time (points are closed to charge the coil) was not enough to fully charge the induction coil. That meant less voltage spark at higher rpm's.

The current in the coil primary circuit doesn't rise from zero to its maximum value instantaneously when the contact breaker closes, but requires a short time interval to overcome the inductive effect of the coil. The contacts must therefore be closed long enough for the current to build up. [7]

As engine speed increases, the dwell angle remains virtually constant but the revolution of the cam becomes more rapid and the time during which the contacts are closed is reduced. The primary current may not have time to build up to its maximum value, resulting in reduced magnetic field intensity and reduced secondary voltage. [7]

To avoid the decreasing of secondary circuit voltage, the dwell time must be fixed to a value (i.e. 4 ms) and independent of engine speed by using interface programme. All in all, when the engine speeds up, ignition advance and dwell angle should be increased.

The injection control unit is responsible for the determining of injection advance and injection duration. The fuel can be injected fully before the intake poppet valve opens or partially while the valve has already opened. Due to the homogeneous mixture of fuel and air in intake manifold of the gasoline engines, injection pressure and injection cone are not substantial for this type injection systems. The sensitive adjustment of injection timing does not play a great role on engine performance and combustion phenomenon. Fuel injection duration determines the fuel quantity injected per cycle by the opened position time of injector which triggered by its solenoid. The main factors to detect the injected fuel quantity are load percentage, engine speed and flow characteristics of used injector.

The preferred case for injection timing includes a finished injection process before the intake poppet valve opens (16 CA before TDC). The valve should be opened shortly after the end of injection. If the fuel is injected before the valve opens, the fuel consumption will deteriorate with the smearing of fuel into valve and manifold walls. There will be a possibility about the vapouring of fuel before penetrating into combustion chamber with regards to high temperatures on cylinder head. Besides, taking into combustion chamber of injected fuel with short time triggers is significant notably.

## *3. Selection of Research engine and constructive modifications*

To carry out the experimental studies, an engine was selected to accommodate our bench marks represented below:

- It must be a single cylinder spark ignition (SI) engine.
- It must be a water-cooled engine for reliable and accurate engine temperature control.
- Auxiliary equipment (alternator, cooling pump, oil pump, etc.) should be driven separately from the engine not to effect the indicated properties of the engine.
- Fuel injection system is necessary to regulate air-fuel mixture correctly.
- Physical properties of the engine such as bore-stroke, compression ratio, combustion chamber (CC) geometry should be similar to the present passenger-car engines.
- Constructive changes could be easily made on the engine.
- Enough space must be on the engine for mounting of control and measurement devices.

Considering the above constraints, a single cylinder compression ignition (CI) engine was chosen (Table 1) from the domestic market. It was decided to convert to a spark ignition (SI) engine subject to necessary physical modifications. We agreed that Lombardini LD450 engine was a valid option because of its specifications such as water cooled, direct injected and enough stroke volume.

***Table 1.** Lombardini 3LD 450 engine specifications*

| | |
|---|---|
| Number of cylinders | 1 |
| Stroke volume | 454 $cm^3$ |
| Bore×Stroke | 85×80 mm |
| Compression ratio | 17,5:1 |
| Intake valve diameter | 32 mm |
| Exhaust valve diameter | 27 mm |
| Intake valve lift | 10 mm |
| Exhaust valve lift | 10 mm |
| Intake valve opening | $16^0$ CA BTDC |
| Intake valve closing | $40^0$ CA ATDC |
| Exhaust valve opening | $40^0$ CA BBDC |
| Exhaust valve closing | $16^0$ CA ATDC |
| Valve overlap duration | $32^0$ CA Symmetric |
| Pushrod length | 145 mm |
| Valve clearance in cold engine | 0,2 mm (Intake and exhaust) |

Changing compression ratio and combustion chamber geometry to meet SI engine requirements were done almost by the modifications on the piston. Original piston cavity wasn't at the cylinder center (was eccentric) but injector was on the center. To get a new compression ratio, the eccentric piston cavity was enlarged to a diameter of 56 mm so that it was brought to the center also depth of the cavity was increased from 14 mm to 19mm. In addition, piston head was chamfered to avoid the damage on cylinder wall (Figure 2)

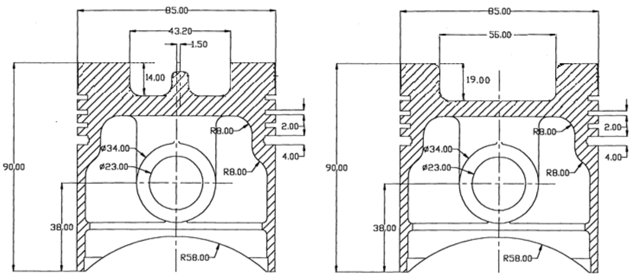


***Figure 2**. Original and revised piston*

The combustion chamber geometry with this piston cavity is not a common design type. It is possible to use other piston variations except this geometry. But, engine performance can't be changed significantly considering the other academic studies.[8] With these modifications, new compression ratio was calculated as 9,5:1.

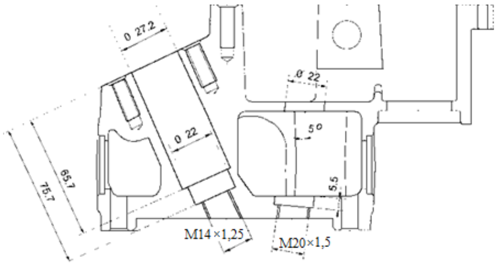


***Figure 3.*** *The holes on cylinder head (Left side hole for spark plug and right side hole for pressure transducer*

The hole belonged to fuel injector for the original head was threaded suitably to mount a standard M14 short threaded spark plug. This hole is very close to the center. (Figure 3) An additional hole was dug on the cylinder head that will be used to mount a pressure transducer (Figure 3) Our main aim in experimental studies doesn't interest with leaning of the mixture (fuel stratified strategies) Besides, recent studies have proved the necessity of centric location of spark plug in lean mixture engines with swirl charge motion. So, a centric spark plug mounting on the cylinder head won't make a negative effect. On the other hand, swirl air motion in the cylinder trails the injected fuel droplets into the intake manifold to outside of the wall. Motion of the charge becomes stronger from cylinder center to cylinder radial direction. Because of this reason, the thought of eccentric mounting of spark plug was practiced. A study in the literature refers to an eccentric spark plug location due to stronger charge motion [9]

One of the most challenging modifications of the research engine was the intake manifold design. Size and location of throttle valve, also location and injection angle of fuel injector are the important issues that must be decided carefully. Size of throttle valve directly effects the load control sensitiveness of the engine at part load conditions. But the load control mechanism which skips the cycle is related with poppet valves, not throttle valve in this study. Injector location is important for mixture formation process and injection angle must be in correct position to avoid fuel film development on the intake manifold and intake valve.

## 4. Configuration of control unit

### 4.1. Description of system components

The control unit is divided into two groups as of hardware and software. The hardware consists of spark plug, ignition module, ignition coil, coil driver, injector driver, injector, incremental encoder and a single cylinder research engine. The software includes a complier programme for microcontroller and a programme written in C language for the computer interface. The working principle of control unit can be seen in Figure 4.

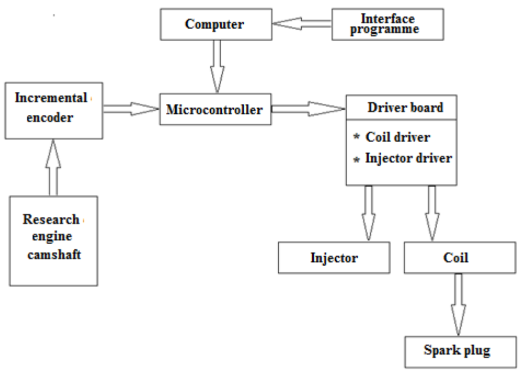


***Figure 4***. *Flow chart of control unit*

The open – sourced Arduino microcontroller operates the driver board via committing the signals come from incremental encoder by means of written programme (Arduino software IDE)on itself. The interface programme is serial communicated with the computer also all the ignition and injection inputs as for ignition timing, dwell duration, injection timing and injection duration can be real – time controlled.

***Table 2.*** *Arduino ATMega 2560 microcontroller specifications*

| | |
|---|---|
| Operating voltage | 5V |
| Input voltage | 7-12V (limits 6-20 V) |
| Digital input/output pin | 54 items |
| Analog input pin | 16 items |
| Counter hardware | 8 bit |
| Timer hardware | 8 bit |
| Clock frequency | 16 MHz |
| USB input | Serial communication |

The controlled parameters via interface are ignition timing (CA), injection timing (CA), injection duration (ms), dwell duration (ms) and cycle modes (N,NS,NSS). In addition, engine speed can be read on the programme. (Figure 5)

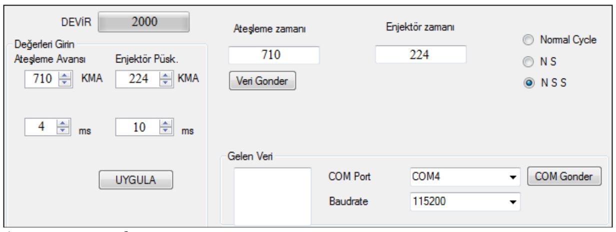


***Figure 5***. *Interface programme*

Cut off injection from injector and ignition from spark plug according to desired flexible crankshaft angle could be controlled by the programmed electronic board. The encoder used for the control unit, works as a pulse counter. It was coupled to a shaft which rotated on the same angular velocity with the engine camshaft. So there was no possibility to confuse the start of intake TDC and end of compression TDC on that shaft.

***Table 3.*** *Specifications of incremental encoder (Heidenhain ROD 426)*

| | |
|---|---|
| Number of signals per a round | 7200 (TTL×2) |
| Power supply | 5V, 120 mA |
| Shaft diameter | 6 mm |
| Electrical connection | Cable |
| Pin connections | 12 pins (with M23 connector) |
| Shaft connection | K17 Diaphragm coupling |

The microcontroller picks up the end of compression TDC and camshaft angle signals, then commands for fuel injected in front of intake port also after for ignition from spark plug into the combustion chamber. The trigger signal (initiator signal) doesn't relate structurally with the end of compression TDC. Trigger is only a random and different voltage level with respect to other signals occurred by the angular motion of incremental encoder.

### 4.2. Working principle of system

The incremental encoder is an angular position determiner that converts the analog signals to digital signals. It sends these signals to the microcontroller and helps to determine the position of engine.

The basic configuration is to correspond the end of compression TDC of skipped cycle to the trigger signal of encoder. The microcontroller detects the difference angle between these two signals. It is called "Trigger Signal Eccentric". The control system was designed to respond all engine speed and load conditions also adapted skip cycle strategies as NS and NSS. The experiments were carried out by the method of fixing some parameters constant and the others changing.

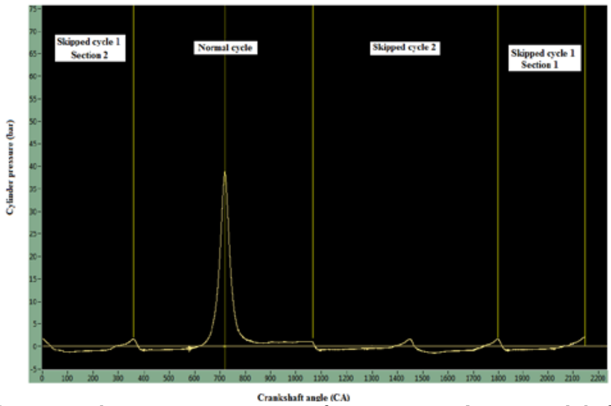


***Figure 6.** Schematic representation of NSS strategy due to crankshaft angle*

The cycle regulation of NSS strategy due to crankshaft angle is represented in Figure 6.

- 0 – 360 crankshaft angle gap : Skipped cycle 1 – Section 2
- 360 – 1080 crankshaft angle gap : Normal cycle
- 1080 – 1800 crankshaft angle gap : Skipped cycle 2
- 1800 – 2160 crankshaft angle gap : Skipped cycle 1 – Section 1

The crankshaft rotates 6 and camshaft 3 times in whole NSS strategy. In the first rotation of camshaft (0-720 crankshaft angle) the exhaust poppet valve is closed and intake is opened. In the second rotation, the exhaust is opened and intake is closed. In the third rotation, both of the valves are closed. The incremental encoder provides a measurement resolution of 0,05 camshaft angle with respect to 7200 pulse production in one rotation.

To position the trigger signal of encoder correctly, first it is necessary to define the TDC of engine. To achieve that detection, cylinder head is pulled out firstly. Then piston rings are removed to reduce the friction and to turn the flywheel easily. Two dial-indicators, one in the top of the piston in centered position, the other on the flywheel surface are mounted to define the position of piston and flywheel. A scale with 0,5 mm intermittent is placed horizontally on the cylinder wall. So it becomes possible to observe crank angle in 0,2° sensitiveness by this scale. Then flywheel is turned in two directions (to the left and to the right) and for each direction one TDC point is worked on the flywheel by the help of dial-indicators.

So there become two marked TDC points on the flywheel. The real TDC point is found by taking middle of these two marked points (Figure7). The reason of turning the flywheel in two directions is to eliminate the mislead effects of clearances in the crank-rod-piston mechanism. Only piston and crankshaft synchronization is determined up to this point.

The marked TDC on the flywheel must be equivalent to the end of compression TDC of skipped cycle and also trigger signal of incremental encoder. After the TDC marking process on the flywheel, the skip cycle mechanism is adapted to the engine. The mechanism must be mounted in a position which fixes the end of compression TDC of skipped cycle to the marked point on the flywheel. This position is balanced to the middle point of skipped cycle. It can be observed by the motion of tappets, pushrods or rocker arm.

Last synchronization is balancing the engine and skip cycle system to the electronic control unit. The trigger signal was marked on the encoder by the manufacturer before. While the skip cycle mechanism is fixed to the end of compression TDC, the trigger point on the encoder must be positioned on the top manually as possible. Then, encoder is mounted and engine is rotated slowly. The interface programme determines the angle difference between the trigger signal and assumed TDC of encoder shaft, also set it to zero. This position is the starting point of engine, running skip cycle mechanism and control unit. Control unit can only collects the correct signals and commands ignition and injection components in order of injection of fuel into intake manifold and ignition of spark into the combustion chamber in first camshaft cycle and they mustn't be decomposed to the other cycle.

After finishing the synchronization, we needn't to determine TDC again unless the encoder is demounted or exposed to a relative slipping.

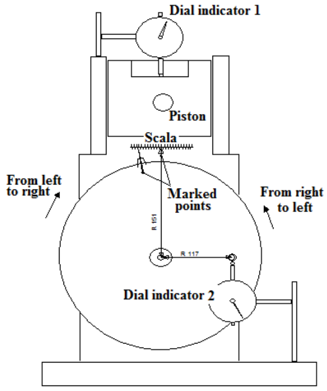


***Figure 7.** Determination of top dead center of the research engine*

Assume that engine speed is 2000 rpm, injection duration is 10 ms and dwell duration is 4 ms fixed for NSS strategy. Incremental encoder counts 7200 pulse per a round or 20 pulse for a camshaft angle. This means, ignition and injection advances also injection duration can be regulated by 1/20 = 0,05 camshaft angle = 0,10 crankshaft angle resolution. The microcontroller must be commanded ignition and injection in the same camshaft cycle. According to this reality, a cycle order has been performed as seen in Figure 6.

The intake poppet valve opens 16 crankshaft angle before TDC. If the injection duration is fixed to 10 ms, the period of injection is in a 120 crankshaft angle period for the related engine speed. For this reason, injection starts at 136 crankshaft angle before start of intake TDC and continues until the intake valve opens. As can be followed in Figure 6, 224. crankshaft angle (or 112. camshaft angle) is the start point of fuel injection.

The spark plug is firing 10 crankshaft angle before the end of compression TDC. It represents the ignition advance angle. Ultimately, the crankshaft angle difference between start of ignition and injection corresponded to 486 degrees, in other words 243 camshaft angle.

The duration of opened position of primer coil circuit was fixed to 4 ms. At the related engine speed, this corresponded to 48 crankshaft angle. Dwell angle could be defined as 662. and 710. crankshaft angle.

If the trigger signal is corresponded to the end of compression TDC of skipped cycle;

- Start of injection: (224/2)x20=2240 signals after trigger signal
- Ignition timing: (710/2)x20=7100 signals after trigger signal
- Start of dwell: (662/2)x20=6620 signals after trigger signal
- Injection duration: ((344-224)/2)x20=1200 signals

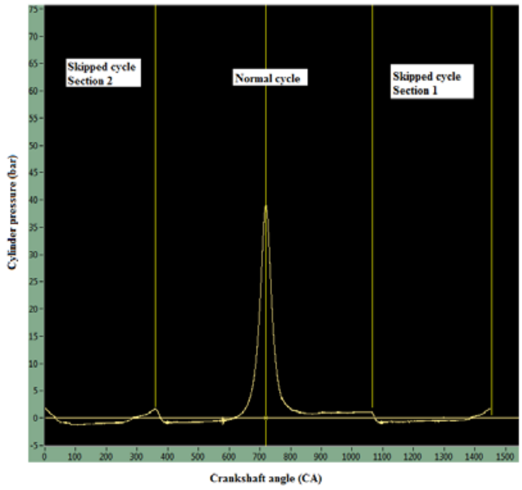


***Figure 8.*** *Schematic representation of NS strategy due to crankshaft angle*

The cycle regulation of NS strategy due to crankshaft angle is represented in Figure 8.

- 0 – 360 crankshaft gap: Skipped cycle – Section 2
- 360 – 1080 crankshaft gap: Normal cycle
- 1080 – 1440 crankshaft gap: Skipped cycle – Section 1

The crankshaft rotates 4 and camshaft 2 times in whole NS strategy. In the first rotation of camshaft (0-720 crankshaft angle), the exhaust poppet valve is closed and intake is opened. In the second rotation, exhaust is opened and intake is closed.

### *4.3. Basic Electronic components of Control Unit*

The details of basic components of ignition and injection control unit are described below. These are; interrupt pin, counter pin, digital input/output pins; power supply, injector driver and coil driver. All of them communicate each other directly or indirectly.(Figure 10)

Interrupt pin : If an interrupt signal occurs, while microcontroller is running another process, it stops the running process and starts interrupt function. Arduino Mega has 3 internal interrupt function. When research engine runs at 6000 rev/min and collects 7200 pulses per cycle, its frequency reaches 360 kHz. So, Atmega 2560 16 MHz processor is enough for all.

Counter pin : Arduino Mega has 5 timer/counter. First timer is for microcontroller's time processing. Each cycle has 7200 pulses and we need 21600 pulses for NSS cycle to count. Timer 5 is a 16 bit counter and it is suitable to count NSS cycle.

Digital input/output pins : Injector and ignition signal outs are defined as digital outs of 11. and 12. pins.

Power supply : A battery is used for power supply unit to support the vehicle standards. No alternator ise used. Because the alternator power consumption obtained from the crank shaft effects the measurements. The battery is charged by power supply unit from outside along the test time. Boards of driver and microcontroller's ground terminal were split up because spark plug's high voltage can damage microcontroller and encoder. Octocoupler is used for this reason. Encoder needs 120mA at 5V and this is acceptable for Arduino 5V output. A 9V 1A power unit is used for Arduino power supplement.

Injector driver : Injector driver switches injector very fast. Lots of injectors need 700mA at 13V. IRFZ44n mosfet is used for switching injector.

Coil driver : For coil driver GM DR100 ignition module is used. DR100 module is chosen because of containing high voltage switching transistor, heat sink, a current limiter. Also supports primer coil resistance 2.5 ohm coils and plug easily.

## *5. Choosing and controlling ignition and injection systems components*

Spark plug, ignition coil, ignition module, injector and injection pumps are chosen for skip cycle mechanism tests. In Figure 9, ignition and injection components can be seen. Each component is managed by electronic control units for controlling ignition and injection system.


***Figure 9.*** *Components of chosen ignition (a) and injection (b) systems*

Microcontroller sends a signal to ignition module according to camshaft position and control program on PC. Normally, this signal is sent by hall sensor in distributor, but in this system, this signal is generated by microcontroller. The signal switches the ignition module and ignition module controls the primary circuit of the ignition coil. Finally, switching of the primary circuit, high voltage happens in secondary circuit then spark plug.

***Table 4.*** *Specifications of chosen ignition coil*

| | |
|---|---|
| Primary resistance ($m\Omega$) | 712 |
| Secondary resistance ($k\Omega$) | 10,33 |
| Primary inductance | 3,23 mili Henry |
| Secondary inductance | 54,4 Henry |

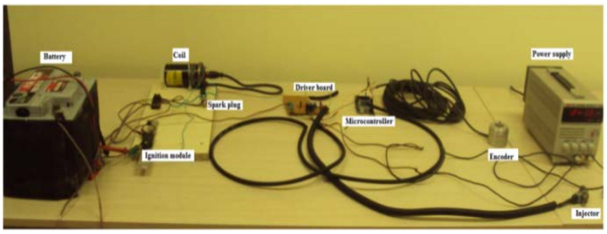


***Figure 10.*** *Electronic control unit and connections with motor equipment*

When engine speed increases, dwell time decreases and ignition advance increases. When dwell time decreases, ignition coil voltage decreases, for this reason dwell time is set constant (i.e. 4 ms), and it isn't related with engine speeds. In tests, AC Delco R4602 spark plug is used. (Table 5)

***Table 5.*** *Specifications of chosen spark plug*

| | |
|---|---|
| Shell thread | 14 mm |
| Seat type | Düz |
| Thread reach | 17,5 mm=(11/16)" |
| Hex | (5/8)" |
| Heat range | 4 |
| Resistor | Var |
| Gap | 0,8 mm |
| Electrode type | J1 tipi |
| Ground electrode | Nikel (Ni) |
| Center electrode | Bakır (Cu) |
| Low voltage resistance (LVR) | 3 Ω |
| High voltage resistance (HVR) | 9 Ω |

In the experimental study, injection units of four cylinder Tofaş Tempra 1.6i engine and six cylinder Bmw 3.0i were used. These components were chosen because of approximate stroke volume ($400cm^3$) with the test engine ($454cm^3$). Also injector flow rate characteristic was defined by experiments in this test bench. These components can be seen in Figure 11.

***Figure 11.*** *Flow rate test set up*

Gasoline with density 0,745 $g/cm^3$ was used as injection liquid. Injection rail pressure was set constant (i.e. 3 bar). Three of four injector on rail was closed and only experimental injector was controlled by microcontroller. Different injection durations were set at a constant injection cumulative and total injection quantity was collected in a measurement beaker and weighted on a sensitive device.

***Table 6.*** *Flow characteristics of chosen injector*

| Injection duration [ms] | Injection amount [g] (Cumulative of 1000 injection) | | Injection flow rate [g/s] | |
|---|---|---|---|---|
| Tempra&Bmw | Tempra | Bmw | Tempra | Bmw |
| 2 | 9,69 | 9,69 | 4,84 | 4,84 |
| 3 | 13,41 | 13,04 | 4,47 | 4,35 |
| 4 | 16,39 | 16,76 | 4,10 | 4,19 |
| 5 | 18,63 | 19,37 | 3,73 | 3,87 |
| 6 | 20,86 | 22,35 | 3,48 | 3,73 |
| 7 | 23,84 | 25,33 | 3,41 | 3,62 |
| 10 | 32,04 | 33,90 | 3,20 | 3,39 |
| 12 | 36,51 | 40,23 | 3,04 | 3,35 |
| 15 | 43,96 | 49,92 | 2,93 | 3,33 |
| 18 | 52,15 | 57,37 | 2,90 | 3,19 |

For injection duration; 2, 3, 4, 5, 6, 7, 8, 10, 12, 15, 18 ms tests are done. Assuming engine speed 2000 rpm, 1000 injection signals are sent by microcontroller in a minute. Test results are seen in Table 6 and Figure 12.

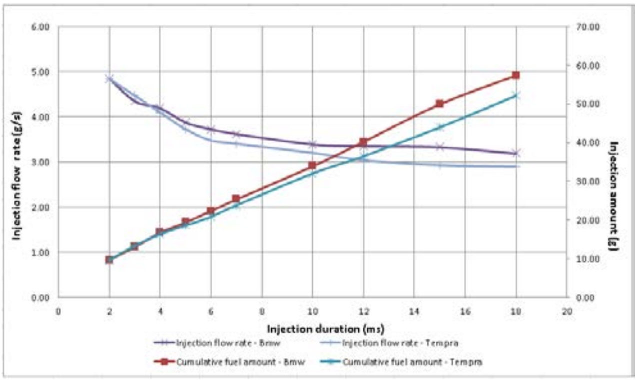


***Figure 12.*** *Flow rate characteristics of test injectors*

## *6. Results*

Engine research and development is very expensive, time consuming and complicated job. Single cylinder engines are preferred because of decreasing prices, time and they are also flexible on controlling. There are various producers which sell research engines and control parts but they are very expensive. So it is not sensible to buy a new turnkey test engine system with university budget. On the other hand, it is much more sensible to build your own research engine and data acquisition system.

In this research, engine with skip cycle mechanism is very suitable for academic research. Also, comparing other options, it is much more cheaper and flexible for other academic research. Ignition and injection advances also injection duration and dwell time values were controlled by a standard PC on computer with microcontroller in this research engine. So it becomes very easy to detect the optimised working conditions with regards to mechanism and engine performance.

For the future work of this study, it is imported to define the most proper parameters of ignition and injection as regards to detailed engine map considering engine speed and load.

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**Symbols**

| | | | |
|---|---|---|---|
| S | Skipped cycle | BDC | Bottom Dead Center |
| N | Normal cycle | $A$ | Amper |
| MBT | Maximum brake torque | V | Volt |
| P | Cylinder pressure | Ω | Ohm |
| $\alpha$ | Crankshaft angle | $TDC$ | Top Dead Center |
| $CA$ | Crankshaft angle | $g$ | Gram |
| $ms$ | Miliseconds | s | Second |

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